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SI units and recommendations for the use of their multiples and of certain other units

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FOREWORD

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The Member Bodies of the following countries expressed disapproval of the document on technical grounds :

Australia
Czechoslovakia
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The document was also approved by the International Union of Pure and Applied Chemistry (IUPAC).

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CONTENTS

SI units and recommendations for the use of their multiples and of certain other units

1 SCOPE AND FIELD OF APPLICATION

This International Standard consists of two parts. In the first part (sections 2 and 3), the International System of Units is described[1]. In the second part (sections 4 and 5, and the Annex), selected decimal multiples and sub-multiples of the SI units are recommended for general use, and certain other units are given which may be used with the International System of Units.

2 SI UNITS

The name Système International d'Unités (International System of Units), with the abbreviation SI, was adopted by the 11th Conférence Générale des Poids et Mesures in 1960.

This system includes three classes of units :

- base units,
- supplementary units,
- derived units,

which together form the coherent system of SI units.

2.1 Base units

The International System of Units is founded on the seven base units listed in Table 1.

TABLE 1

Quantity	Name of base SI unit	Symbol
length	metre	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

For the definitions of the base units and the supplementary units, see the Appendix.

2.2 Supplementary units

The Conférence Générale des Poids et Mesures has not classified certain units of the International System under either base units or derived units.

These units, listed in Table 2, are called "supplementary units" and may be regarded either as base units or as derived units.

TABLE 2

Quantity	Name of supplementary SI unit	Symbol
plane angle	radian	rad
solid angle	steradian	sr

2.3 Derived units

Derived units are expressed algebraically in terms of base units and/or supplementary units. Their symbols are obtained by means of the mathematical signs of multiplication and division; for example, the SI unit for velocity is metre per second (m/s) and the SI unit for angular velocity is radian per second (rad/s).

For some of the derived SI units, special names and symbols exist; those approved by the Conférence Générale des Poids et Mesures are listed in Table 3.

It may sometimes be advantageous to express derived units in terms of other derived units having special names; for example, the SI unit for electric dipole moment is usually expressed as C·m instead of A·s·m.

3 MULTIPLES OF SI UNITS

The prefixes given in Table 4 (SI prefixes) are used to form names and symbols of multiples (decimal multiples and sub-multiples) of the SI units.

1) Full information about the International System of Units is given in a publication from the International Bureau of Weights and Measures : *Le Système International d'Unités* (authorized English translations have been published in the United Kingdom through the National Physical Laboratory, and in the United States of America through the National Bureau of Standards).

The symbol of a prefix is considered to be combined with the unit symbol[1] to which it is directly attached, forming with it the symbol for a new unit which can be provided with a positive or negative exponent and which can be combined with other unit symbols to form symbols for compound units.

Examples

$1\ cm^3 = (10^{-2} m)^3 = 10^{-6} m^3$

$1\ \mu s^{-1} = (10^{-6} s)^{-1} = 10^{6} s^{-1}$

$1\ mm^2/s = (10^{-3} m)^2/s = 10^{-6} m^2/s$

Compound prefixes should not be used; for example, write nm (nanometre) instead of mμm.

NOTE – Because the name of the base unit, kilogram, for mass contains the name of the SI prefix "kilo", the names of the decimal multiples and sub-multiples of the unit of mass are formed by adding the prefixes to the word "gram"; for example, milligram (mg) instead of microkilogram (μkg).

TABLE 3

Quantity	Name of derived SI unit	Symbol	Expressed in terms of base or supplementary SI units or in terms of other derived SI units
frequency	hertz	Hz	$1\ Hz = 1\ s^{-1}$
force	newton	N	$1\ N = 1\ kg{\cdot}m/s^2$
pressure, stress	pascal	Pa	$1\ Pa = 1\ N/m^2$
energy, work, quantity of heat	joule	J	$1\ J = 1\ N{\cdot}m$
power	watt	W	$1\ W = 1\ J/s$
electric charge, quantity of electricity	coulomb	C	$1\ C = 1\ A{\cdot}s$
electric potential, potential difference, tension, electromotive force	volt	V	$1\ V = 1\ J/C$
electric capacitance	farad	F	$1\ F = 1\ C/V$
electric resistance	ohm	Ω	$1\ \Omega = 1\ V/A$
electric conductance	siemens	S	$1\ S = 1\ \Omega^{-1}$
flux of magnetic induction, magnetic flux	weber	Wb	$1\ Wb = 1\ V{\cdot}s$
magnetic flux density, magnetic induction	tesla	T	$1\ T = 1\ Wb/m^2$
inductance	henry	H	$1\ H = 1\ Wb/A$
luminous flux	lumen	lm	$1\ lm = 1\ cd{\cdot}sr$
illuminance	lux	lx	$1\ lx = 1\ lm/m^2$

TABLE 4

Factor by which the unit is multiplied	Prefix	
	Name	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10	deca	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

4 USE OF THE SI UNITS AND THEIR MULTIPLES

4.1 The choice of the appropriate multiple (decimal multiple or sub-multiple) of an SI unit is governed by convenience, the multiple chosen for a particular application being the one which will lead to numerical values within a practical range.

4.2 The multiple can usually be chosen so that the numerical values will be between 0,1 and 1 000.

Examples

$1{,}2 \times 10^4$ N	can be written as	12 kN
0,003 94 m	can be written as	3,94 mm
1 401 Pa	can be written as	1,401 kPa
$3{,}1 \times 10^{-8}$ s	can be written as	31 ns

However, in a table of values for the same quantity or in a discussion of such values within a given context, it will generally be better to use the same multiple for all items, even when some of the numerical values will be outside the range 0,1 to 1 000. For certain quantities in particular applications, the same multiple is customarily used; for example, the millimetre is used for dimensions in most mechanical engineering drawings.

4.3 It is recommended that only one prefix be used in forming a multiple of a compound SI unit.

1) In this case, the term "unit symbol" means only a symbol for a base unit, a derived unit with a special name or a supplementary unit; see, however, the note about the base unit kilogram.

4.4 Errors in calculations can be avoided more easily if all quantities are expressed in SI units, prefixes being replaced by powers of 10.

4.5 Rules for writing unit symbols :

4.5.1 Unit symbols should be printed in roman (upright) type (irrespective of the type used in the rest of the text), should remain unaltered in the plural, should be written without a final full stop (period) and should be placed after the complete numerical value in the expression for a quantity, leaving a space between the numerical value and the unit symbol.

Unit symbols should be written in lower-case letters except that the first letter is written in upper case when the name of the unit is derived from a proper name.

Examples :

m metre
s second
A ampere
Wb weber

4.5.2 When a compound unit is formed by multiplication of two or more units, this may be indicated in one of the following ways :

N·m N.m N m

NOTE – When using a unit symbol which coincides with the symbol for a prefix, special care should be taken to avoid confusion. The unit newton metre for torque should be written, for example, N m or m · N to avoid confusion with mN, the millinewton.

When a compound unit is formed by dividing one unit by another, this may be indicated in one of the following ways :

$\frac{m}{s}$ or m/s or by writting the product of m and s^{-1}, for example $m{\cdot}s^{-1}$

In no case should more than one solidus (as in m/s) on the same line be included in such a combination unless parentheses be inserted to avoid all ambiguity. In complicated cases, negative powers or parentheses should be used.

5 NON SI UNITS WHICH MAY BE USED TOGETHER WITH THE SI UNITS AND THEIR MULTIPLES

5.1 There are certain units outside the SI which are nevertheless recognized by the Comité International des Poids et Mesures (CIPM) as having to be retained either because of their practical importance (Table 5) or because of their use in specialized fields (Table 6).

5.2 Prefixes given in Table 4 may be attached to many of the units given in Tables 5 and 6; for example, millilitre, ml; megaelectronvolt, MeV. See also the Annex, column 6.

5.3 In a limited number of cases, compound units are formed with the units given in Tables 5 and 6 together with SI units and their multiples; for example, kg/h; km/h. See also the Annex, columns 5 and 6.

TABLE 5

Quantity	Name of unit	Unit symbol	Definition
time	minute	min	1 min = 60 s
	hour	h	1 h = 60 min
	day	d	1 d = 24 h
plane angle	degree	°	1° = (π/180) rad
	minute	'	1' = (1/60)°
	second	"	1" = (1/60)'
volume	litre	l	1 l = 1 dm^3
mass	tonne	t	1 t = 10^3 kg

TABLE 6

Quantity	Name of unit	Unit symbol	Definition
energy	electronvolt	eV	1 electronvolt is the kinetic energy acquired by an electron in passing through a potential difference of 1 volt in vacuum; 1 eV = 1,602 19 × 10^{-19} J (approximately)
mass of an atom	atomic mass unit	u	1 (unified) atomic mass unit is equal to the fraction 1/12 of the mass of an atom of the nuclide ^{12}C; 1 u = 1,660 53 × 10^{-27} kg (approximately)
length	astronomic unit	AU[1)]	1 AU = 149 600 × 10^6 m (System of astronomic constants, 1964)
	parsec	pc	1 parsec is the distance at which 1 astronomic unit subtends an angle of 1 second of arc; 1 pc = 206 265 AU = 30 857 × 10^{12} m (approximately)
pressure of fluid	bar[2)]	bar	1 bar = 10^5 Pa

1) This unit has no international symbol; AU is the abbreviation of the English name; the abbreviation of the French name is UA.

2) The bar is not mentioned by CIPM in this group of units; in many countries, however, there are special requirements for this unit.

ANNEX

EXAMPLES OF DECIMAL MULTIPLES AND SUB-MULTIPLES OF SI UNITS AND OF SOME OTHER UNITS WHICH MAY BE USED

For a number of commonly used quantities, examples of decimal multiples and sub-multiples of SI units, as well as of some other units which may be used, are given in this Annex. It is suggested that the selection shown, while not intended to be restrictive, will none the less prove helpful in presenting values of quantities in an identical manner in similar contexts within the various sectors of technology. For some needs (for example, in applications in science and education) it is recognized that greater freedom will be required in the choice of decimal multiples and sub-multiples of SI units than is exemplified in the list which follows.

NOTE — Factors for conversion to SI units from the other units listed are given in the relevant parts of ISO/R 31.

Item No. in ISO/R 31	Quantity	SI unit	Selection of multiples of the SI unit	Units outside the SI which are nevertheless recognized by the CIPM as having to be retained either because of their practical importance or because of their use in specialized fields		Remarks, and information about units used in special fields
				Units	Multiples of units given in column 5	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
PART I : SPACE AND TIME						
1-1.1	plane angle	rad (radian)	mrad µrad	° (degree) ′ (minute) ″ (second)		The units degree and grade (or gon), with their decimal subdivisions, are recommended for use when the unit radian is not suitable. grade (^{g}) or gon, $1^{g} = 1\ \text{gon} = \frac{\pi}{200}\ \text{rad}$
1-2.1	solid angle	sr (steradian)				
1-3.1 . . . 7	length	m (metre)	km cm mm µm nm			1 international nautical mile = 1 852 m
1-4.1	area	m^2	km^2 dm^2 cm^2 mm^2			ha (hectare), 1 ha = $10^4\ m^2$ a (are), 1 a = $10^2\ m^2$

(1)	(2)	(3)	(4)	(5)	(6)	(7)
1-5.1	volume	m^3	dm^3 cm^3 mm^3	l (litre)	hl $1\ hl = 10^{-1}\ m^3$ cl $1\ cl = 10^{-5}\ m^3$ ml $1\ ml = 10^{-6}\ m^3 = 1\ cm^3$	In 1964, the Conférence Générale des Poids et Mesures declared that the name litre (l) may be used as a special name for the cubic decimetre (dm^3) and advised against the use of the name litre for high-precision measurements.
1-6.1	time	s (second)	ks ms µs ns	d (day) h (hour) min (minute)		Other units such as week, month and year (a) are in common use.
1-8.1	angular velocity	rad/s				
1-10.1	velocity	m/s			km/h $1\ km/h = \frac{1}{3,6}\ m/s$	1 knot = 0,514 444 m/s
1-11.1	acceleration	m/s^2				
PART II : PERIODIC AND RELATED PHENOMENA						
2-3.1	frequency	Hz (hertz)	THz GHz MHz kHz			
2-3.2	rotational frequency	s^{-1}		min^{-1}		The designations revolution per minute (r/min) and revolution per second (r/s) are widely used in specifications on rotating machinery.[1]

1) See also IEC Publication 27-1 (1971).

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				Units	Multiples of units given in column 5	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
PART III : MECHANICS						
3-1.1	mass	kg (kilogram)	Mg g mg µg	t (tonne)		
–	linear density	kg/m	mg/m			1 tex = 10^{-6} kg/m The tex is used in the textile industry.
3-2.1	density (mass density)	kg/m³	Mg/m³ or kg/dm³ or g/cm³	t/m³ or kg/l	g/ml g/l	For litre, see item 1-5.1.
3-5.1	momentum	kg·m/s				
3-6.1	moment of momentum, angular momentum	kg·m²/s				
3-7.1	moment of inertia	kg·m²				
3-8.1	force	N (newton)	MN kN mN µN			

(1)	(2)	(3)	(4)	(5)	(6)	(7)
3·10,1	moment of force	N·m	MN·m kN·m mN·m μN·m			
3·11,1	pressure	Pa (pascal)	GPa MPa kPa mPa μPa	bar[1]	mbar μbar	1 bar = 10^5 Pa
3·11,2	stress	Pa or N/m²	GPa MPa or N/mm² kPa			
3·19,1	viscosity (dynamic)	Pa·s	mPa·s			P (poise)[2] 1 cP = 1 mPa·s
3·20,1	kinematic viscosity	m²/s	mm²/s			St (stokes)[2] 1 cSt = 1 mm²/s
3·21,1	surface tension	N/m	mN/m			

1) For the bar, see 5.1 and Table 6, page 3.

2) Belongs to the CGS system; ought not to be used together with SI units.

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				Units	Multiples of units given in column 5	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
3-22.1	energy, work	J (joule)	TJ GJ MJ kJ mJ	eV (electronvolt)	GeV MeV keV	The units W·h, kW·h, MW·h, GW·h and TW·h are used in the field of consumption of electrical energy. The units keV, MeV and GeV are used in atomic and nuclear physics and in accelerator technology.
3-23.1	power	W (watt)	GW MW kW mW µW			
PART IV : HEAT						
4-1.1	thermodynamic temperature	K (kelvin)				
4-2.1	Celsius temperature	°C (degree Celsius)[1]				The Celsius temperature t is equal to the difference $t = T - T_0$ between two thermodynamic temperatures T and T_0, where $T_0 = 273{,}15$ K.
4-1.1 4-2.1	temperature interval	K				For temperature interval, °C may be used instead of K.

1) For the definition and the use of degree Celsius (°C), see Note 2 under the definition of kelvin in the Appendix, page 20.

(1)	(2)	(3)	(4)	(5)	(6)	(7)
4-3.1	linear expansion coefficient	K^{-1}				For degree Celsius, see footnote, page 8.
4-4.1	heat, quantity of heat	J	TJ GJ MJ kJ mJ			
4-6.1	heat flow rate	W	kW			
4-7.1	thermal conductivity	W/(m·K)				For degree Celsius, see footnote, page 8.
4-8.1	coefficient of heat transfer	$W/(m^2·K)$				For degree Celsius, see footnote, page 8.
4-10.1	heat capacity	J/K	kJ/K			For degree Celsius, see footnote, page 8.
4-11.1	specific heat capacity	J/(kg·K)	kJ/(kg·K)			For degree Celsius, see footnote, page 8.
4-13.1	entropy	J/K	kJ/K			
4-14.1	specific entropy	J/(kg·K)	kJ/(kg·K)			
4-16.1	specific energy	J/kg	MJ/kg kJ/kg			
4-18.1	specific latent heat	J/kg	MJ/kg kJ/kg			

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				Units	Multiples of units given in column 5	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
PART V : ELECTRICITY AND MAGNETISM						
5-1.1	electric current	A (ampere)	kA mA µA nA pA			
5-2.1	electric charge, quantity of electricity	C (coulomb)	kC µC nC pC			1 A·h = 3,6 kC
5-3.1	volume density of charge, charge density	C/m^3	C/mm^3 MC/m^3 or C/cm^3 kC/m^3 mC/m^3 $\mu C/m^3$			
5-4.1	surface density of charge	C/m^2	MC/m^2 or C/mm^2 C/cm^2 kC/m^2 mC/m^2 $\mu C/m^2$			

(1)	(2)	(3)	(4)	(5)	(6)	(7)
5-5.1	electric field strength	V/m	MV/m kV/m or V/mm V/cm mV/m μV/m			
5-6.1 5-6.2 5-6.3	electric potential potential difference (tension) electromotive force	V (volt)	MV kV mV μV			
5-7.1	displacement	C/m^2	C/cm^2 kC/m^2 mC/m^2 $\mu C/m^2$			
5-9.1	electric flux, flux of displacement	C	MC kC mC			
5-11.1	capacitance	F (farad)	mF μF nF pF			
5-12.1	permittivity	F/m	μF/m nF/m pF/m			

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				Units	Multiples of units given in column 5	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
5-17.2	electric polarization	C/m^2	C/cm^2 kC/m^2 mC/m^2 $\mu C/m^2$			
5-18.1	electric dipole moment	C·m				
5-19.1	current density	A/m^2	MA/m^2 or A/mm^2 A/cm^2 kA/m^2			
5-20.1	linear current density	A/m	kA/m or A/mm A/cm			
5-21.1	magnetic field strength	A/m	kA/m or A/mm A/cm			
5-23.1	magnetic potential difference	A	kA mA			
5-24.1	magnetic flux density, magnetic induction	T (tesla)	mT µT nT			

(1)	(2)	(3)	(4)	(5)	(6)	(7)
5-25.1	magnetic flux (flux of magnetic induction)	Wb (weber)	mWb			
5-26.1	magnetic vector potential	Wb/m	kWb/m or Wb/mm			
5-27.1 5-27.2	self inductance mutual inductance	H (henry)	mH μH nH pH			
5-29.1	permeability	H/m	μH/m nH/m			
5-34.1	electromagnetic moment, magnetic moment	$A{\cdot}m^2$				
5-35.1	magnetization	A/m	kA/m or A/mm			
5-36.1	magnetic polarization	T	mT			
(IEC Pub. 27, item 86)	magnetic dipole moment	$N{\cdot}m^2/A$ or $Wb{\cdot}m$				
5-41.1	resistance	Ω (ohm)	GΩ MΩ kΩ mΩ μΩ			

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				Units	Multiples of units given in column 5	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
5-42.1	conductance	S (siemens)	kS mS µS			
5-43.1	resistivity	Ω·m	GΩ·m MΩ·m kΩ·m Ω·cm mΩ·m µΩ·m nΩ·m			µΩ·cm = 10^{-8} Ω·m $\frac{\Omega \cdot mm^2}{m} = 10^{-6}\ \Omega \cdot m = \mu\Omega \cdot m$ are also used.
5-44.1	conductivity	S/m	MS/m kS/m			
5-45.1	reluctance	H^{-1}				
5-46.1	permeance	H				
5-49.1 5-49.2 5-49.3 5-49.4	impedance modulus of impedance reactance resistance	Ω	MΩ kΩ mΩ			
5-51.1 5-51.2 5-51.3 5-51.4	admittance modulus of admittance susceptance conductance	S	kS mS µS			

(1)	(2)	(3)	(4)	(5)	(6)	(7)
5-52.1	active power	W	TW GW MW kW mW µW nW			In electric power technology, "apparent power" is expressed in volt-amperes (VA) and "reactive power" is expressed in vars (var).
PART VI : LIGHT AND RELATED ELECTROMAGNETIC RADIATIONS						
6-3.1	wavelength	m	nm pm			Å (ångström), 1 Å = 10^{-10} m = 0,1 nm = 10^{-4} µm
6-6.1	radiant energy	J				
6-9.1	radiant flux, radiant power	W				
6-11.1	radiant intensity	W/sr				
6-12.1	radiance	W/(sr·m²)				
6-13.1	radiant exitance	W/m²				
6-14.1	irradiance	W/m²				
6-19.1	luminous intensity	cd (candela)				
6-20.1	luminous flux	lm (lumen)				
6-21.1	quantity of light	lm·s				1 lm·h = 3600 lm·s

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				Units	Multiples of units given in column 5	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
6-22.1	luminance	cd/m^2				
6-23.1	luminous exitance	lm/m^2				
6-24.1	illuminance	lx (lux)				
6-25.1	light exposure	lx·s				
6-26.1	luminous efficacy	lm/W				
PART VII : ACOUSTICS						
7-1.1	period, periodic time	s	ms µs			
7-2.1	frequency	Hz	MHz kHz			
7-5.1	wavelength	m	mm			
7-7.1	density (mass density)	kg/m^3				

(1)	(2)	(3)	(4)	(5)	(6)	(7)
7-8.1	static pressure	Pa				
7-8.2	(instantaneous) sound pressure		mPa µPa			
7-10.1	(instantaneous) sound particle velocity	m/s	mm/s			
7-12.1	(instantaneous) volume velocity	m^3/s				
7-13.1	velocity of sound	m/s				
7-15.1	sound energy flux; sound power	W	kW mW µW pW			
7-16.1	sound intensity	W/m^2	mW/m^2 $\mu W/m^2$ pW/m^2			
7-17.1	specific acoustic impedance	Pa·s/m				
7-18.1	acoustic impedance	$Pa{\cdot}s/m^3$				
7-19.1	mechanical impedance	N·s/m				
7-20.1	sound power level					dB (decibel)

Item No. in ISO/R 31	Quantity	SI units	Selection of multiples of the SI unit	Units outside the SI which are nevertheless recognized by the CIPM as having to be retained either because of their practical importance or because of their use in specialized fields		Remarks, and information about units used in special fields
				Units	Multiples of units given in column 5	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
7-21.1	sound pressure level					dB
7-26.1	sound reduction index, sound transmission loss					dB
7-27.1	equivalent absorption area of a surface or object	m^2				
7-28.1	reverberation time	s				
PART VIII : PHYSICAL CHEMISTRY AND MOLECULAR PHYSICS						
8-3.1	amount of substance	mol (mole)	kmol mmol μmol			
8-5.1	molar mass	kg/mol	g/mol			
8-6.1	molar volume	m^3/mol	dm^3/mol cm^3/mol	l/mol		
8-7.1	molar internal energy	J/mol	kJ/mol			
8-8.1	molar heat capacity	J/(mol·K)				

(1)	(2)	(3)	(4)	(5)	(6)	(7)
8-9.1	molar entropy	J/(mol·K)				
8-13.1	concentration	mol/m³	mol/dm³ or kmol/m³	mol/l		
8-15.1	molality	mol/kg	mmol/kg			
8-36.1	diffusion coefficient	m²/s				
8-38.1	thermal diffusion coefficient	m²/s				

APPENDIX

DEFINITIONS OF THE BASE UNITS AND SUPPLEMENTARY UNITS OF THE INTERNATIONAL SYSTEM OF UNITS

BASE UNITS

metre

The metre is the length equal to 1 650 763,73 wavelengths in vacuum of the radiation corresponding to the transition between the levels $2p_{10}$ and $5d_5$ of the krypton-86 atom.

(11th CGPM (1960), Resolution 6)

kilogram

The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.

(1st CGPM (1889) and 3rd CGPM (1901))

second

The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium-133 atom.

(13th CGPM (1967), Resolution 1)

ampere

The ampere is that constant electric current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre of length.

(CIPM (1946), Resolution 2 approved by the 9th CGPM (1948))

kelvin

The kelvin, unit of thermodynamic temperature, is the fraction 1/273,16 of the thermodynamic temperature of the triple point of water.

(13th CGPM (1967), Resolution 4)

NOTES

1 The 13th CGPM (1967, Resolution 3) also decided that the unit kelvin and its symbol K should be used to express an interval or a difference of temperature.

2 In addition to the thermodynamic temperature (symbol T) expressed in kelvins, use is also made of Celsius temperature (symbol t) defined by the equation $t = T - T_0$ where T_0 = 273,15 K by definition. The Celsius temperature is in general expressed in degrees Celsius (symbol °C). The unit "degree Celsius" is thus equal to the unit "kelvin" and an interval or a difference of Celsius temperature may also be expressed in degrees Celsius.

mole

The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0,012 kilogram of carbon 12. When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.

(14th CGPM (1971), Resolution 3)

candela

The candela is the luminous intensity, in the perpendicular direction, of a surface of 1/600 000 square metre of a black body at the temperature of freezing platinum under a pressure of 101 325 newtons per square metre.

(13th CGPM (1967), Resolution 5)

SUPPLEMENTARY UNITS

radian

The radian is the plane angle between two radii of a circle which cut off on the circumference an arc equal in length to the radius.

(ISO Recommendation R 31, part I, second edition, December 1965)

steradian

The steradian is the solid angle which, having its vertex in the centre of a sphere, cuts off an area of the surface of the sphere equal to that of a square with sides of length equal to the radius of the sphere.

(ISO Recommendation R 31, part I, second edition, December 1965)

c. 2

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S1.11-1966
(R1971)

American Standard Specification for

Octave, Half-Octave, and Third-Octave Band Filter Sets

American National Standard

This standard is one of more than 4000 approved as either a USA Standard or as an American Standard. It became an American National Standard in October 1969 when the Institute changed its name to American National Standards Institute, Inc.

ANSI, 1430 Broadway, New York, N.Y. 10018

Sponsor
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Approved May 4, 1966
AMERICAN STANDARDS ASSOCIATION
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American Standard

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Foreword

(This Foreword is not a part of American Standard Specification for Octave, Half-Octave, and Third-Octave Band Filter Sets, S1.11-1966.)

This American Standard comprises part of a group of definitions, standards, and specifications prepared for use in acoustical work. It has been developed under the Sectional Committee Method of ASA procedure, and has been sponsored by the Acoustical Society of America which has been the leader in standardization activities in this area since 1932.

This standard comes under the jurisdiction of Sectional Committee S1 on Acoustics. The S1 Sectional Committee has the following scope:

Standards, specifications, methods of measurement and test, and terminology, in the fields of physical acoustics, including architectural acoustics, electroacoustics, sonics and ultrasonics and underwater sound, but excluding those aspects which pertain to safety, tolerance, and comfort.

Suggestions for improvement gained through the use of this standard will be welcome. They should be sent to the American Standards Association, Incorporated, 10 East 40th Street, New York, N.Y. 10016.

The ASA Sectional Committee on Acoustics, S1, which reviewed and approved this standard, had the following personnel at the time of approval:

R. K. Cook, *Chairman* W. Koidan, *Vice-Chairman*
S. D. Hoffman, *Secretary*

Organization Represented	*Name of Representative*
Acoustical Materials Association	W. A. Jack
Acoustical Society of America	R. W. Benson
	R. B. Watson
Air-Conditioning & Refrigeration Institute	J. R. Schreiner
	R. J. Evans *(Alt)*
Air Moving & Conditioning Association	R. E. Parker
	R. A. Gerlitz *(Alt)*
American Society of Heating, Refrigerating & Air-Conditioning Engineers	R. E. Parker
	R. P. Tinning *(Alt)*
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This standard was developed by Writing Group S1-W-43 on Octave, Half-Octave, and Third-Octave Filter Sets, whose personnel is shown below:

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Octave, Half-Octave, and Third-Octave Band Filter Sets

Introduction

General Objective

Noises and related signals are subjected to spectrum analysis for various purposes. These purposes include scientific, technological, legal, and artistic areas. The types of signals involved cover wide variations of such factors as waveform, amplitude, frequency bandwidth, coherence, etc. Currently, no practical single instrument can render the optimum or most economical analysis for all signals. For this reason, the present standard includes the concept of several instruments, each adapted to the needs of a user having certain interests.

Spectrum Analysis

From the standpoint of human acceptability, there is a great distinction between desired sounds, such as speech, music, or testing signals, and acoustical noise which is defined as unwanted sound. However, for measurement purposes they are merely different types of the same phenomenon and for brevity will be called noise in this document. Because noises may differ widely in spectrum, waveform, and time variation, no single number, such as that given by the reading of a sound-level meter, can describe a noise to the extent required for use in many situations. The meter measurement is often supplemented by other measurements, important among which is spectrum analysis. The spectrum analyses may be made by a continuously adjustable narrow-band wave analyzer, by a series of contiguous broadband filters, or by some system intermediate between these two. Suitable standards are required for these analysis systems, so that satisfactorily uniform results can be obtained by using any analyzer that meets the standard for its type.

The selective networks used in spectrum analyzers fall into two broad classes: (1) constant bandwidth filters where the upper band-edge[1] frequency remains a constant number of cycles per second (c/s) above the lower band-edge frequency over the tuning range of the analyzer; and (2) constant percentage bandwidth filters where the upper band-edge frequency bears a constant ratio to the lower band-edge frequency over the tuning range. This specification is concerned with the latter type of filter, which has been found particularly applicable to the analysis of sounds extending over a broad frequency range.

[1]See Note to 2.2.

Selection of Frequency Bands

An octave band filter set divides the spectrum into a series of octave bands, each of which has a nominal upper band-edge frequency that is twice the nominal lower band-edge frequency. A particular set of band-edge frequencies was specified in the previous American Standard Z24.10-1953 for octave-band filter sets in the interest of uniformity, since for broadband noises the choice of the band-edge frequencies is arbitrary. In January 1960, Preferred Frequencies for Acoustical Measurements, S1.6-1960, established preferred frequencies for acoustical measurements, and the filter band-edge frequencies in the present standard have been adjusted upward approximately 18 percent to conform to the preferred frequency series. The filters in the new specified series are identified by the midband frequency, f_m, which is the geometric mean of the nominal band-edge frequencies.

It is appreciated that the frequency bands and filter characteristics specified in American Standard Z24.10-1953 have been specified in many documents of legal significance and many organizations are equipped with filter sets conforming to that standard. For the class of noises for which octave band analysis is appropriate, covering a broad frequency range, measurements made with either the former series or with the series specified herein are compatible. A method of transferring measurements of continuous spectrum broadband noise made with filters of one series to the equivalent readings with filters in the other series is given in Appendix A.

Experience has shown that in many cases greater resolution of the frequency spectrum than is provided by octave band filters is desirable and justifiable. This need resulted in extensive use of half-octave band and third-octave band filters although no performance standards were available. The present standard, therefore, includes specifications for half-octave band and third-octave band filters, which have a ratio of upper to lower band-edge frequency of $2^{1/2}$ and $2^{1/3}$, respectively. Frequency designations for these filters have been specified in concurrence with the preferred number series and with those chosen for the octave band series. As stressed in American Standard S1.6-1960, a certain amount of rounding was done in selecting the preferred number series to secure compatible sets of frequencies progressing both by powers of two (for octaves) and by powers of ten. Any deviations caused by the rounding are less than the frequency tolerances permitted by this specification. For all filters, the specifications for characteristics are given in terms of frequency ratios and could be applied to units based on other midband frequency series.

Designation of Filter Sets

For many purposes of standardization, it is desirable to specify a filter set containing a particular number of filters covering the usual audio-frequency range, as was done in American Standard Z24.10-1953. However, other applications require fewer filters than this, or filters at frequencies in a different combination above or below the usual range. To extend the basic characteristic specifications to include all of these situations, filter sets of three types have been delineated in this standard:

Type R (restricted range)
Type E (extended range)
Type O (optional range)

The Type R filter set contains a moderate number of filter bands and is intended to satisfy user requirements similar to those for which the former set specified by American Standard Z24.10-1953 is appropriate. The Type E filter set includes additional filter bands which experience has shown to be desirable for many research problems and more extensive industrial and military investigations. In Type O filter sets, the manufacturer may provide any set of filter bands he specifies, but each filter furnished must meet the performance requirements of this standard. Type O, therefore, allows special-purpose filter sets to qualify under the standard, adding needed flexibility.

Designation of Filter Characteristics

In view of the great variety of sounds to be measured, it is necessary to select for a standard the characteristics that are judged to be useful for the greatest number of cases. The committee preparing this standard has approached the problem by reviewing many spectra taken on a wide variety of acoustic sources. This review was necessary to ensure that the filter characteristics to be specified would be adequate to measure the spectra that occur in practice. At the same time, the group reviewed the filter characteristics that are economically obtainable, so that an adequate filter that is also reasonable in cost could be specified. Unless the specifications are made sufficiently restrictive, many users may be unable to obtain a reasonable spectrum analysis of commonly encountered noises by the use of filters that meet the standard. The serious aspect of this situation is that they may be misled into thinking that the result is correct, because they are using a standard filter. On the other hand, some hardship would result to those with minimal needs if only the requirements of the most severe usage were to be placed on the filter characteristics. The filters would then be more costly, their use not be as widespread as is desirable, and the development of the field of noise evaluation and control not be as rapid as would otherwise be possible.

The committee concluded that the use of filters for noise and signal analysis has become so extensive and varied that it is no longer practicable to meet all needs with a standard specifying a single transmission loss characteristic for each bandwidth. In this standard, three grades of performance are specified, two for each bandwidth. The nomenclature selected allots a Class number to each grade of performance. This system allows the specification of additional, more rigid requirements in future standards, if this proves necessary to meet advancing technological needs, without invalidating those Classes specified herein.

The standard includes minimum performance specifications for three Classes of filters as follows:

Bandwidth	Class Designation	Qualitative Description of Transmission Loss Slope
Octave	Class I	Low
	Class II	Moderate
Half Octave	Class II	Moderate
	Class III	High
Third Octave	Class II	Moderate
	Class III	High

The Class II characteristic as specified for octave, half-octave, and third-octave band filters is considered to meet the majority of needs for each bandwidth. For the octave band filter, it is similar to the characteristic specified in the former American Standard Z24.10-1953. A Class I characteristic of lower slope has also been specified for octave band filters to provide a measurement standard for a large class of field tests that can be conducted with such economical filters. For half-octave and third-octave filters, a Class III with higher slope has been specified to meet the needs of users requiring greater discrimination.

These are the Classes which the committee believed should be specified at the time of preparation of this standard. Additional characteristics with appropriate Class numbers can be added at any time they become sufficiently needed. The specification requires that the Type and Class symbols be included in the designation of a filter.

The choice of filter for a given measurement is based upon the accuracy required. The bandwidth error of a filter depends upon its transmission loss at the band edges, the slope of the transmission loss characteristic outside the band, and the input noise spectrum slope. Appendix B discusses this subject and gives data and references allowing selection of filter characteristics which will yield measurements falling within specified error limits at various noise spectrum slopes.

Specification of Filter Characteristic Shape

From the standpoint of simplicity in wording a specification, a small number of straight-line segments is desirable to describe the shapes of limiting transmission loss characteristics. Experience has shown, however, that this often complicates the design of economical real filters, since real filters do not yield characteristics approximating long straight-line segments. It was decided that the limiting characteristics would be specified by mathematical expressions based upon the design formulas of modern maximally-flat band-pass filters. This makes it easier for the designer to provide filters that meet both the transmission loss slope characteristic specification and the equivalent bandwidth and nominal mean frequency requirements. Consequently, it was considered feasible to be more strict in these requirements.

In the body of the standard the mathematical statement of each characteristic is the basic requirement. It is unambiguous and not subject to errors of curve plotting, interpretation, or reproduction. In each case, however, the mathematical requirement is accompanied by a graphical representation which is convenient and will be adequate for most engineering comparisons. To meet the requirements of the standard, not only must all points on a filter characteristic lie between the two curves shown, but the other requirements on effective bandwidth, nominal mean frequency, maximum ripple, etc, must also be met.

Transient Response

The transient response characteristics of a filter set are not of primary concern in this standard. It is assumed that an rms (root-mean-square) indicating device of the type specified in American Standard Specification for General-Purpose Sound Level Meters, S1.4-1961, is used to determine filtered levels and that the effect of any transient distortion introduced by the set on the indicated filtered level is negligible. The characteristics and tolerances have been selected by the Committee to represent physically attainable results according to current advanced theory and manufacturing processes. With the specified characteristics, when the filtered output is applied to an oscillograph, a transient response, particularly damped oscillations sometimes called "ringing," may be observed even though the filters meet the requirements of this standard. However, a limit is placed upon the allowable amount of this type of response in the standard.

Influence of External Conditions

Requirements for temperature and humidity are included. The Writing Group concluded, however, that available knowledge when the standard was written could not support rigid numerical requirements for the influence of magnetic and electrostatic fields, sonic excitation, and vibration, with any assurance that they would be both adequate and nonhampering to future development. The specification includes a qualitative statement on these influences, and recommends the development of objective tests and specifications so that future standards may include effective quantitative requirements.

1. Purpose and Scope

1.1 Purpose. The purpose of this standard for filter sets is to specify particular bandwidths and characteristics which may be used to ensure that all analyses of noise will be consistent within known tolerances when made with similar filter sets meeting these specifications.

1.2 Scope. The standard for filter sets is suited to the requirements for analyzing, as a function of frequency, a broadband electrical signal. For acoustical measurements an electro-acoustic-transducer and amplifier are employed to convert the acoustic signal to be analyzed into the required electrical signal.

2. Definitions

These definitions are based upon those given in American Standard Acoustical Terminology (Including Mechanical Shock and Vibration), S1.1-1960.

2.1 Wave Filter (Filter). A wave filter is a transducer for separating waves on the basis of their frequency. It introduces relatively small insertion loss to waves in one or more frequency bands, and relatively large insertion loss to waves of other frequencies. (See 6.12 of American Standard S1.1-1960.)

2.2 Band-Pass Filter. A band-pass filter is a wave filter that has a single transmission band extending from a lower band-edge frequency greater than zero to a finite upper band-edge frequency.

NOTE: This definition is identical to the definition in 6.15 of American Standard S1.1-1960 except that the words "band-edge frequency" are substituted for "cutoff frequency." Cutoff frequency in 6.16 of American Standard S1.1-1960 is restricted to a frequency at which the response is 3 dB below the maximum response. In this standard the restriction does not apply to the frequencies limiting the passband. Therefore, the term "band-edge frequency" is used to avoid confusion. See 3.3 and Appendix B.

2.3 Filter Bandwidth. The bandwidth of a filter is the difference between the upper and lower band-edge frequencies, and defines the transmission band or pass band. In this specification the bandwidth is described by the interval in octaves between the upper and lower band-edge frequencies.

2.4 Spectrum. The spectrum of a function of time is a description of its resolution into components, each of a different frequency and (usually) different in amplitude and phase. [See 1.34 (1) of American Standard S1.1-1960.] A *Continuous Spectrum* is the spectrum of a wave the components of which are continuously distributed over a frequency region. (See 1.37 of American Standard S1.1-1960.) A *White Noise Spectrum* is a continuous spectrum whose spectrum density (mean-square amplitude per unit frequency) is independent of frequency over a specified frequency range.

2.5 Transmission Loss. Transmission Loss is the reduction in the magnitude of some characteristic of a signal, between two stated points in a transmission system. (See 4.29 of American Standard S1.1-1960.)

NOTE 1: In this specification the *Transmission Loss* is the reduction in power level or voltage level between the input applied to the filter in series with its proper input terminating impedance, and the output delivered by the filter to its proper load impedance.

NOTE 2: In this specification the *Transmission Loss Characteristic* of a filter, representing the change of Transmission Loss with frequency, is specified with respect to the minimum Transmission Loss in the passband measured when the filter is inserted between the proper terminating impedances.

NOTE 3: *Attenuation* (not defined in American Standard S1.1-1960) is frequently used as synonymous with Transmission Loss as defined above, in connection with filter characteristics.

NOTE 4: *Insertion Loss* is a term also frequently used in connection with filters. The Insertion Loss resulting from insertion of a transducer in a transmission system is 10 times the logarithm to the base 10 of the power delivered to that part of the system that will follow the transducer, before insertion of the transducer, to the power delivered to that same part of the system after insertion of the transducer. (See 7.2 of American Standard S1.1-1960.) For passive filters operated between resistive terminating impedances, the *Insertion Loss Characteristic* employing the minimum value as referent is the same as the *Transmission Loss Characteristic*.

2.6 Terminating Impedances. The terminating impedances are the impedances of the external input and output circuits between which the filter is connected.

2.7 Peak-to-Valley Ripple. When the transmission loss characteristic in the transmission band contains a series of maxima and minima, or ripples, the peak-to-valley ripple is defined as the difference in decibels between the extremes of minimum and maximum transmission loss in the pass band region.

3. Requirements

3.1 Filter Sets. The filter set shall provide a number of filter bands according to the schedules listed in Table 1, and shall bear the corresponding Type symbol:

R for Restricted Range
E for Extended Range
O for Optional Range

The filter bands are identified by the designation mean frequency f_m of the band as defined in 3.2.

3.2 Nominal Mean Frequency, f_m

3.2.1 ***Band Designation Frequencies.*** The values of mean frequency, f_m, used for band designation in Table 1 are based upon the recommendations of 5.2, page 3, of American Standard S1.6-1960. Band designation frequencies shall be rounded according to American Standard S1.6-1960.

3.2.2 ***Precise Values of f_m.*** Precise values of nominal mean frequency f_m shall be calculated from the formulas given in Table 2.

3.3 Nominal Frequency Bandwidths. The nominal band-edge frequencies and bandwidths for the octave, half-octave, and third-octave band filters are defined by the relations given in Table 3. The frequency f_m in each band is the geometric mean of the upper and lower nominal band-edge frequencies, f_1 and f_2, which are defined by Table 3.

3.4 Transmission Loss vs Frequency Characteristics of Individual Filters. When tested as specified in Section 4, the separate filters of a set shall conform to the requirements in the paragraphs below. For each filter characteristic, transmission loss is specified with respect to the minimum transmission loss in the frequency range f_1 to f_2 delineated in Table 3. Transmission loss characteristics are grouped under three classes (I, II, or III) depending upon the steepness of the slope of the transmission loss vs frequency curve. Filter designations must bear the appropriate Class symbol.

NOTE: In the transmission loss characteristics specified below, the mathematical statement is the governing consideration. The graphical representation accompanying each characteristic requirement is added for convenience. The actual filter characteristic, in addition to falling within the transmission loss limits shown, must simultaneously meet the requirements on *Passband Uniformity* (see 3.6) and on *Effective Bandwidth* (see 3.7). On each plot a dotted curve is shown as an example of a characteristic meeting all requirements.

Table 1

Table of Filter Bands To Be Provided

Band Number	Mean Frequency f_m (c/s)	Octave Bands Type R	Octave Bands Type E	Half-Octave Bands Type R	Half-Octave Bands Type E	Third-Octave Bands Type R	Third-Octave Bands Type E	Any Band Type O
14	25						x	Filter Bands as Specified by the Manufacturer
15	31.5		x		x		x	
16	40						x	
16.5	45				x			
17	50						x	
18	63		x		x		x	
19	80						x	
19.5	90				x			
20	100					x	x	
21	125	x	x	x	x	x	x	
22	160					x	x	
22.5	180			x	x			
23	200					x	x	
24	250	x	x	x	x	x	x	
25	315					x	x	
25.5	355			x	x			
26	400					x	x	
27	500	x	x	x	x	x	x	
28	630					x	x	
28.5	710			x	x			
29	800					x	x	
30	1000	x	x	x	x	x	x	
31	1250					x	x	
31.5	1400			x	x			
32	1600					x	x	
33	2000	x	x	x	x	x	x	
34	2500					x	x	
34.5	2800			x	x			
35	3150					x	x	
36	4000	x	x	x	x	x	x	
37	5000					x	x	
37.5	5600				x			
38	6300						x	
39	8000		x		x		x	
40	10000						x	
40.5	11200				x			
41	12500						x	
42	16000						x	
43	20000						x	

Table 2
Nominal Mean Frequencies, f_m

Octave Bands	$f_m = 10^{3n/10}$
Half-Octave Bands	$f_m = 10^{3n/20}$
Third-Octave Bands	$f_m = 10^{3n/30}$

NOTE: n is any integer, positive, negative, or zero.

Table 3
Nominal Band-Edge Frequencies and Frequency Bandwidths

	Octave Band	Half-Octave Band	Third-Octave Band
Formula	$f_1 = 2^{-1/2} f_m$	$f_1 = 2^{-1/4} f_m$	$f_1 = 2^{-1/6} f_m$
	$f_2 = 2^{1/2} f_m$	$f_2 = 2^{1/4} f_m$	$f_2 = 2^{1/6} f_m$
Numerical Value	$f_1 = 0.7071 f_m$	$f_1 = 0.8409 f_m$	$f_1 = 0.8909 f_m$
	$f_2 = 1.4142 f_m$	$f_2 = 1.1892 f_m$	$f_2 = 1.1225 f_m$
Bandwidth $f_2 - f_1$	$0.7071 f_m$	$0.3483 f_m$	$0.2316 f_m$

f_1 = nominal lower band-edge frequency
f_2 = nominal upper band-edge frequency
f_m = calculated from formulas of Table 2

3.4.1 *Octave Band Filters — Class I*

(1) At any frequency, f, in the range from $\frac{3f_m}{4}$ to $\frac{4f_m}{3}$ the transmission loss shall not be more than

$$10 \log_{10} \frac{8}{5} \left[1 + 3 \left(\frac{f}{f_m} - \frac{f_m}{f} \right)^2 \right] \text{ decibels.}$$

(2) At any frequency, f, in the range from $\frac{f_m}{5}$ to $\frac{f_m}{\sqrt{2}}$ the transmission loss shall be more than

$$10 \log_{10} \left[\frac{1}{8} \left(\frac{f_m}{f} \right)^6 \right] \text{ decibels.}$$

(3) At any frequency, f, in the range from $\frac{f_m}{10}$ to $\frac{f_m}{5}$ the transmission loss shall be more than

$$10 \log_{10} \left[1 + \frac{25}{8} \left(\frac{f}{f_m} \right)^4 \right] \text{ decibels.}$$

(4) At any frequency, f, in the range from $\sqrt{2} f_m$ to $5 f_m$ the transmission loss shall be more than

$$10 \log_{10} \left[\frac{1}{8} \left(\frac{f}{f_m} \right)^6 \right] \text{ decibels.}$$

(5) At any frequency, f, in the range from $5 f_m$ to $10 f_m$ the transmission loss shall be more than

$$10 \log_{10} \left[1 + \frac{25}{8} \left(\frac{f}{f_m} \right)^4 \right] \text{ decibels.}$$

(6) At any frequency, f, below $\frac{f_m}{10}$ or above $10 f_m$ the transmission loss shall be more than 45 decibels.

(7) A graphical representation of the allowable limits is given in Fig. 1.

3.4.2 *Octave Band Filters — Class II*

(1) At any frequency, f, in the range from $\frac{3f_m}{4}$ to $\frac{4f_m}{3}$ the transmission loss shall not be more than

$$10 \log_{10} \frac{5}{4} \left[1 + 30 \left(\frac{f}{f_m} - \frac{f_m}{f} \right)^6 \right] \text{ decibels.}$$

(2) At any frequency, f, in the range from $\frac{f_m}{8}$ to $\frac{f_m}{\sqrt{2}}$ and from $\sqrt{2} f_m$ to $8 f_m$ the transmission loss shall be more than

$$10 \log_{10} \frac{2}{3} \left[1 + 4 \left(\frac{f}{f_m} - \frac{f_m}{f} \right)^6 \right] \text{ decibels.}$$

(3) At any frequency, f, below $\frac{f_m}{8}$ or above $8 f_m$ the transmission loss shall be more than 60 decibels.

(4) A graphical representation of the allowable limits is given in Fig. 2.

3.4.3 *Half-Octave Band Filters — Class II*

(1) At any frequency, f, in the range from $\frac{6f_m}{7}$ to $\frac{7f_m}{6}$ the transmission loss shall not be more than

$$10 \log_{10} \frac{5}{4} \left[1 + 200 \left(\frac{f}{f_m} - \frac{f_m}{f} \right)^4 \right] \text{ decibels.}$$

(2) At any frequency, f, in the range from $\frac{9f_m}{100}$ to $2^{-1/4} f_m$ and from $2^{1/4} f_m$ to $\frac{100 f_m}{9}$ the transmission loss shall be more than

$$10 \log_{10} \left[68 \left(\frac{f}{f_m} - \frac{f_m}{f} \right)^4 \right] \text{ decibels.}$$

(3) At any frequency, f, below $\frac{9f_m}{100}$ or above $\frac{100 f_m}{9}$ the transmission loss shall be more than 60 decibels.

(4) A graphical representation of the allowable limits is given in Fig. 3.

3.4.4 *Half-Octave Band Filters — Class III*

(1) At any frequency, f, in the range from $\frac{6f_m}{7}$ to $\frac{7f_m}{6}$ the transmission loss shall not be more than

$$10 \log_{10} \frac{5}{4} \left[1 + 200 \left(\frac{f}{f_m} - \frac{f_m}{f} \right)^4 \right] \text{ decibels.}$$

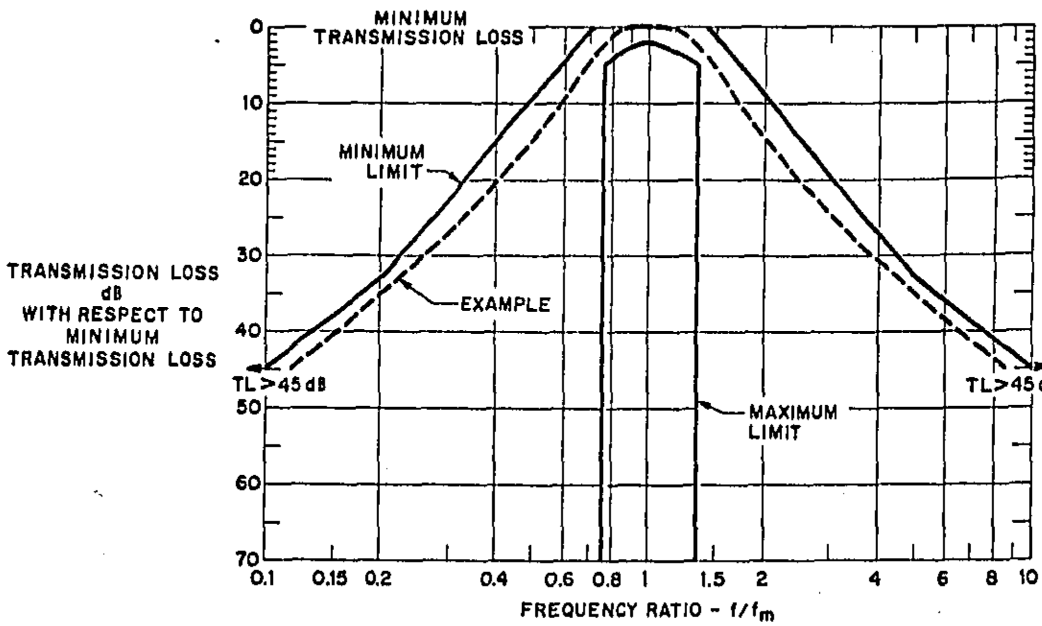


Fig. 1

Transmission Loss Limits — Octave Band Filter, Class I

(Filter Characteristic Must Also Meet Requirements in 3.6 and 3.7)

(2) At any frequency, f, in the range from $\frac{f_m}{6}$ to $2^{-1/4}f_m$ and from $2^{1/4}f_m$ to $6f_m$ the transmission loss shall be more than

$$10 \log_{10} \left[\frac{5}{9} + 250 \left(\frac{f}{f_m} - \frac{f_m}{f}\right)^6\right] \text{ decibels.}$$

(3) At any frequency, f, below $\frac{f_m}{6}$ or above $6f_m$ the transmission loss shall be more than 70 decibels.

(4) A graphical representation of the allowable limits is given in Fig. 4.

3.4.5 *Third-Octave Band Filters — Class II*

(1) At any frequency, f, in the range from $\frac{9f_m}{10}$ to $\frac{10f_m}{9}$ the transmission loss shall not be more than

$$10 \log_{10} \frac{5}{4} \left[1 + 1040 \left(\frac{f}{f_m} - \frac{f_m}{f}\right)^4\right] \text{ decibels.}$$

(2) At any frequency, f, in the range from $\frac{f_m}{8}$ to $2^{-1/6}f_m$ and from $2^{1/6}f_m$ to $8f_m$ the transmission loss shall be more than

$$10 \log_{10} \frac{1}{4} \left[1 + 1040 \left(\frac{f}{f_m} - \frac{f_m}{f}\right)^4\right] \text{ decibels.}$$

(3) At any frequency, f, below $\frac{f_m}{8}$ or above $8f_m$ the transmission loss shall be more than 60 decibels.

(4) A graphical representation of the allowable limits is given in Fig. 5.

3.4.6 *Third-Octave Band Filters — Class III*

(1) At any frequency, f, in the range from $\frac{9f_m}{10}$ to $\frac{10f_m}{9}$ the transmission loss shall not be more than

$$10 \log_{10} \frac{5}{4} \left[1 + 1040 \left(\frac{f}{f_m} - \frac{f_m}{f}\right)^4\right] \text{ decibels.}$$

(2) At any frequency, f, in the range from $\frac{f_m}{5}$ to $2^{-1/6}f_m$ and from $2^{1/6}f_m$ to $5f_m$ the transmission loss shall be more than

$$10 \log_{10} \left[\frac{8}{13} + 2500 \left(\frac{f}{f_m} - \frac{f_m}{f}\right)^6\right] \text{ decibels.}$$

(3) At any frequency, f, below $\frac{f_m}{5}$ or above $5f_m$ the transmission loss shall be more than 75 decibels.

(4) A graphical representation of the allowable limits is given in Fig. 6.

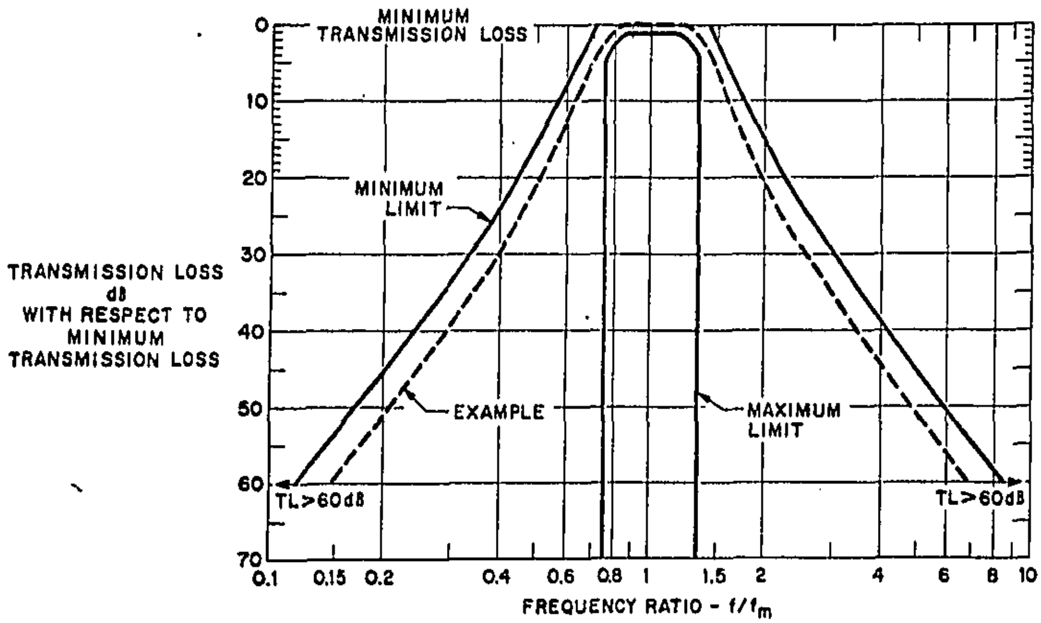


Fig. 2

Transmission Loss Limits — Octave Band Filter, Class II

(Filter Characteristic Must Also Meet Requirements in 3.6 and 3.7)

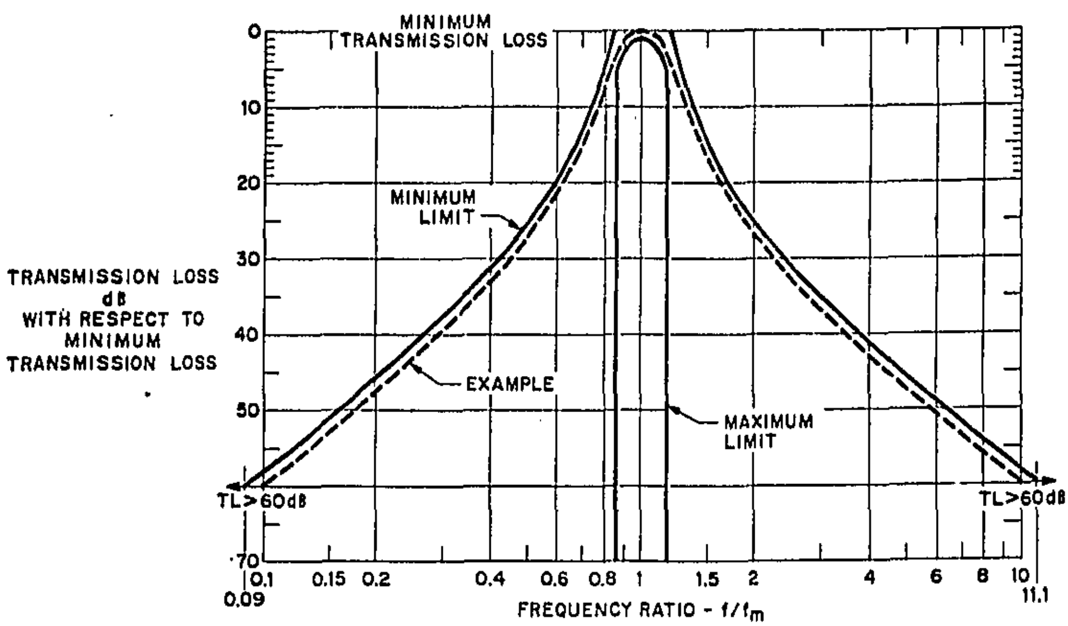


Fig. 3

Transmission Loss Limits — Half-Octave Band Filter, Class II

(Filter Characteristic Must Also Meet Requirements in 3.6 and 3.7)

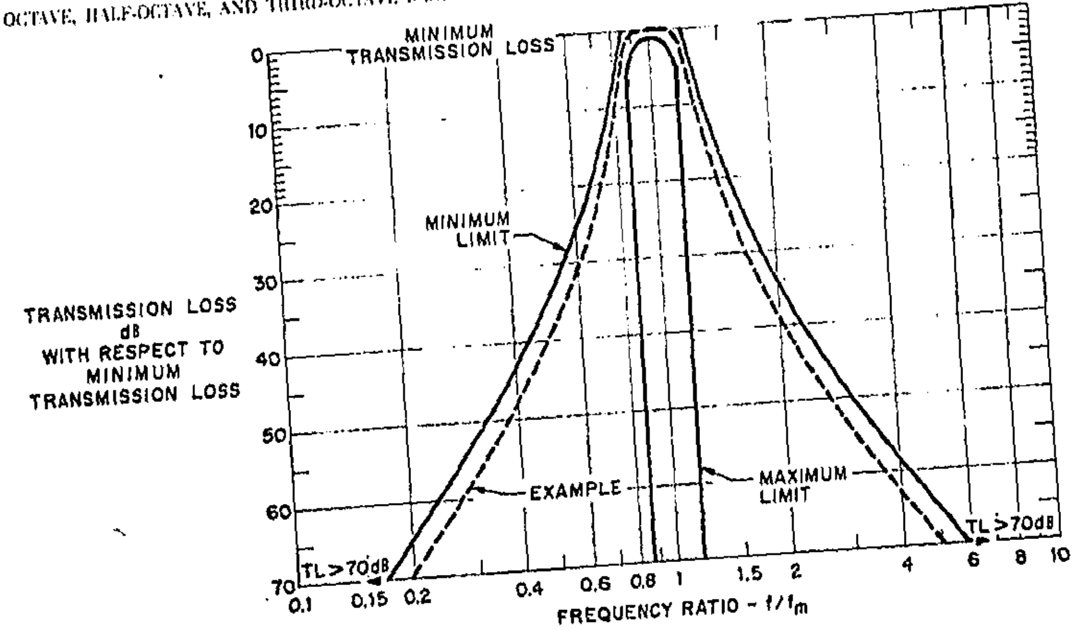


Fig. 4
Transmission Loss Limits – Half-Octave Band Filter, Class III
(Filter Characteristic Must Also Meet Requirements in 3.6 and 3.7)

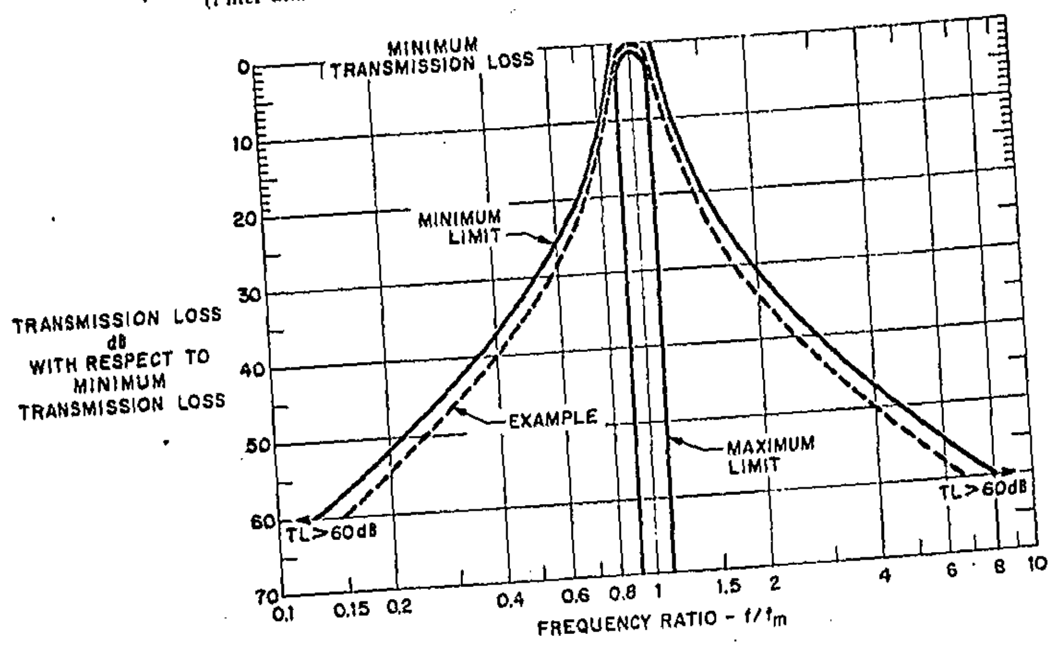


Fig. 5
Transmission Loss Limits – Third-Octave Band Filter, Class II
(Filter Characteristic Must Also Meet Requirements in 3.6 and 3.7)

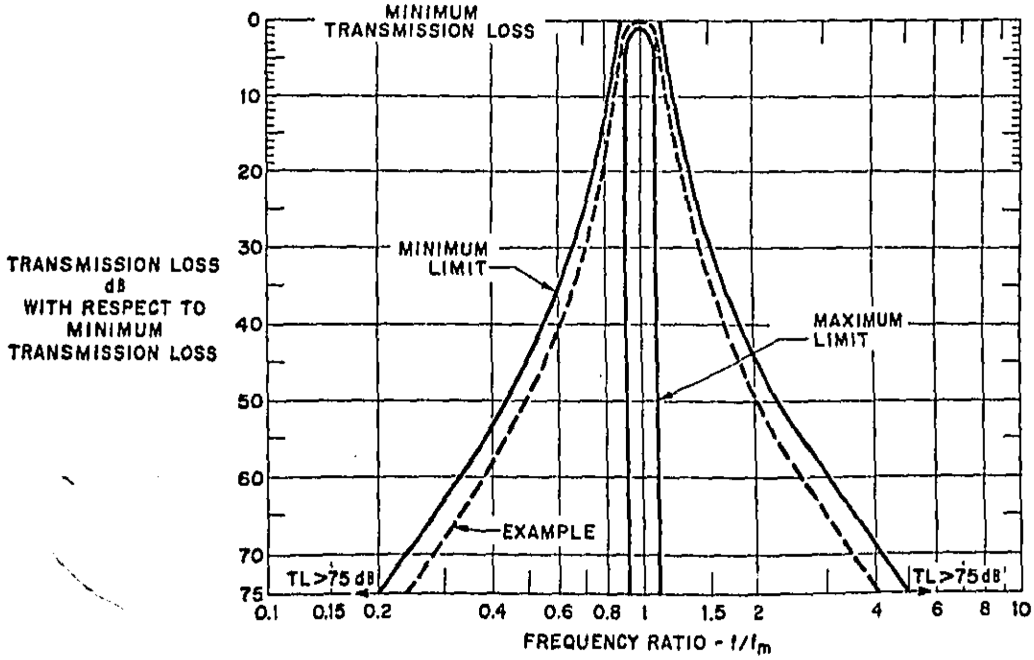


Fig. 6

Transmission Loss Limits — Third-Octave Band Filter, Class III
(Filter Characteristic Must Also Meet Requirements in 3.6 and 3.7)

3.5 Frequency Tolerance on Geometric Mean Frequency. For each band designated on the filter set in accordance with Table 1 of 3.1 or its extension, the geometric mean of the two frequencies where the transmission loss is 6 dB greater than the minimum transmission loss shall not depart by more than the tolerances shown in Table 4 from the designated preferred frequency nominal f_m calculated by the formulas of Table 2.

Table 4
Frequency Tolerances
on Geometric Mean Frequency, f_m

	Octave Bands	Half-Octave Bands	Third-Octave Bands
Tolerance	± 5%	± 3%	± 3%

3.6 Tolerance on Passband Uniformity. The peak-to-valley ripple in the transmission loss characteristic between the upper and lower nominal band-edge frequencies shall not exceed the values given in Table 5 for filters of the indicated bandwidths and classes.

3.7 Effective Bandwidth. For each filter band, the total integrated random white noise power (constant noise power per unit frequency) passed by the filter shall be within ±10 percent of that which would be passed by an ideal filter with flat passband between the nominal band-edge frequencies of 3.3 and infinite attenuation outside the passband. The white noise power passed by such an ideal filter is given by:

$$2^{-1/2} f_m P_m = 0.7071 f_m P_m \text{ for Octave bands}$$

$$(2^{1/4} - 2^{-1/4}) f_m P_m = 0.3483 f_m P_m \text{ for Half-Octave bands}$$

$$(2^{1/6} - 2^{-1/6}) f_m P_m = 0.2316 f_m P_m \text{ for Third-Octave bands}$$

where P_m is the noise power per unit frequency at the filter midband frequency f_m. The minimum transmission loss in the passband shall be used as the reference for calculating the effective bandwidth.

NOTE: See Appendix B for the nominal band-edge frequency transmission loss required to produce zero bandwidth error for Butterworth filters.

Table 5
Tolerance on Passband Uniformity

Filter Band	Filter Class	Maximum Allowable Peak-to-Valley Ripple dB
Octave	all	2
Half-Octave	II	1
	III	0.5
Third-Octave	II	1
	III	0.5

3.8 Tolerance on Variation of Minimum Transmission Loss. The minimum transmission loss of any filter band in a set shall not differ from the minimum transmission loss of any other filter band by more than 2 dB for Class I and II filters, or by more than 1 dB for Class III filters. If this difference exceeds these values, conformance with this specification may be achieved by determining the difference by measurement to an accuracy of 0.5 dB and by making the information available to the user of the filter set.

3.9 Removal of Filters From Circuit. If means are incorporated in the filter set to remove all filter bands from the circuit, the manufacturer shall explicitly state the characteristics of the substituted broadband circuit as to midband transmission loss and frequency characteristic. It is recommended that the midband transmission loss fall within the tolerance on minimum transmission loss given for the individual filter bands in 3.8.

3.10 Filter Terminating Impedances. The input and output terminating impedances necessary to ensure proper operation of the filters shall be purely resistive and constant, preferably equal to 600 or 10,000 ohms. The filter shall satisfy the requirements of this specification with ±5 percent deviation in value of the terminating impedances. If the filter is designed to operate with special connections, the necessary terminating conditions shall be explicitly stated by the manufacturer.

3.11 Maximum Input. The manufacturer shall state the maximum input (power or voltage) for which the filter set will meet the performance requirements of this specification. It is recommended that general purpose filter sets be capable of accepting at least one milliwatt, or one volt, input.

3.12 Transient Response. When a sinusoidal signal of nominal mean frequency f_m is suddenly applied to the properly terminated input of a filter, the peak of the envelope of signal appearing at its properly terminated output shall not exceed the steady state value by more than a factor of 1.26, or 2 dB.

3.13 Influence of External Conditions

3.13.1 ***Temperature.*** The transmission loss characteristic shall conform to the applicable sections of this standard over the temperature range of −10° to 50°C, but with all tolerances increased by 0.5 dB. If the influence of temperature exceeds this value, conformance with this specification may be achieved by determining the influence by measurement to an accuracy of 0.5 dB and by making the information available to the user of the filter set.

The manufacturer shall indicate the ambient temperature limits and corresponding periods of exposure which cannot be exceeded without risk of permanent damage to the apparatus.

3.13.2 ***Humidity.*** The manufacturer shall specify the hygrometric values between which the filter set will function correctly and the corresponding permissible exposure periods. The transmission loss characteristic shall conform to the applicable sections of this standard over the range of relative humidities of 0 to 90 percent, but with all tolerances increased by 0.5 dB.

3.13.3 ***Radiation Fields.*** The influence of magnetic and electrostatic fields, vibration, and sonic excitation shall be reduced to a level consistent with satisfactory usage in the environmental situations for which the filter set is intended.

NOTE: Manufacturers are encouraged to develop objective tests and state specifications for this category of influence.

3.14 Filter Designation. To meet the requirements of this standard, a filter set designation shall include the applicable Type and Class symbols. No filter set shall be stated to be in accord with this standard unless its Type and Class symbols are given. (Example: American Standard Octave Band Filter Type E Class II.)

4. Method of Test

4.1 Filter Transmission Loss Characteristic. The transmission loss characteristic of each filter band and the broadband circuit of 3.9 shall be measured according to the following basic procedure. The input terminals of the filter shall be connected to a variable-frequency, sine-wave oscillator of zero equivalent source impedance in series with an input terminating impedance of the value specified by 3.10. The oscillator output voltage shall be measured on a suitable, accurate voltmeter, V_1. The output terminals of the filter shall be connected to an output terminating impedance of the value specified by 3.10, and the output voltage across this impedance shall be measured with a second suitable, accurate voltmeter, V_2. The ratio V_1/V_2 shall be determined at appropriate frequencies throughout the frequency range necessary to demonstrate compliance with this specification, and the minimum value of V_1/V_2 shall be noted. Then:

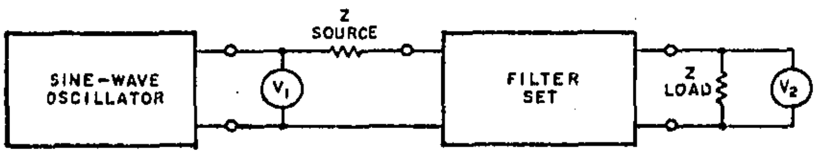
Reference Transmission Loss =

$$20 \log \frac{V_1}{V_2}, \text{ Minimum Value}$$

Filter Transmission Loss at Any Frequency =

$$20 \log \frac{V_1}{V_2} - \text{Reference Transmission Loss}$$

4.1.1 ***Characteristics of Sine-Wave Test Signal.*** When the transmission loss at frequencies below the passband is being measured, a suitable technique must be employed for removing the effects of oscillator harmonics from the apparent response of the filter. A tuned voltmeter at the output of the filter is not to be used for removing these effects, since it would simultaneously



$$\text{Reference Transmission Loss} = 20 \log_{10} \frac{V_1}{V_2}, \text{ Minimum Value}$$

$$\text{Filter Band Transmission Loss at Any Frequency} = 20 \log_{10} \frac{V_1}{V_2} - \text{Reference Transmission Loss}$$

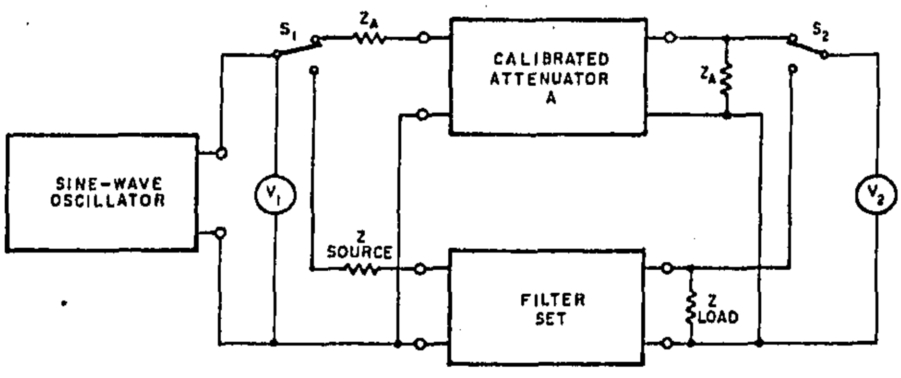
Fig. 7
Schematic of Two-Voltmeter Test Arrangement

remove any distortion or noise introduced by the filter set, which should properly be ascribed to analysis error of the set.

4.1.2 *Input Level During Test.* In establishing compliance with this standard, the filter set shall be measured at the maximum input specified by the manufacturer according to 3.11 and also at input levels of 10 decibels and 30 decibels below the maximum input level. Compliance shall be obtained at all three input levels except that at 10 decibels and 30 decibels below the maximum level the ultimate transmission loss may be limited by noise and hum to 10 decibels and 30 decibels, respectively, less than that required for maximum level.

4.2 Test Circuits

4.2.1 *Two-Voltmeter Method.* The two-voltmeter method of measuring transmission loss of the filter set may be carried out as shown in Fig. 7. Connect a suitable, accurate, sine-wave oscillator to the input of the filter with a series impedance equal to that from which the filter set is normally expected to operate. The oscillator source impedance is not a part of this series impedance. The output of the oscillator is measured by a suitable, accurate voltmeter V_1, which then makes the apparent source impedance at the voltmeter equal to zero. Terminate the filter by its rated terminating impedance and determine the output voltage using a suit-



For any measurement point:
V_1 must be identical for Filter and Attenuator positions of S_1 and S_2.
Attenuator is adjusted to make V_2 identical for Filter and Attenuator positions of S_1 and S_2.
Then:
Reference Transmission Loss = Smallest A found = A_{min}
Filter Band Transmission Loss at Any Frequency = $A_{\text{Any Frequency}} - A_{min}$

Fig. 8
Schematic of Alternate Substitution Test Arrangement

able, accurate voltmeter V_2. The parallel combination of load impedance and voltmeter impedance constitutes this terminating impedance. The transmission loss characteristic of the filter at any frequency is calculated in relation to the minimum absolute transmission loss by the formulas given in Fig. 7.

NOTE: With available test equipment it is possible to instrument this basic circuit for direct-reading or automatic test operation.

4.2.2 ***Substitution Method.*** Use of an adjustable, calibrated attenuator, properly terminated, in a substitution method is a suitable alternate for determining the transmission loss characteristic. This substitution process avoids the need for accurately calibrated voltmeters of a wide range of sensitivity. The technique of measurement and calculation is given in Fig. 8.

5. References

[1] American Standards Association. *American Standard Specification for Octave-Band Filter Set for Analysis of Noise and Other Sounds,* Z24.10-1953. New York: 1953. (Superseded by American Standard S1.11-1966.)

[2] American Standards Association. *American Standard Acoustical Terminology (Including Mechanical Shock and Vibration),* S1.1-1960. New York: 1960.

[3] American Standards Association. *American Standard Preferred Frequencies for Acoustical Measurements,* S1.6-1960. New York: 1960.

[4] Sepmeyer, L. W. Bandwidth error of symmetrical band-pass filters used for analysis of noise and vibration. *Journal of the Acoustical Society of America,* vol 34, 1962, p 1653.

[5] Sepmeyer, L. W. On bandwidth error of Butterworth band-pass filters. *Journal of the Acoustical Society of America,* vol 35, 1963, p 404.

[6] International Telephone and Telegraph Corporation. *Reference Data for Radio Engineers.* New York, Chapters 5 to 8.

[7] White Electromagnetics, Inc. *A Handbook on Electrical Filters. Synthesis, Design and Application.* Rockville, Maryland: 1963. Contains extensive bibliography.

[8] Schultz, T. J. Conversion between old and new octave band levels. *Journal of the Acoustical Society of America,* vol 36, no. 12, Dec 1964, p 2415.

Appendixes

(These Appendixes are not a part of American Standard Specification for Octave, Half-Octave, and Third-Octave Band Filter Sets, S1.11-1966, but are included to facilitate its use.)

Appendix A

Conversion Between Octave Band Levels Measured with Filters Meeting American Standard Z24.10-1953 and Filters Meeting This Standard

A1. Basis of Conversion

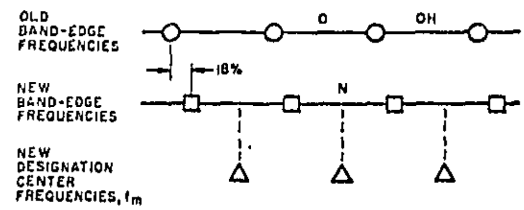
American Standard Z24.10-1953 for an octave band filter set specified a particular series of band-edge frequencies, whereas this standard specifies a series shifted upward approximately 18 percent to be in accordance with the preferred frequencies of American Standard S1.6-1960. Octave band filter measurements are used principally for measuring broadband noises with relatively continuous spectra. This Appendix gives a method of transferring the results of measurements made with one set of filters to corresponding results with the other set, for noises of this Class. In the following discussion, octave bands specified in American Standard Z24.10-1953 are called "old bands," whereas octave bands specified herein are called "new bands."

It is assumed that the frequency spectrum through contiguous octave bands has a continuously sloping characteristic wherein the power per unit frequency varies as a power of the frequency. It can then be shown that for octave bands the level (in dB) in a new band differs from the level in the corresponding old band by a correction that is 0.237 times the difference between the levels of the two old bands that include the new band. The correction is positive if the higher-frequency band has a higher level. Conversely, the level in an old band differs from the level in the corresponding new band by a correction that is 0.237 times the difference between the levels in the two new bands that include the old band. The correction is negative if the higher-frequency band has a higher level.

Computation directions and tabular aids for performing these interpolations are given in A2 and A3. The method is easily applied and its accuracy is considered consistent with the characteristic accuracy obtained in field measurements of noise. For a discussion of the basic problems in conversion, see Reference 8.

A2. Interpolation of New Band Level From Old Band Levels

This diagram represents the relationship of a new band, N, and the corresponding old band, O.



Let:

L_O = level in any old octave band, O

L_{OH} = level in next higher old octave band, OH

L_N = level in corresponding new octave band, N, contained in O and OH, where N is 18 percent above O in frequency

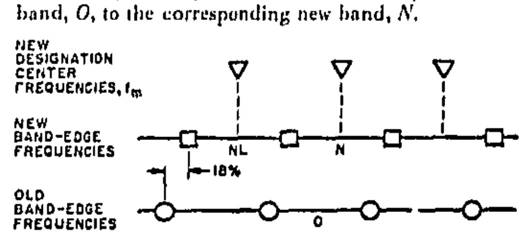
Then:

$$L_N = L_O + 0.237(L_{OH} - L_O)$$

The correction to be applied to L_O is shown in Table A1. Table A2 shows corresponding old and new filter bands.

A3. Interpolation of Old Band Level From New Band Levels

This diagram represents the relationship of an old band, O, to the corresponding new band, N.



Let:

L_N = level in any new octave band, N

L_{NL} = level in next lower new octave band, NL

L_O = level in corresponding old octave band, O contained in $NL + N$, where N is 18 percent above O in frequency

Then:

$$L_O = L_N - 0.237(L_N - L_{NL})$$

The correction term to be applied to L_N is shown in Table A3. Table A4 shows corresponding new and old filter bands.

Table A1
Corrections to L_O To Obtain L_N

Upward Spectrum Slope (Higher Frequency Band Has Higher Level) $L_{OH} - L_O$ in dB	Correction ADD to L_O dB	Downward Spectrum Slope (Higher Frequency Band Has Lower Level) $L_{OH} - L_O$ in dB	Correction SUBTRACT from L_O dB
0	0	0	0
1	0.2	- 1	0.2
2	0.5	- 2	0.5
3	0.7	- 3	0.7
4	1.0	- 4	1.0
5	1.2	- 5	1.2
6	1.4	- 6	1.4
7	1.7	- 7	1.7
8	1.9	- 8	1.9
9	2.1	- 9	2.1
10	2.4	-10	2.4
11	2.6	-11	2.6
12	2.8	-12	2.8

Table A2
Old Octave-Band Levels To Be Used for Calculating New Octave-Band Levels

Use Levels for These Old Octave Bands: O (c/s)	OH (c/s)	To Calculate Levels For New Octave Band Centered on N (c/s)
37-75	75-150	63
75-150	150-300	125
150-300	300-600	250
300-600	600-1200	500
600-1200	1200-2400	1000
1200-2400	2400-4800	2000
2400-4800	4800-9600	4000
4800-9600	—*	8000

* Take same $L_{OH} - L_O$ as for next band.

Table A3
Corrections to L_N To Obtain L_O

Upward Spectrum Slope (Higher Frequency Band Has Higher Level) $L_N - L_{NL}$ in dB	Correction SUBTRACT from L_N dB	Downward Spectrum Slope (Higher Frequency Band Has Lower Level) $L_N - L_{NL}$ in dB	Correction ADD to L_N dB
0	0	0	0
1	0.2	- 1	0.2
2	0.5	- 2	0.5
3	0.7	- 3	0.7
4	1.0	- 4	1.0
5	1.2	- 5	1.2
6	1.4	- 6	1.4
7	1.7	- 7	1.7
8	1.9	- 8	1.9
9	2.1	- 9	2.1
10	2.4	-10	2.4
11	2.6	-11	2.6
12	2.8	-12	2.8

Table A4

New Octave-Band Levels To Be Used for Calculating Old Octave-Band Levels

Use Levels for New Octave Band Centered on N (c/s)	NL (c/s)	To Calculate Levels For Old Octave Bands O (c/s)
63	—*	37-75
125	63	75-150
250	125	150-300
500	250	300-600
1000	500	600-1200
2000	1000	1200-2400
4000	2000	2400-4800
8000	4000	4800-9600

* Take same $L_N - L_{NL}$ as for next band.

Appendix B

Band-Edge Transmission Loss for Minimum Bandwidth Error

Traditionally, filter bandwidths have been expressed in terms of the half-power or 3 dB down frequencies of the filter. However, when random noise is analyzed the energy which is transmitted by a band-pass filter depends not only on the frequency interval between two points of equal transmission loss, but also on the steepness of the transmission loss characteristic of the filter and the slope of the spectrum being analyzed. Thirty representative spectra examined by the Writing Group revealed spectrum level slopes ranging from +6 to −21 dB per octave.

The bandwidth error* for a number of filter characteristics and spectrum level slopes was first computed for an idealized filter (see Reference 4) and then for the maximally flat or Butterworth filter characteristic (see Reference 5). In addition, the band-edge attenuation for Butterworth filters required to give zero bandwidth error when analyzing white and pink noise was computed. The results of the latter two investigations are given in Table B1.

The bandwidth error curves for fractional octave filters are symmetrical about the −3 dB per octave slope in spectrum level (pink noise). This is the slope which provides equal power in each band of a series of constant percentage bandwidth filters. However, Table B1 reveals that a very small difference is involved between correcting for zero bandwidth error on pink or white noise. In addition, it was found that the analytical solution for zero error in white noise analysis gave the same band-edge attenuation for all bandwidths of the same filter complexity, while the zero pink noise error adjustment produced a slightly different band-edge attenuation for each filter bandwidth of the same complexity. For third-octave filters, the two criteria differ only one part in the second decimal place. Owing to the much greater simplicity in carrying out numerical integration to determine the effective bandwidth for white noise and the slight shifting in the bandwidth error axis toward plus and minus errors, the Committee decided on white noise for the effective bandwidth referent.

*Bandwidth error refers to the difference between the noise power transmitted by the real filter and that transmitted by an ideal filter of nominal bandwidth.

Table B1
Performance of Butterworth Bandpass Filters

	n	δ dB/octave	H_1 dB	H_2 dB	A_1 dB	A_2 dB
For one-octave bandwidth	2	−3	0.37	0	3.84	
		− 6, 0	0.46	0.07		4.02
		− 9, +3	0.78	0.32		
		−12, +6	1.55	0.92		
	3	−3	0.16	0	3.56	
		− 6, 0	0.20	0.03		3.65
		− 9, +3	0.31	0.11		
		−12, +6	0.50	0.26		
	4	−3	0.08	0	3.42	
		− 6, 0	0.11	0.014		3.48
		− 9, +3	0.17	0.056		
		−12, +6	0.26	0.128		
For half-octave bandwidth	2	−3	0.13	0	3.96	
		− 6, 0	0.16	0.023		4.02
		− 9, +3	0.56	0.10		
		−12, +6	0.78	0.26		
	3	−3	0.18	0	3.63	
		− 6, 0	0.20	0.007		3.65
		− 9, +3	0.23	0.030		
		−12, +6	0.25	0.070		
	4	−3	0.10	0	3.46	
		− 6, 0	0.11	0.003		3.48
		− 9, +3	0.13	0.015		
		−12, +6	0.15	0.035		
For third-octave bandwidth	2	−3	0.44	0	4.03	
		− 6, 0	0.46	0.011		4.02
		− 9, +3	0.51	0.047		
		−12, +6	0.61	0.120		
	3	−3	0.19	0	3.64	
		− 6, 0	0.20	0.003		3.65
		− 9, +3	0.21	0.014		
		−12, +6	0.24	0.032		
	4	−3	0.10	0	3.48	
		− 6, 0	0.11	0.001		3.48
		− 9, +3	0.12	0.007		
		−12, +6	0.13	0.016		

n = number of resonant elements or pole pairs
δ = spectrum level slope in dB/octave
H_1 = bandwidth error for filter 3 dB down at nominal cutoff or band-edge frequencies
H_2 = bandwidth error for filter adjusted for zero bandwidth error on pink noise
A_1 = nominal band-edge frequency transmission loss required to give zero bandwidth error on pink noise
A_2 = nominal band-edge frequency transmission loss required to give zero bandwidth error on white noise

American National Standards

The standard in this booklet is one of nearly 4,000 standards approved to date by the American National Standards Institute, formerly the USA Standards Institute.

The Standards Institute provides the machinery for creating voluntary standards. It serves to eliminate duplication of standards activities and to weld conflicting standards into single, nationally accepted standards under the designation "American National Standards."

Each standard represents general agreement among maker, seller, and user groups as to the best current practice with regard to some specific problem. Thus the completed standards cut across the whole fabric of production, distribution, and consumption of goods and services. American National Standards, by reason of Institute procedures, reflect a national consensus of manufacturers, consumers, and scientific, technical, and professional organizations, and governmental agencies. The completed standards are used widely by industry and commerce and often by municipal, state, and federal governments.

The Standards Institute, under whose auspices this work is being done, is the United States clearinghouse and coordinating body for standards activity on the national level. It is a federation of trade associations, technical societies, professional groups, and consumer organizations. Some 1,000 companies are affiliated with the Institute as company members.

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For a free list of all American National Standards, write:

American National Standards Institute, Inc

1430 Broadway **New York, N. Y. 10018**

8.3 Power setting

8.4 Surface wind and direction

8.5 Surface temperature

8.6 Surface relative humidity

8.7 Comments on local terrain, topography and ground cover

5.3.2 The equivalent sound pressure level (SPL) of the ambient noise signal should be determined from the tape recording of the ambient noise signal obtained at the test site without the presence of the aircraft noise signal. It is desirable to record the ambient noise signal with the system gain set at the levels where aircraft noise measurements will be made.

5.3.3 The gain of the tape recorder should be adjusted so that the record level will be within the linear operating characteristics of the tape recorder for the peak of the aircraft noise signal. (It is suggested that the maximum rms level should be 12 db below the maximum of the linear response level).

6. DATA REDUCTION EQUIPMENT - The following equipment is the minimum required to reduce the basic data acquired in the field on aircraft exterior noise:

6.1 Band Pass Filters - Octave band pass filter sets designed to meet requirements of ASA S 1.6-1960, are recommended. The use of filters designed to meet requirements of ASA Z24.10-1953, is also satisfactory, but standardization on ASA S 1.6-1960 should be anticipated.

6.2 Sound Level Meter or Graphic Level Recorder - Average or rms-type indication with the rms type preferred

6.3 Tape Recorder - Playback to be compatible with recorder used for data acquisition.

7. DATA REDUCTION TECHNIQUES

7.1 Calibration - The data reduction system should be calibrated in the same manner as used to calibrate the electrical recording system (3.2).

7.2 Pen Speed - The graphic level recorder's pen speed should be at the minimum which will not distort the signal trace to simplify the "fairing" of the recorded signal.

A typical pen speed for reducing aircraft fly-over noise data is 100 mm/sec.

7.3 Sound-Level Meter Indicator - The dynamic characteristics of the sound-level meter indicator, if used, should conform to the IEC Draft Recommendation, Specification for Precision Sound Level Meters.

8. DATA REPORTING - Graphs, tables or reports containing data -- all data shall be converted to rms -- on aircraft exterior noise should be accompanied by the following minimum information on test conditions:

8.1 Airplane and engine type

8.2 Airplane heading, altitude, airspeed, and location relative to the microphones.

3.3.2 An insert voltage device is recommended to record a known signal on the tape recorder just prior to and after recording aircraft noise data. It is recommended that this check be made under field-operating conditions to ensure against drift or error and to supplement the calibrations described in paragraphs 3.1, 3.2, and 7.1.

4. ACCURACY

4.1 Combined System Accuracy - The combined recording and reduction system when calibrated as recommended should be capable of measuring a plane progressive wide band sound wave arriving in the direction of the axis of calibration of the microphone with an accuracy of ± 1 db.

4.2 Frequency Response - The response of the combined system to a plane, progressive sinusoidal sound wave should be constant within ± 3 db over the frequency range from 37.5 cps to 12,000 cps excluding the directional frequency characteristics of the microphone.

4.3 Directional Frequency Characteristics - The sensitivity of the microphone to plane sound waves arriving from any direction within 45 deg of the axis of calibration should not differ by more than 1 db below 1000 cps, 2 db between 1000 and 4000 cps, 5 db between 4000 and 8000 cps and 6 db between 8000 and 12,000 cps.

5. FIELD MEASUREMENT TECHNIQUES

5.1 Acoustical Environment - Basic data on aircraft noise should be acquired under conditions of wind velocity less than 10 kn. It is also recommended that data be taken when the relative humidity is above 30%. The test should be run in an area free of obstructions, such as hills or buildings, which could reflect, obstruct or ~~defract~~ the measured sound wave.

5.2 Microphone Positioning and Orientation - For measurements made of aircraft flying directly overhead, the microphones should be oriented with their longitudinal axes parallel to the ground and perpendicular to the vertical projection of the flight path. For other than overhead flights, the microphone diaphragm should be oriented to receive as close to grazing incidence of the sound as the test conditions permit.

The height of the microphone above ground level should be 5 ft.

5.3 Recording of the Ambient Noise - The ambient noise of the measurement system and the test area (that is, the composite response of the system to the background noise and the electrical noise of the equipment) must be determined so that the validity of the measured aircraft noise level can be established.

5.3.1 The octave band pressure level of the aircraft noise signal should exceed the corresponding octave band pressure level of the ambient noise by at least 10 db

(F)

SOCIETY OF AUTOMOTIVE ENGINEERS, Inc. 485 LEXINGTON AVENUE NEW YORK 17, N.Y.	AEROSPACE RECOMMENDED PRACTICE	ARP 796
MEASUREMENTS OF AIRCRAFT EXTERIOR NOISE IN THE FIELD		Issued 6-15-65 Revised

1. <u>PURPOSE</u> - The purpose of this recommended practice is to define measurement techniques and equipment for acquisition and reduction of basic data on aircraft exterior noise. ~~It is not~~ its purpose is not to propose use of these techniques or this equipment for research or monitoring-type tests.

2. <u>MEASUREMENT EQUIPMENT</u> - The following equipment should be used to acquire basic data in the field on aircraft exterior noise:

2.1 Microphone system

2.2 Microphone windscreen - optional

2.3 Tripod or similar microphone mounting provisions

2.4 Gain control (or attenuator)

2.5 Tape recorder with N.A.B. equalization for 7-1/2 or 15 ips or a tape recorder having uniform frequency characteristics over the range from 20 to 12,000 cps.

2.6 Acoustic calibrator system using sine wave or broad band noise of known sound pressure level.*

2.7 Insert voltage device - optional.

3. <u>CALIBRATION</u>

3.1 <u>Microphone Calibration</u> - The microphone should be calibrated according to ASA Standard Z24.11 - 1954, or the latest approved revision thereof.

3.2 <u>Recording System Calibration</u> - The complete electrical recording system should receive a frequency and amplitude calibration by use of sine wave voltage of known amplitude and at frequencies covering the range from 20 to 12,000 cps. A broad band signal of known amplitude can also be used.*

3.3 <u>Sensitivity Checks in the Field</u>

3.3.1 Prior to and after each test an acoustic calibration of the system should be made in the field as a sensitivity check. This acoustic calibration should be used to establish a reference level during subsequent analysis of the stored data. The acoustic calibrator should produce a sine wave or broad band noise of known sound pressure level at the face of the microphone button.*

*If broad band noise is used, the signal should be described in terms of its rms value and maximum peak/rms factor for a "no clipping" level.

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AEROSPACE RECOMMENDED PRACTICE

ARP 866

STANDARD VALUES OF ATMOSPHERIC ABSORPTION AS A FUNCTION OF TEMPERATURE AND HUMIDITY FOR USE IN EVALUATING AIRCRAFT FLYOVER NOISE

Issued 8-31-64
Revised

1. INTRODUCTION - This report proposes a method by which values can be obtained for the absorption of sound in air over a wide range of temperature and humidity conditions. Although it was developed primarily for use in evaluating aircraft fly-over noise measurements, the information should be applicable to other noise problems as well.

There are a number of factors which influence the propagation of aircraft noise from an aircraft flying overhead to a point on the ground. The purpose here, however, is to consider only the classical and molecular absorption of sound energy by the atmosphere. It is felt that spherical divergence, scattering, refraction, and other effects should be treated separately.

The method presented is based on the theory of Kneser[1], the laboratory results of Harris[2] and field data from Rolls Royce,[3] Boeing[4] and Douglas[5]. Although the final information was used from these sources only, the works of many other individuals and groups were used to arrive at a selection of the present method.

The experimental results of Harris were obtained for a single temperature of 20 C (68 F). Essentially, these data were used, and curves based on Kneser's theory were "modified" to fit them. The modified curves then serve as a basis for obtaining values over a wide range of temperatures, humidities and frequencies. Once these curves were established they were compared with field results to select a method for predicting absorption values for bands of noise by using the absorption value for a single frequency.

Comments on the use of the proposed method, absorption values and some discussion of standard atmospheric conditions are included in the report.

2. THE THEORETICAL CURVES OF KNESER - The theory of Kneser indicates that there are two significant types of atmospheric absorption. These are classical absorption which is a function of frequency and temperature, and molecular absorption which is a function of frequency, temperature and humidity. Both types are linear with distance and are expressed here in units of decibels per 1000 feet.

Classical absorption results from energy dissipation through the effects of heat conduction and radiation, viscosity and diffusion. It is relatively unimportant except at higher frequencies and varies only slightly with temperature; however, it should be considered, since at 10,000 cps it amounts to a little over 5 dB/1000 feet. Values of classical absorption are given in Figure 1.

Molecular absorption results from a relaxation process of oxygen molecules. It varies over a wide range of values and may be as high as 100 dB/1000 feet at 10,000 cps over a range of temperatures between 0 and 100 F.

Both theory and experimental results indicate that for a given frequency there is a value of humidity at which molecular absorption has a maximum value. As the humidity goes above or below this value the absorption decreases. The absolute humidity* at which maximum absorption will occur increases with frequency in the manner shown in Figure 2 from an empirical formula by Kneser. Kneser also provided values of maximum molecular absorption as a function of frequency and temperature (Figure 3). The remaining problem is to determine what portion of the maximum molecular attenuation will occur at humidities other than that for the maximum value. Here again Kneser's theory supplied a curve to accomplish this. This curve is shown in Figure 4 and is a plot of normalized molecular absorption against normalized humidity. One need only know the temperature and absolute humidity in order to obtain both classical and molecular attenuation from the curves in Figures 1 through 4.

3. MODIFICATION OF KNESER'S THEORETICAL CURVES - Most of the experimental data reported in the literature show the same trends predicted by Kneser's theory. However, they do not agree with the values obtained by Kneser's theory, nor do the different sets of experimental data agree with each other. Unfortunately, the experimental data from the laboratory were usually obtained at only one temperature and none offer a complete set of data over a wide range of temperatures and humidities. The general practice used to obtain a fairly complete set of data is to alter the theoretical curves to fit experimental data. This is the manner in which the currently proposed set of curves has been obtained.

An investigation of the experimental data in the literature indicated that those obtained by Harris were the most dependable from the standpoint of the manner in which the tests were conducted and the manner in which the data seemed to check out with data from the field. The method presented here essentially follows the pattern of adjusting Kneser's theoretical curves to fit Harris' data.

*Relative humidity is a more familiar term than absolute humidity, because it has significance to weather and comfort. It is the ratio of the amount of water in a parcel of air at a given temperature divided by the amount of water that percel of air would have at the condensation point times 100 percent. However, molecular absorption is concerned with the amount of water in the air regardless of how much there could be. Therefore, absolute humidity in grams per cubic meter is used here. A curve relating temperature, relative humidity and absolute humidity is presented in Figure 9.

Because the determination of atmospheric absorption depends on several curves one must be arbitrary in deciding which of these curves should be altered to make the theoretical curves agree with experimental data. The approach taken here was to use both the classical absorption curve (Figure 1) and the curve of absolute humidity at which maximum absorption occurs as a function of frequency (Figure 2), as presented by Kneser. The theoretical curve relating normalized molecular absorption to normalized absolute humidity (Figure 4) and the curve presenting maximum molecular absorption values for different frequencies and temperatures (Figure 3) were then adjusted to fit the data of Harris.

The total absorption values (i.e., a combination of molecular and classical) in Figure 3 of Harris' paper were used as presented. However, in Figure 4 of Harris' paper, his plot of normalized absorption as a function of normalized humidity includes the effects of classical absorption. Classical absorption was subtracted from Harris' total absorption values and a modified curve relating normalized molecular absorption as a function of normalized humidity was obtained. This curve is plotted in Figure 5 along with the curve from Figure 4 in Harris' paper, a similar curve presented by Beranek[6] and Kneser's theoretical curve. The modified Harris curve was selected for the currently proposed method.

In Figure 5 of Harris' paper a comparison is made between his experimental values and Kneser's theoretical values for maximum absorption coefficients as a function of frequency. However, Harris' values once again include classical absorption and the theoretical values do not. Comparing only the molecular absorption of Harris' total absorption values show them to be lower than theory would predict. Harris' data are approximately parallel to the theoretical curve of $\alpha_{mol\ max}$ as a function of frequency (Figure 3). The theoretical curve was simply shifted downward to match Harris' data. The adjustment is shown in Figure 6.

Theoretical values of maximum molecular absorption for three frequencies were plotted as functions of temperature. The measured or extrapolated values of Harris obtained at 20 C (68 F) were plotted and modified curves parallel to the theoretical curves were drawn through them. The modified curves in Figure 6 were used to obtain the complete set of modified data presented in Figure 7.

The curves in Figures 1, 2 and 7 and the curve in Figure 8 which is taken from the modified curve in Figure 5 then supply a complete set of curves on which to base total atmospheric absorption for a wide range of temperature and humidity conditions. The curves in Figure 9 are presented to show the relationship between temperature, relative humidity and absolute humidity. These curves are taken from Evans and Bazley.

4. FIELD DATA - While laboratory data are obtained under comparatively carefully controlled conditions, field values of atmospheric absorption coefficients are obtained under a fairly wide range of conditions which are not carefully measured. These data are usually obtained from a series of tests in which the sound levels are measured on the ground as a particular type airplane flies over the measurement point at a range of altitudes from a few hundred to a few thousand feet. The data are plotted as a function of altitude, inverse square losses are removed, and the excess attenuation is attributed to atmospheric absorption. It is usually assumed that the surface temperature and relative humidity are representative of conditions at all altitudes and that the sound propagation was in all cases vertical.

Three fairly complete sets of atmospheric absorption values obtained from field tests of aircraft fly-over noise levels are discussed below. These three sets of data, taken by completely independent groups and under a variety of atmospheric conditions, indicate that by making certain general assumptions a fairly reliable prediction of absorption values can be made using the proposed procedure.

4.1 Rolls Royce Data - Figure 10 is a plot of atmospheric absorption values in one-third octave bands as obtained by Rolls Royce using a Canberra aircraft over a fly-over altitude range of 500 to 4000 feet. The measured values are plotted as flat lines, extending across the frequency range of the band for which they were determined.

Surface temperatures ranged from 13 to 19 C and surface relative humidities ranged from 45 to 53%. The upper solid line plotted in Figure 10 was calculated by the method described above using the average of the surface temperatures and average of the surface relative humidities. The averages were a temperature of 60.8 F, a relative humidity of 49% and an absolute humidity of 6.5 gm/meter^3. The lower solid line was calculated from the same method but for different atmospheric conditions. The conditions were based on the assumptions that the absolute humidity was constant over the altitude range, but that the temperature decreased with altitude at the lapse rate given by a NASA standard atmosphere. The average temperature over the test altitudes was then 53.2 F. The lower curve varies more from the measured data than the upper curve in the middle frequency range, but shows much better agreement with the measured data in the upper frequency range. If we assume further that, because the fly-over noise spectra slopes down rather rapidly with frequency, and that the band level at higher frequencies is controlled by energy in the lower part of the band, we have very good agreement between the lower curve and the measured values. This leads to a general rule that for one-third octave bands up to about 4000 cps the geometric mean frequency adequately represents the band for atmospheric absorption analyses, but above 4000 cps the lower limiting frequency of the band should be used. On this basis the circles plotted on the lower curve would be the values derived from the currently proposed method.

The band centered at 5000 cps indicates that a frequency between the GMF and the lower limit of the band offers the best fit, but for simplicity the lower limiting frequency is assumed. Also the frequency absorption values measured are consistently higher than those predicted. This could well be because jet exhaust noise in this frequency range is propagated aft from the engine rather than straight down. The measured values then would represent the absorption over a distance greater than the airplane altitude. The available data are not sufficient to check out this possibility.

4.2 Boeing Data - The Boeing data were extracted from Boeing Document No. D6-4084 TN, dated September 1962. Values for the commercial octave bands at 53 F and 61% relative humidity (absolute humidity 6.3 gm/meter^3) were obtained by correcting the proposed standard day values with the data in Figure 4 of the Boeing report. It was assumed that these were the data determined by Boeing under the stated conditions. The values determined by Boeing are plotted in Figure 11 as the flat lines extending across the frequency range of the band. The levels calculated for the estimated average conditions over the test altitude range of 200 to 3200 feet are shown in the solid line. Again, the measured data fall below the calculated data in the upper frequencies. However, assuming the GMF for the first seven bands, and 1.05* times the lower limiting frequency for the 8th band, the calculated and measured data show very good agreement. The predicted values based on these assumptions are plotted as circles.

4.3 Douglas Data - The absorption values determined by Douglas were obtained from DC-8 fly-over noise tests.[6] Surface-averaged atmospheric conditions were 77 F, 59% relative humidity and 13.5 gm/meter^3 absolute humidity. The measured values are plotted in Figure 12 as straight lines over the frequency range of each band. The solid line was calculated on the basis of the estimated average conditions over the test altitude range of 300 to 3400 feet. The same general trend toward values measured in the upper frequencies which were less than those predicted is seen here, but again the agreement is good by assuming the GMF through the 7th band and 1.05 times the lower limiting frequency for the 8th band.

On the basis of the preceding comparisons with field data it is felt that fairly realistic atmospheric absorption evaluations can be made for bands of jet exhaust noise using the absorption values of the following frequencies as representative of the absorption in octave or one-third-octave bands:

a. Octave Bands (Preferred or Commercial)

1. Geometric mean frequency for the first seven octave bands

2. 1.05 times the lower limiting frequency for the 8th octave band

*Beranek has suggested in Noise Reduction that using a factor of 1.2 times the lower limiting frequency of the octave band as representative of the octave band offers a best fit in some cases. The 1.05 factor was selected on the basis of the best fit for the 4800/9600 cps band for both the Boeing data and the Douglas data that follow.

b. One-Third Octave Bands (Preferred)

1. Geometric mean frequency for bands centered at 4000 cps and below

2. The lower limiting frequencies for bands centered above 4000 cps

Figures 13 and 14 present total absorption values proposed for preferred and commercial octave bands, respectively, over a temperature range of 0 to 100 F and over a relative humidity range from 10 to 90%. Data are given for the 4th through 8th octave bands. While there is a small amount of absorption in the lower bands it can usually be neglected.

Similar information is provided for one-third octave bands in Figure 15. In cases where absorption at these low frequencies may be significant, (e.g. for propagation over very large distances), values can be obtained from the information in Figures 2, 7, 8, and 9.

5. STANDARD ATMOSPHERIC CONDITIONS - Both Boeing[4] and Douglas have conducted surveys of temperature and humidity conditions at United States and World Airports. Both studies resulted in average surface conditions of 59 F and 70% relative humidity. Another standard of 59 F and 60% relative humidity has been proposed from Europe. Although such standards are arbitrary and the means of averaging to obtain such standards are rather dubious, it is recommended that the 59 F and 70% relative humidity standard be adopted. It is felt that these conditions are more representative of most airports which are involved in serious noise problems. The resulting total absorption coefficients for preferred and commercial octave bands are given below.

Preferred Octave Bands

Band No	4	5	6	7	8
GMF (cps)	500	1000	2000	4000	8000
α total dB/1000 feet	0.7	1.4	3.0	7.7	14.4

Common Octave Bands

Band No	4	5	6	7	8
Frequency Range cps	300/600	600/1200	1200/2400	2400/4800	4800/9600
α total dB/1000 feet	0.6	1.1	2.5	6.2	11.3

6. USE OF THE DATA PRESENTED - The air absorption values which have been proposed should be used with caution in making estimates of sound propagation losses. The values at high frequencies vary over a wide range with changes in frequency and changes in atmospheric conditions. Where large propagation distances are involved large discrepancies can occur if consideration is not given to the spectrum shape of the noise and to the actual conditions of the atmosphere. In aircraft fly-over noise evaluations, consideration should also be given to the angle between the source and the receiver, so that the best estimate of the propagation distance is obtained.

Many of today's aircraft will not meet all the requirements necessary to permit application of the octave band values as presented. It is believed, however, that if the frequency and directivity characteristics of the noise are known, engineering estimates of the frequencies representative of bands of noise can be made and absorption values can be determined, using the curves in Figures 1, 2, 7 and 8.

7. RECOMMENDATIONS - It is recommended that the following standards be adopted:

a. The curves of Figures 1, 2, 7 and 8 for determining atmospheric absorption values as a function of frequency.

b. The supplementary octave band values in Figures 13 and 14 when the frequency and directivity characteristics of the noise permit. (Broad band noise with a spectrum falling off fairly rapidly at high frequencies, nearly vertical propagation and atmospheric conditions representative of the altitude range.)

c. Conditions at the earth's surface of 59 F and 70% relative humidity (absolute humidity 8.7 gm/meter^3) as a standard atmosphere for acoustical evaluations.

PREPARED BY SAE COMMITTEE A-21,
AIRCRAFT EXTERIOR NOISE MEASUREMENT

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CLASSICAL ATMOSPHERIC ABSORPTION OF SOUND

α_{class} IN dB/1000 FT

FROM NYBORG AND MINTZER

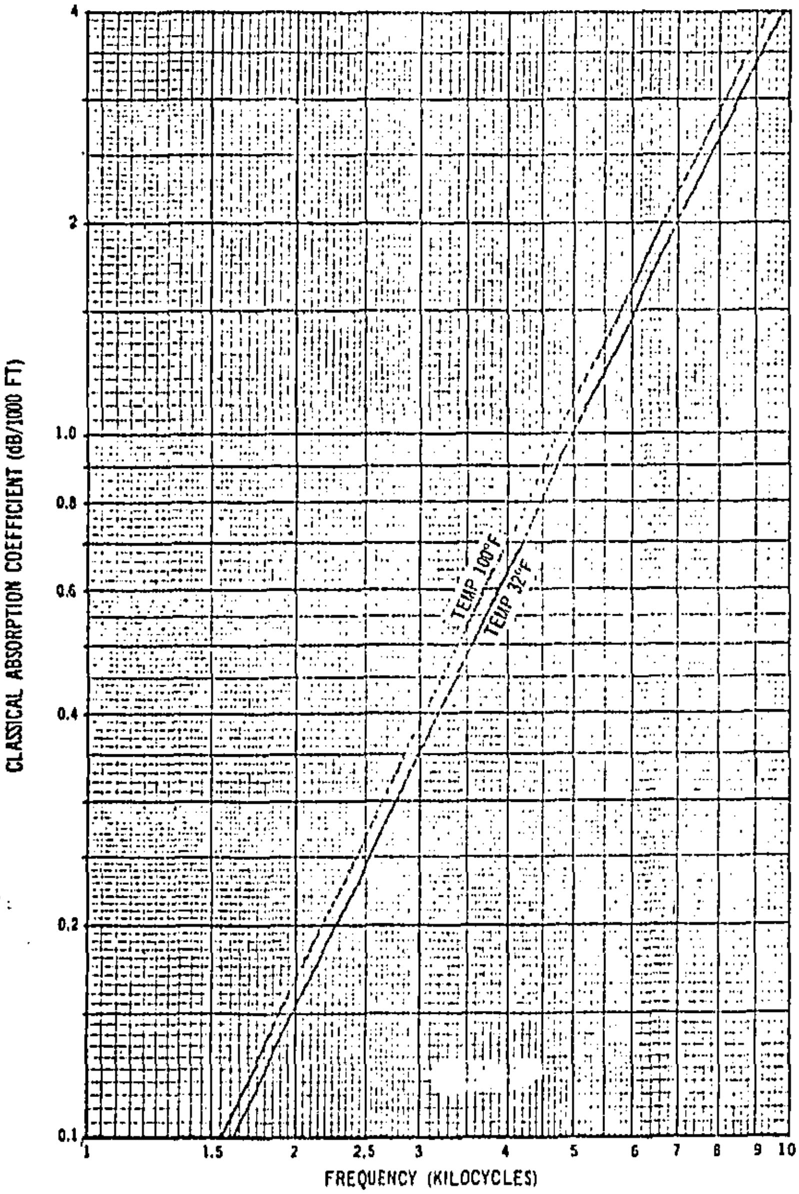


FIGURE 1.

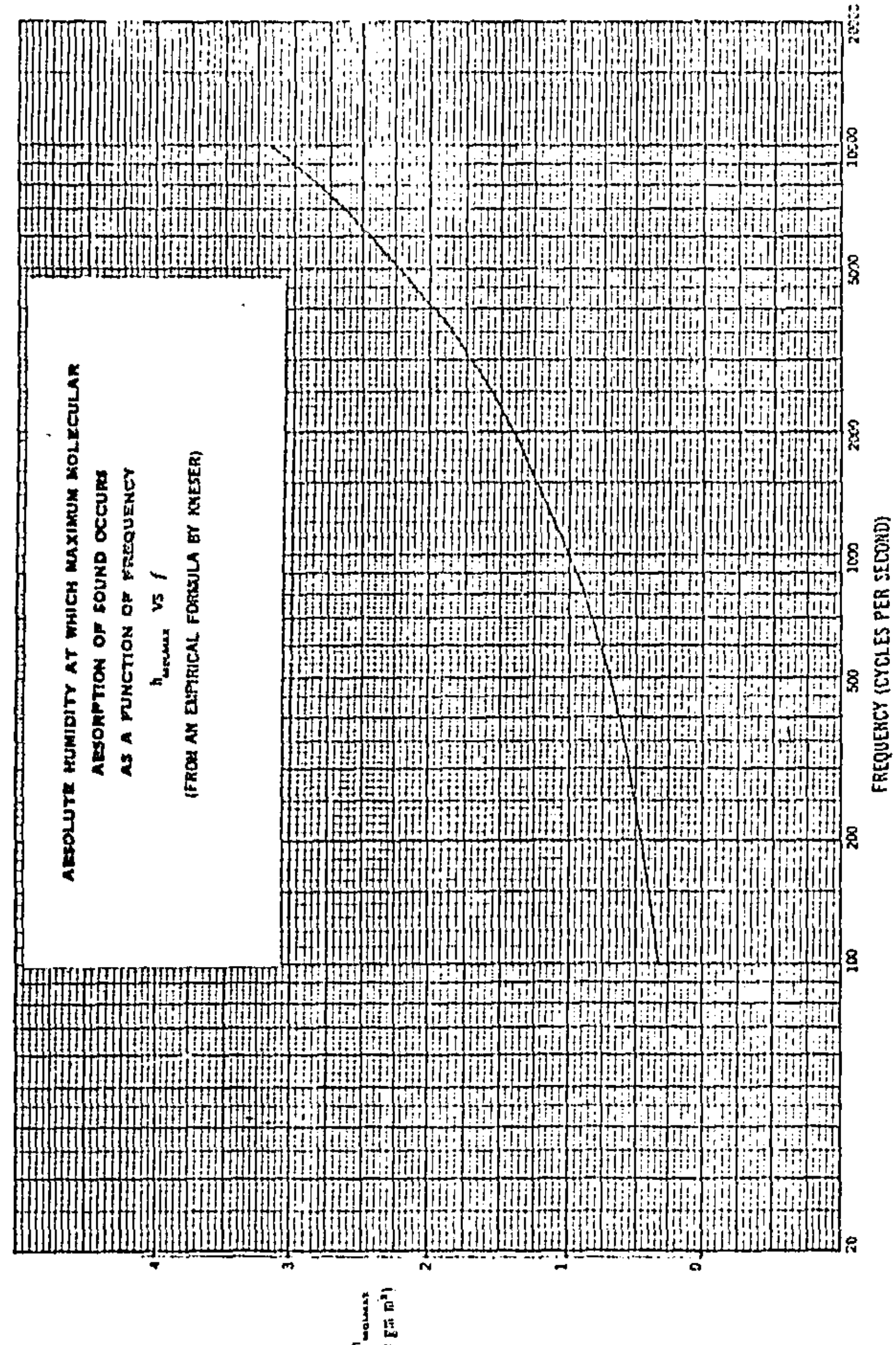

ABSOLUTE HUMIDITY AT WHICH MAXIMUM MOLECULAR
ABSORPTION OF SOUND OCCURS
AS A FUNCTION OF FREQUENCY
h_{molmax} VS f
(FROM AN EMPIRICAL FORMULA BY KNESER)
FREQUENCY (CYCLES PER SECOND)
20
100
200
500
1000
2000
5000
10000
20000
0
1
2
3
4
h_{molmax} (g/m^3)

FIGURE 2.

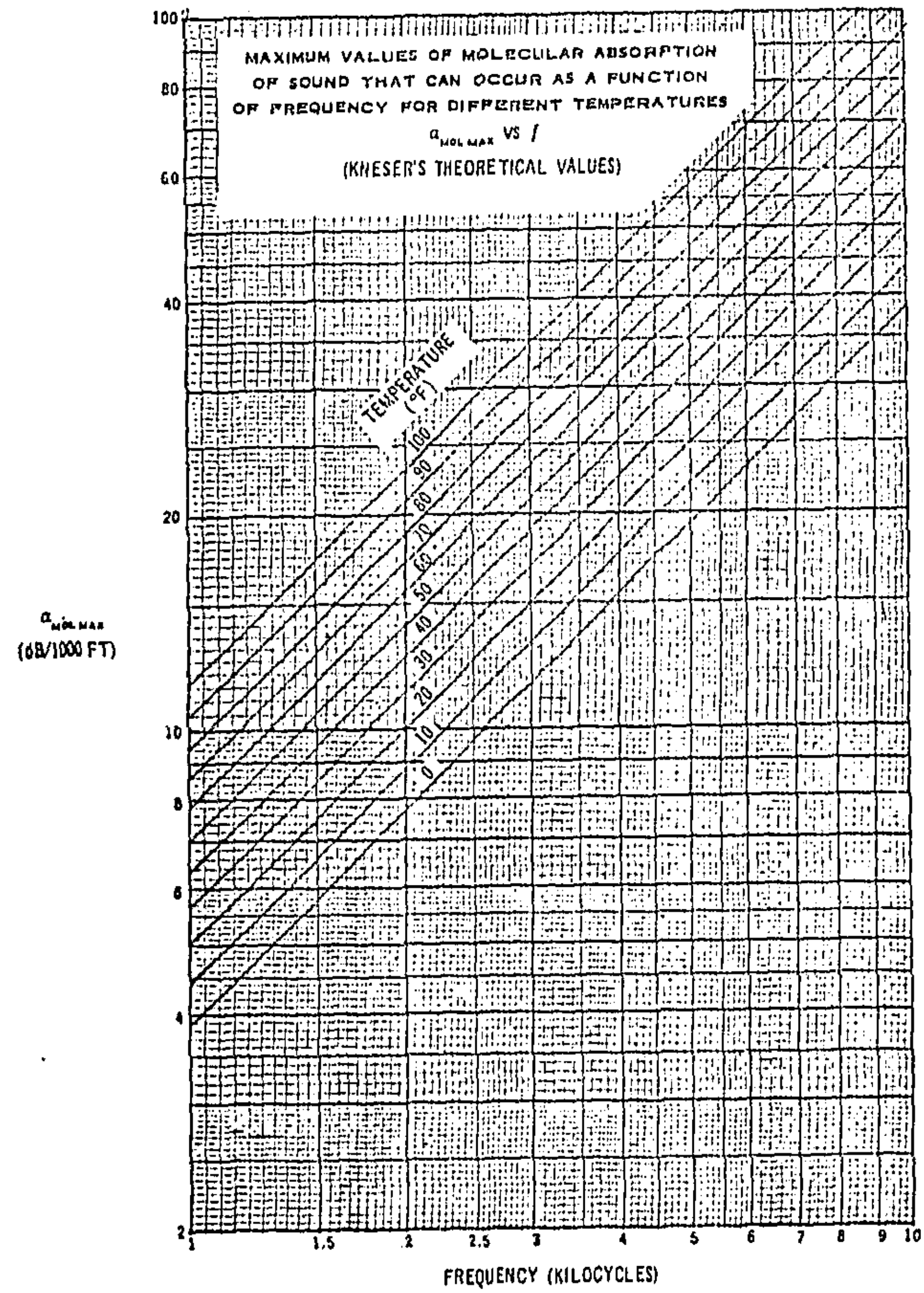

MAXIMUM VALUES OF MOLECULAR ABSORPTION OF SOUND THAT CAN OCCUR AS A FUNCTION OF FREQUENCY FOR DIFFERENT TEMPERATURES
$\alpha_{MOL\,MAX}$ VS f
(KNESER'S THEORETICAL VALUES)
TEMPERATURE (°F)
100
90
80
70
60
50
40
30
20
10
0
$\alpha_{MOL\,MAX}$ (dB/1000 FT)
100
80
60
40
20
10
8
6
4
2
1
1.5
2
2.5
3
4
5
6
7
8
9
10
FREQUENCY (KILOCYCLES)

FIGURE 3.

NORMALIZED MOLECULAR ABSORPTION AS A FUNCTION OF NORMALIZED ABSOLUTE HUMIDITY

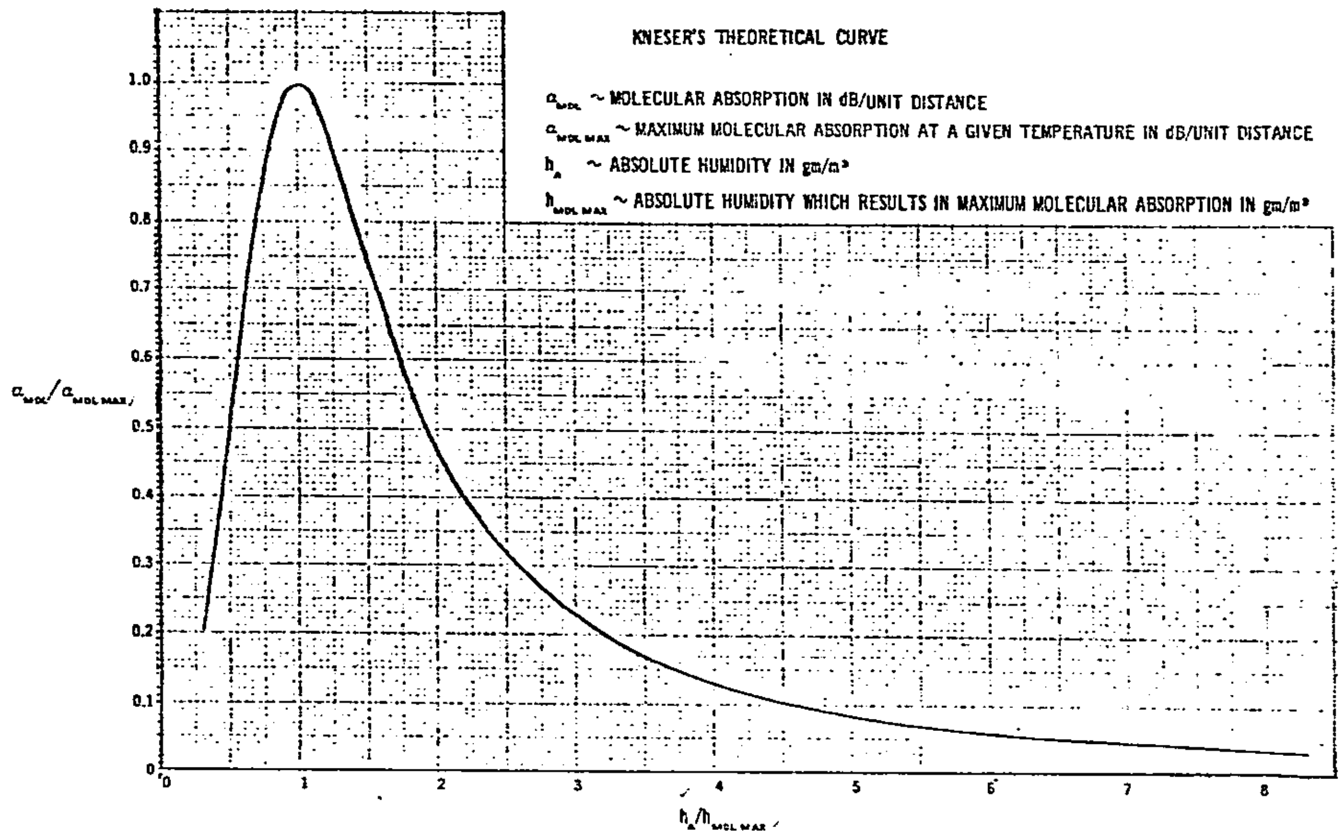


FIGURE 4.

NORMALIZED MOLECULAR ABSORPTION AS A FUNCTION OF NORMALIZED ABSOLUTE HUMIDITY

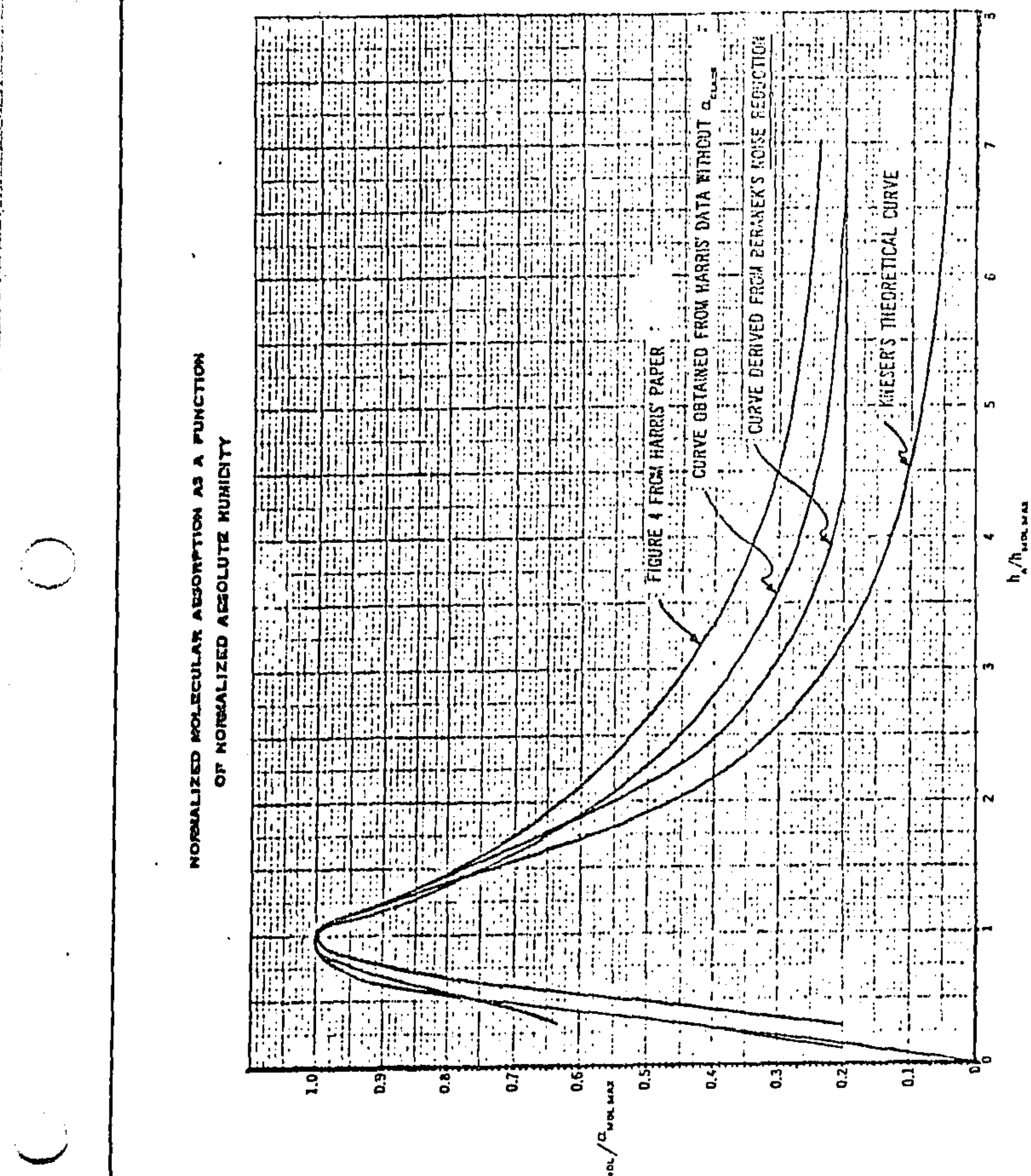


FIGURE 5.

MAXIMUM MOLECULAR ABSORPTION OF SOUND AS A FUNCTION OF TEMPERATURE

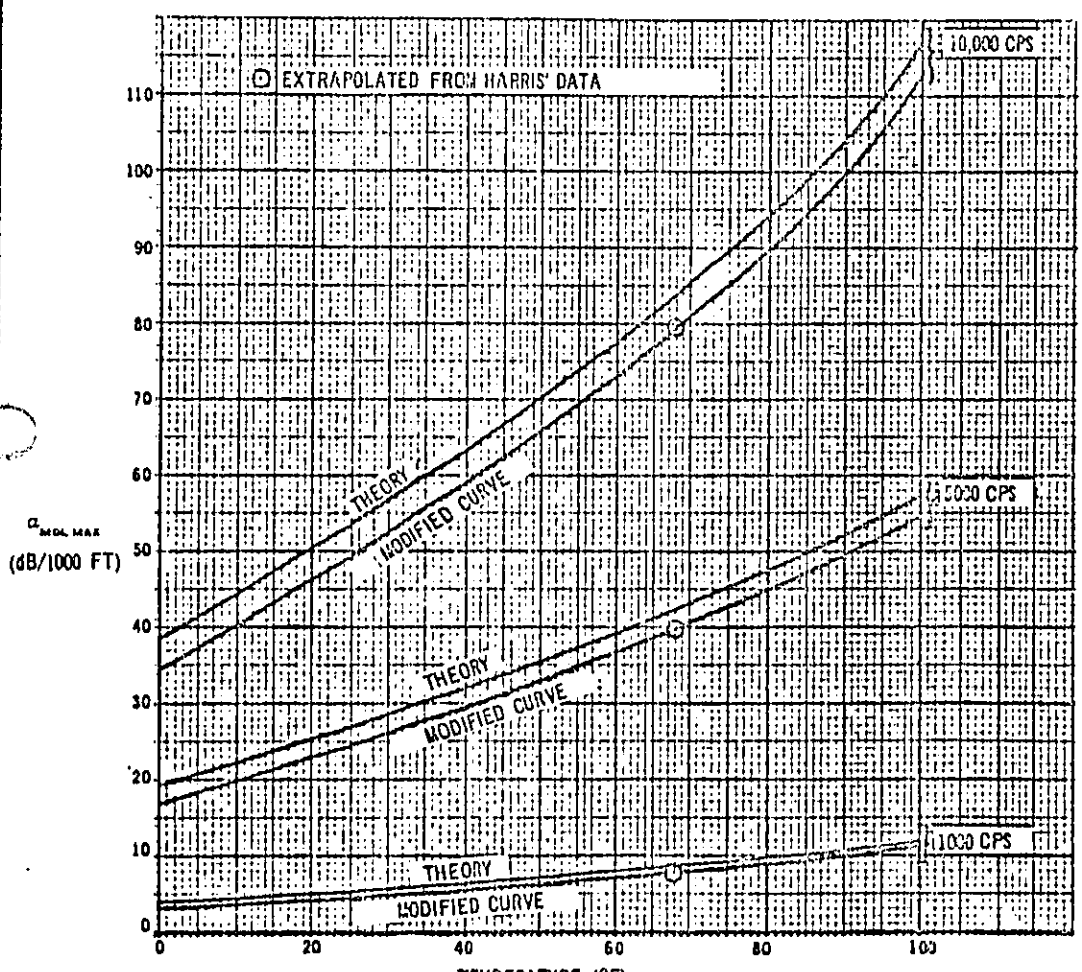


FIGURE 6.

MODIFIED CURVES OF MAXIMUM MOLECULAR ABSORPTION OF SOUND AS A FUNCTION OF FREQUENCY FOR DIFFERENT TEMPERATURES

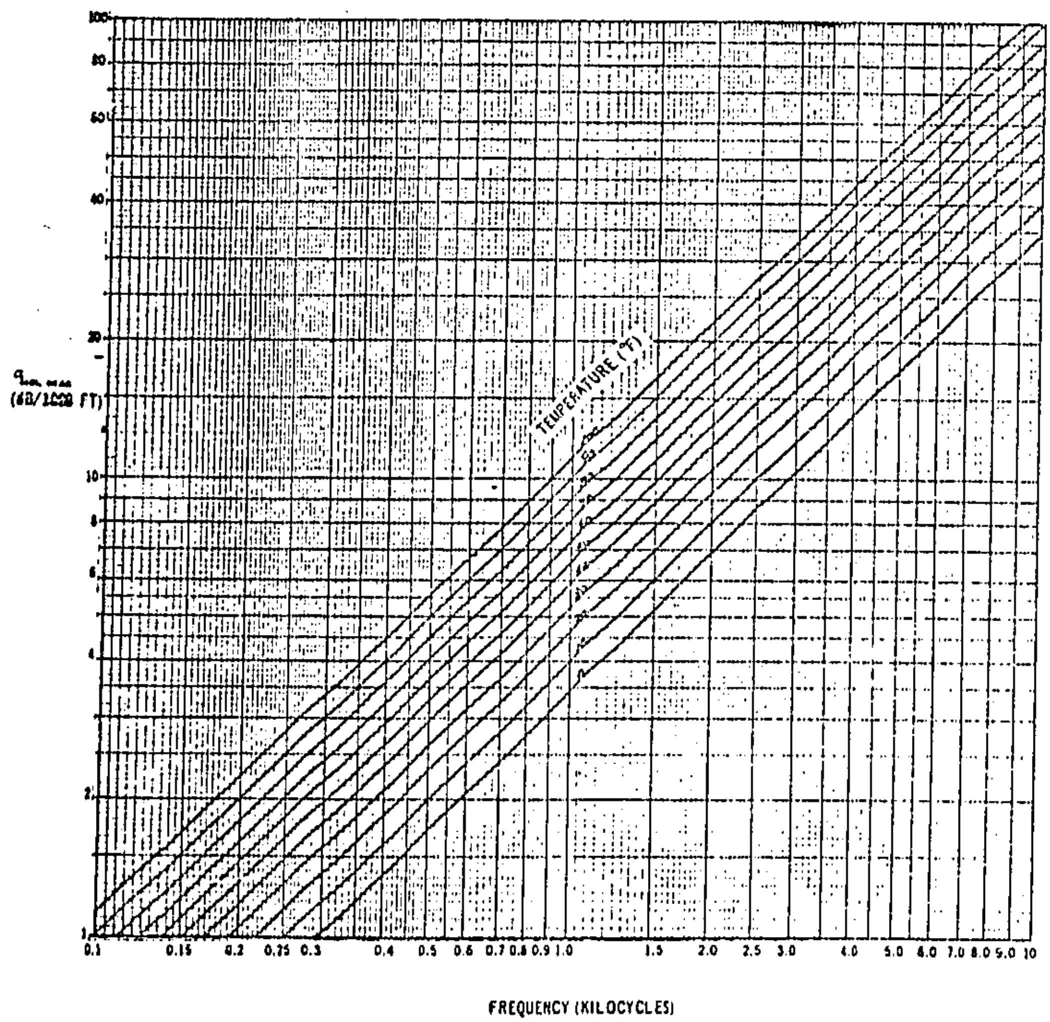


FIGURE 7.

NORMALIZED MOLECULAR ABSORPTION AS A FUNCTION OF NORMALIZED ABSOLUTE HUMIDITY

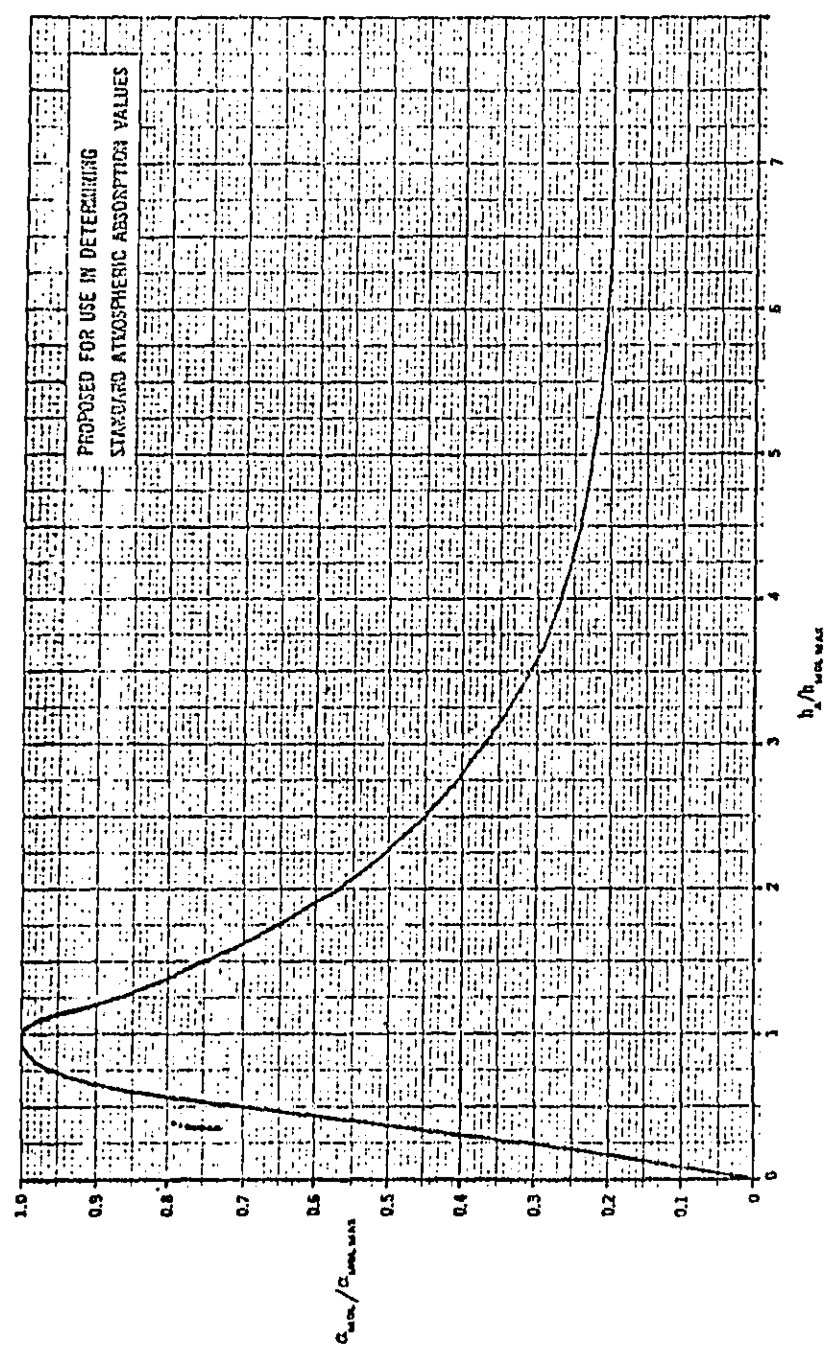


FIGURE 8.

ABSOLUTE HUMIDITY AS A FUNCTION OF TEMPERATURE AND RELATIVE HUMIDITY

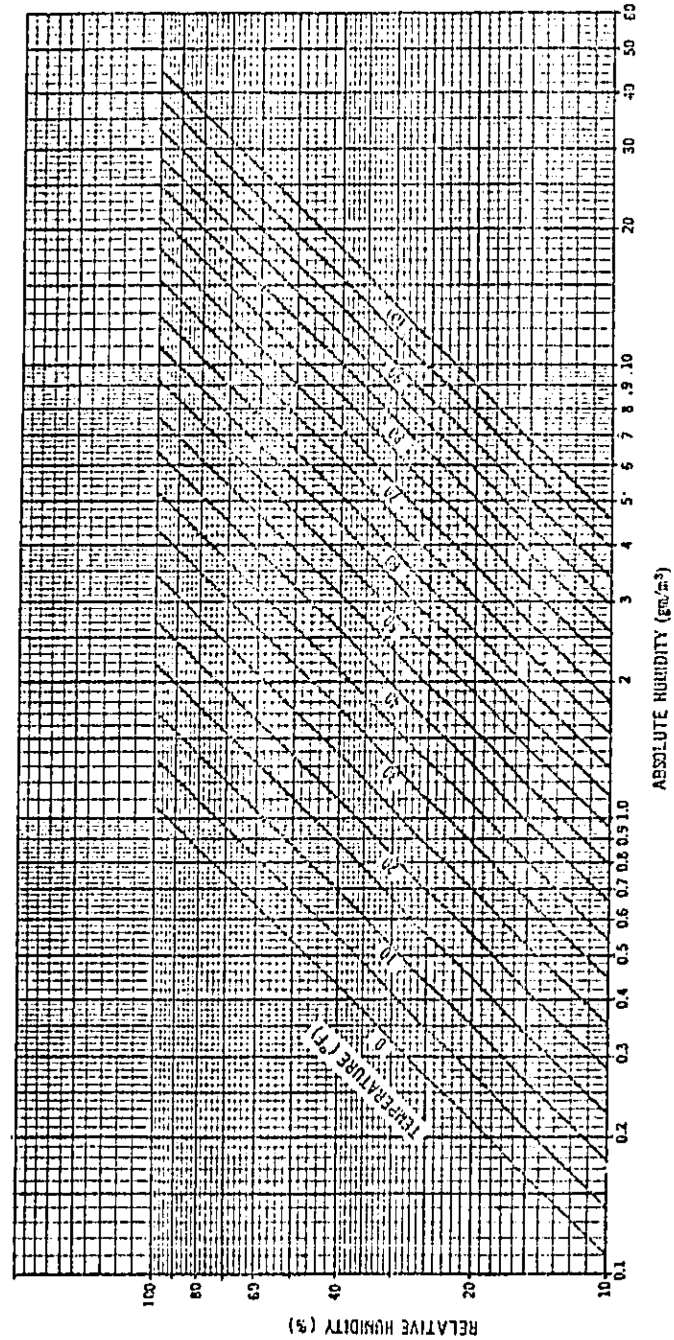


FIGURE 9.

COMPARISON OF TOTAL AIR ABSORPTION VALUES MEASURED IN THE FIELD BY ROLLS-ROYCE WITH VALUES CALCULATED BY THE CURRENTLY PROPOSED METHOD

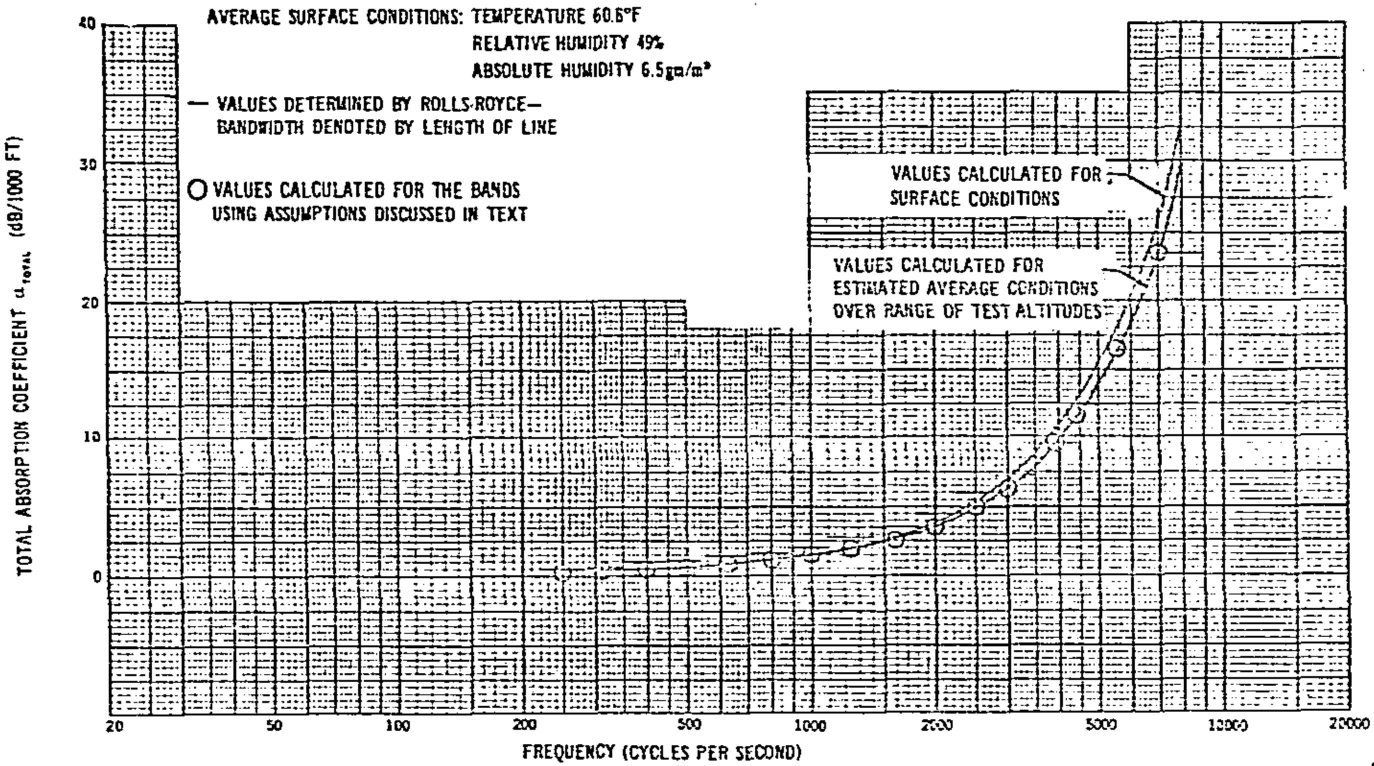


FIGURE 10.

COMPARISON OF TOTAL AIR ABSORPTION VALUES MEASURED IN THE FIELD BY BOEING WITH VALUES CALCULATED BY THE CURRENTLY PROPOSED METHOD

AVERAGE SURFACE CONDITIONS: TEMPERATURE 53°F
RELATIVE HUMIDITY 61%
ABSOLUTE HUMIDITY 6.3 gm/m³

— VALUES DETERMINED BY BOEING. BANDWIDTH DENOTED BY LENGTH OF HORIZONTAL LINE.

O VALUES CALCULATED FOR THE BANDS USING ASSUMPTIONS DISCUSSED IN TEXT.

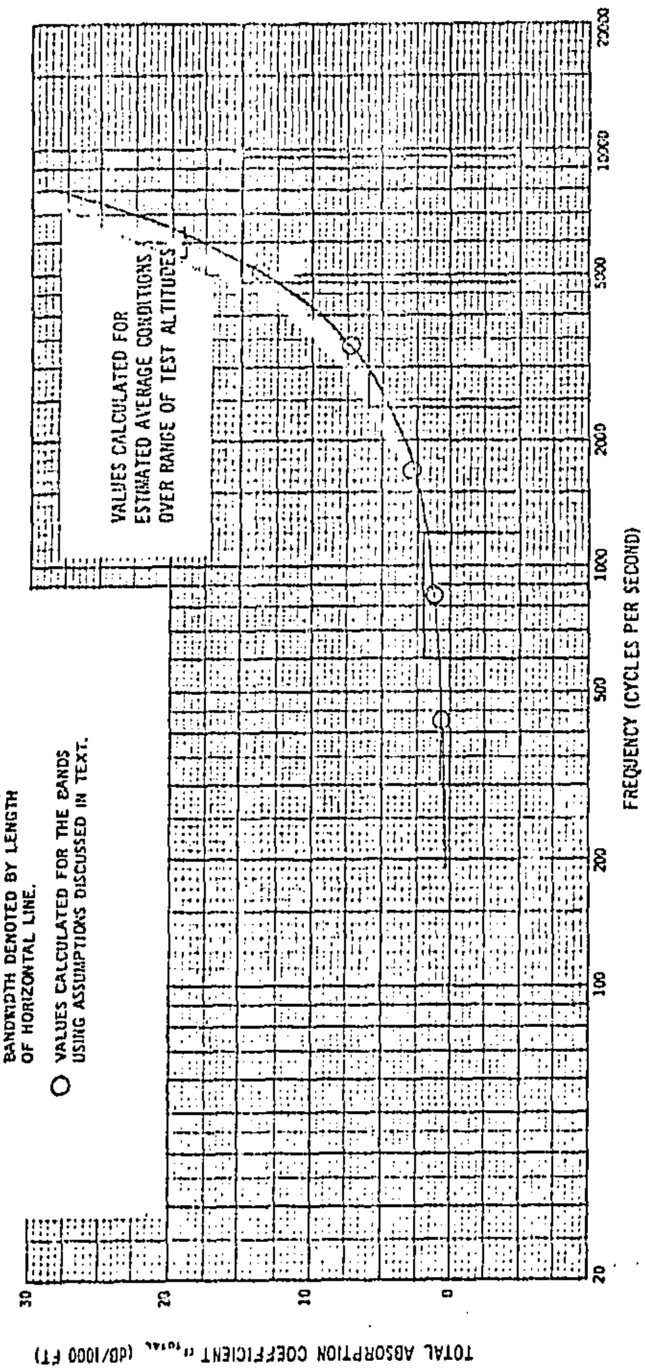


FIGURE 11.

COMPARISON OF TOTAL AIR ABSORPTION VALUES MEASURED IN THE FIELD BY DOUGLAS WITH VALUES CALCULATED BY THE CURRENTLY PROPOSED METHOD

AVERAGE SURFACE CONDITIONS: TEMPERATURE 77°F
RELATIVE HUMIDITY 59%
ABSOLUTE HUMIDITY 13.5gm m³

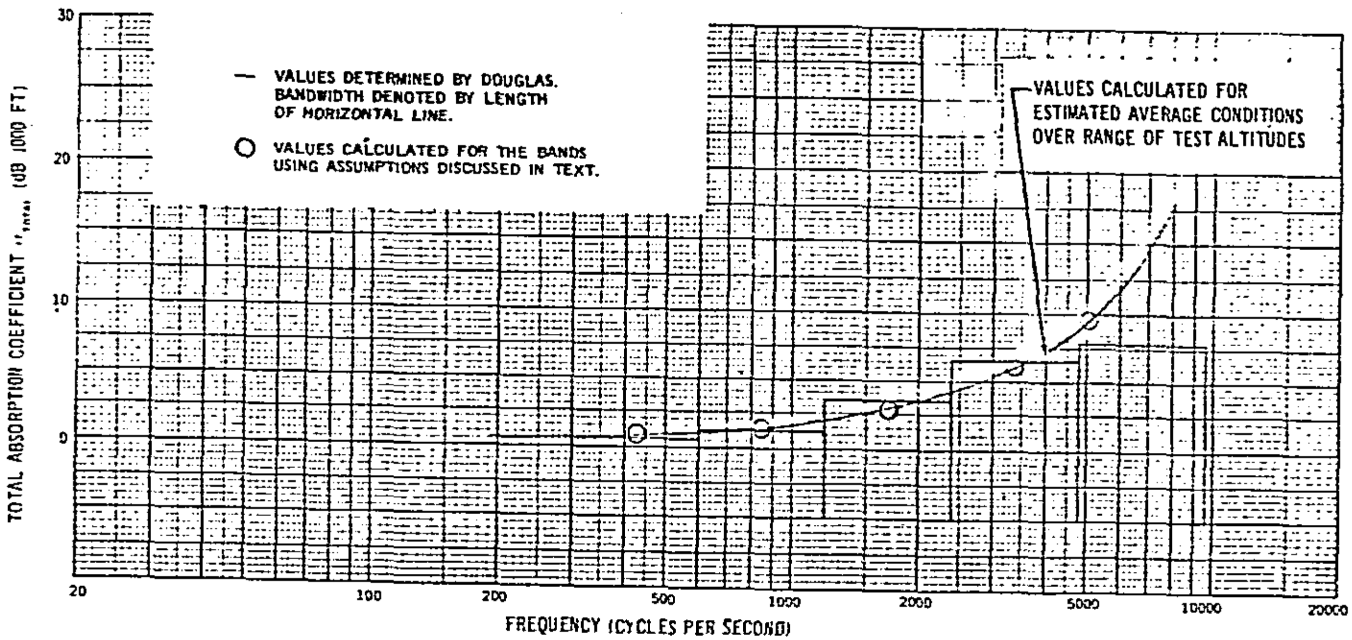


FIGURE 12.

ATMOSPHERIC ABSORPTION COEFFICIENTS FOR OCTAVE BANDS OF NOISE FOR DIFFERENT TEMPERATURES

PREFERRED OCTAVE BANDS

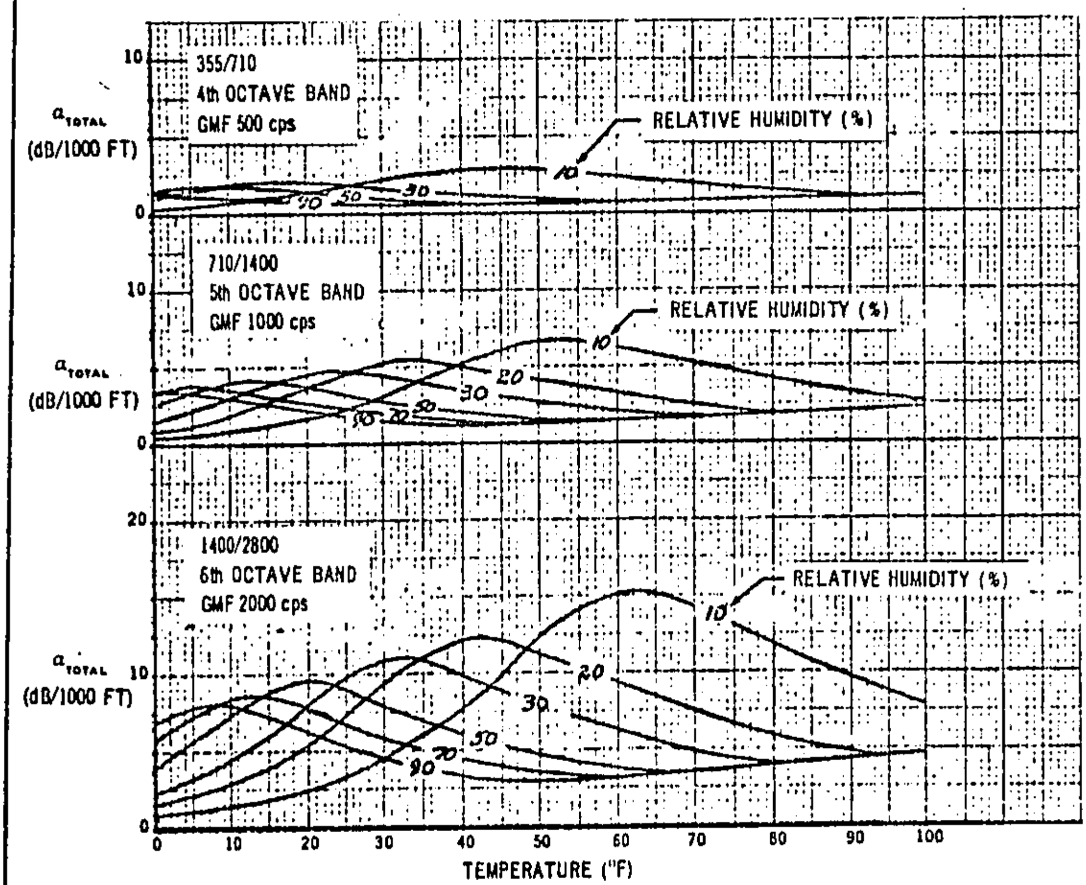


FIGURE 12.

ATMOSPHERIC ABSORPTION COEFFICIENTS FOR OCTAVE BANDS OF NOISE FOR DIFFERENT TEMPERATURES

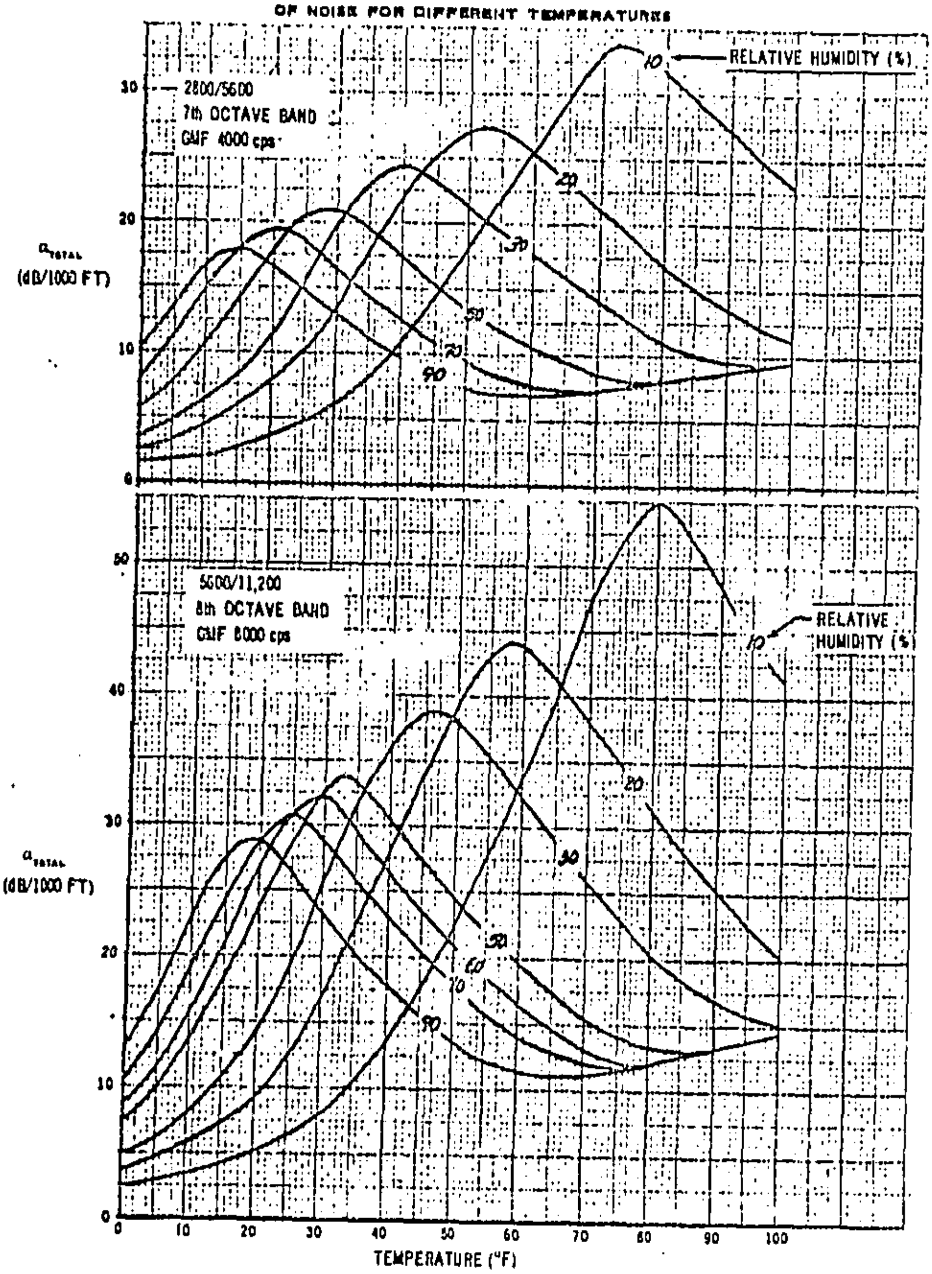


FIGURE 13. (CONT)

ATMOSPHERIC ABSORPTION COEFFICIENTS FOR OCTAVE BANDS OF NOISE FOR DIFFERENT TEMPERATURES

COMMERCIAL OCTAVE BANDS

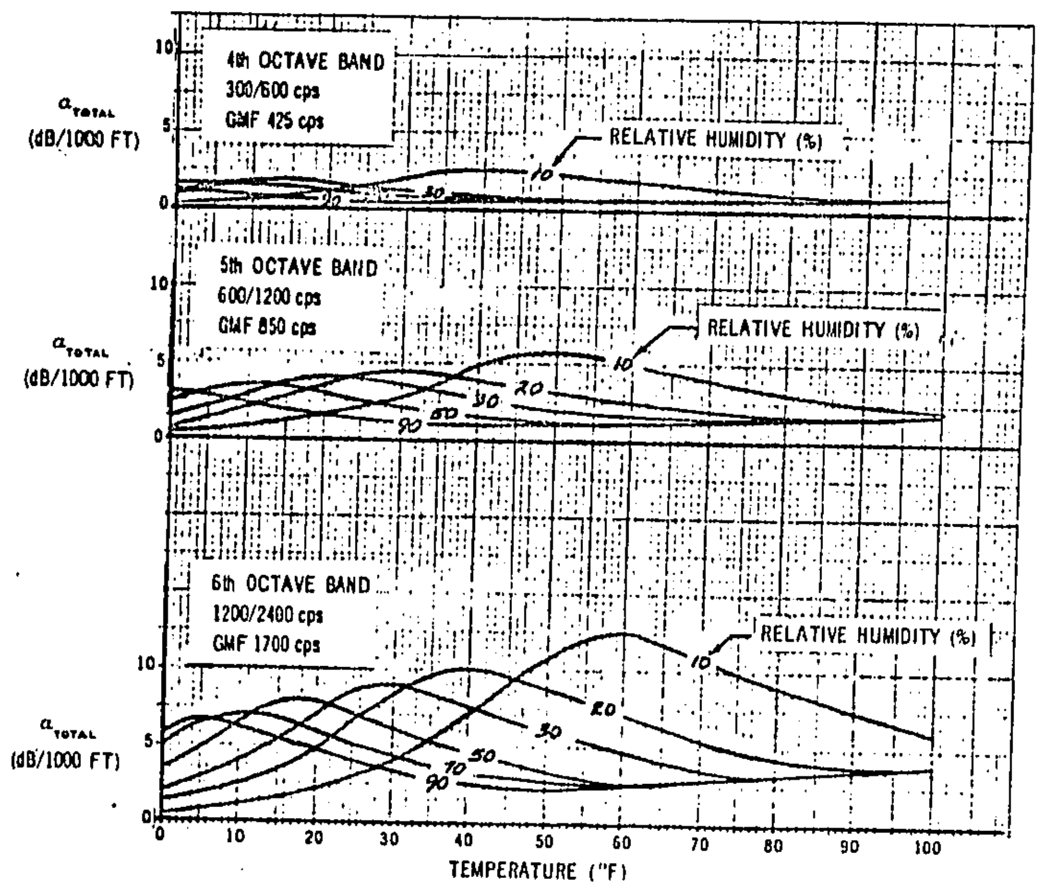
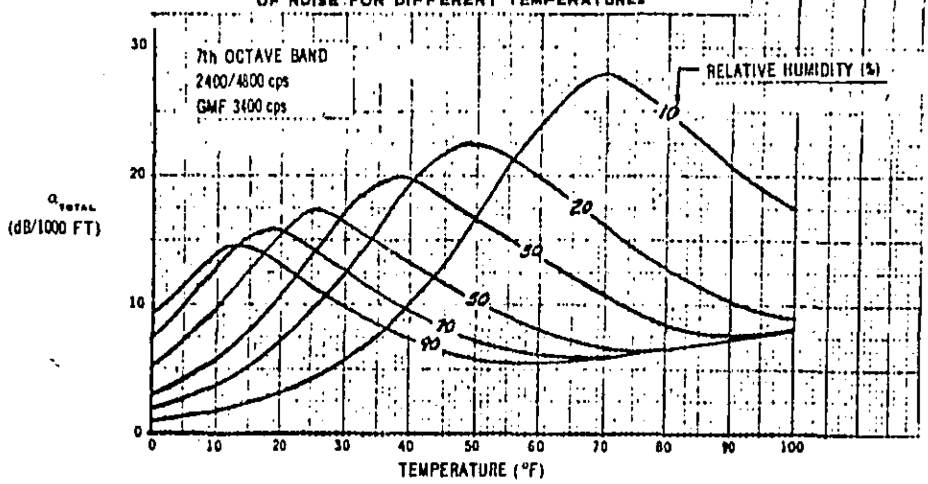


FIGURE 14.

ATMOSPHERIC ABSORPTION COEFFICIENTS FOR OCTAVE BANDS OF NOISE FOR DIFFERENT TEMPERATURES



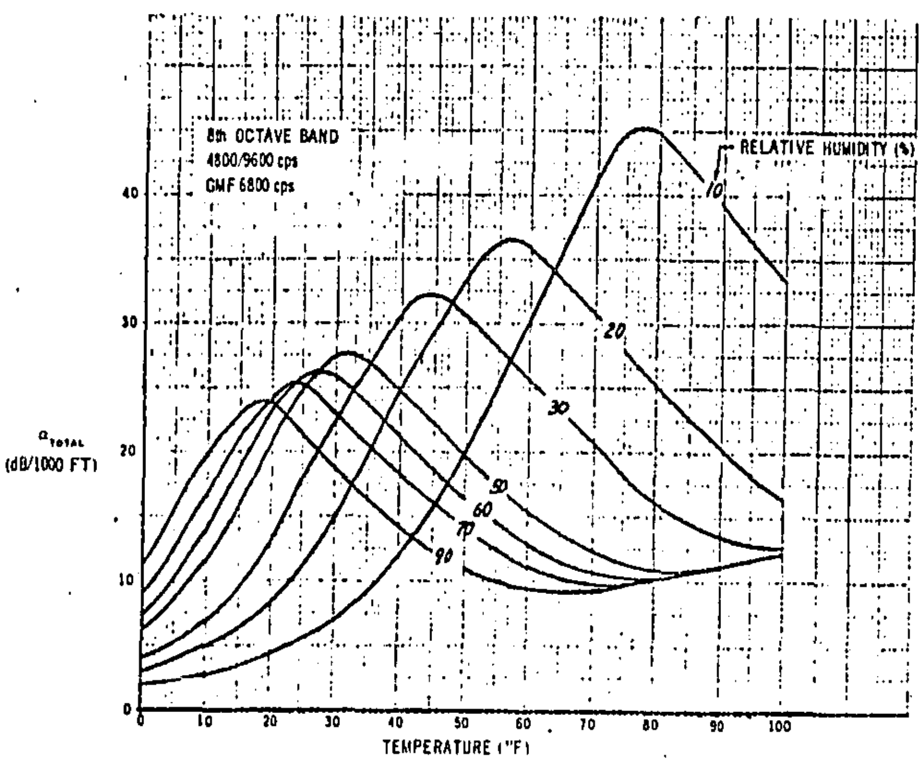


FIGURE 14. (CONT)

ATMOSPHERIC ABSORPTION COEFFICIENTS FOR 1/3 RD OCTAVE BANDS OF NOISE FOR DIFFERENT TEMPERATURES AND HUMIDITIES

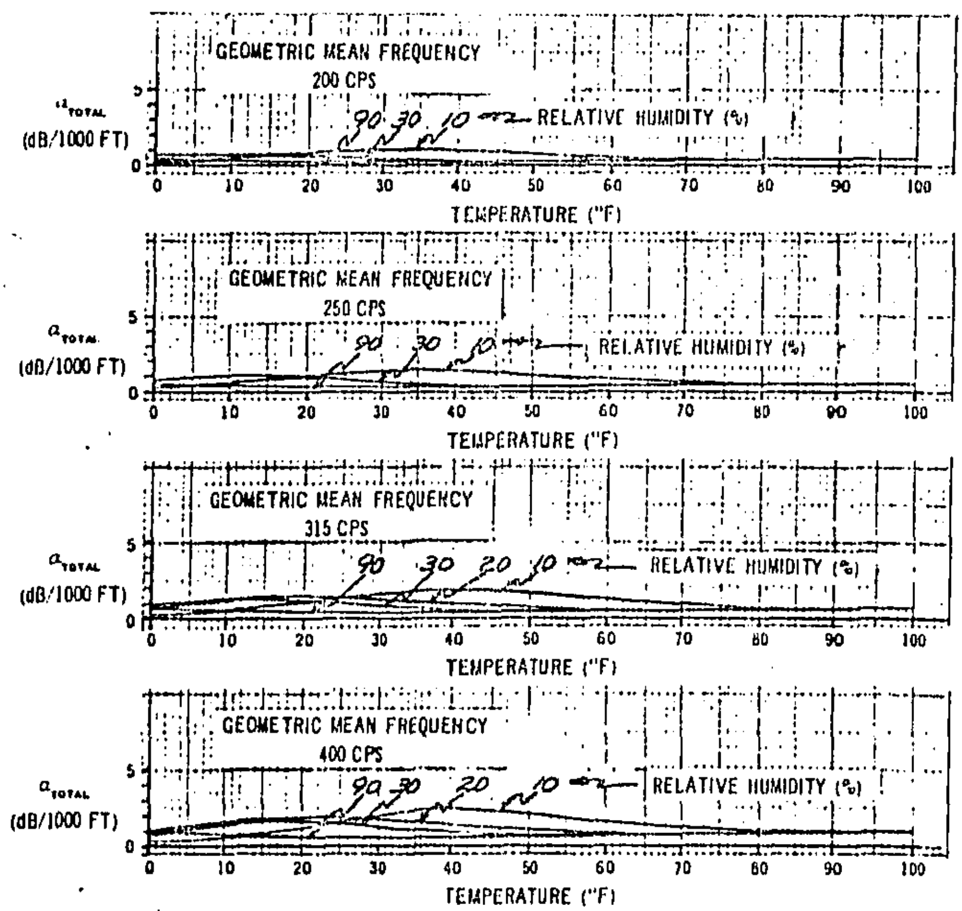


FIGURE 15

ATMOSPHERIC ABSORPTION COEFFICIENTS FOR 1/3RD OCTAVE BANDS OF NOISE FOR DIFFERENT TEMPERATURES AND HUMIDITIES

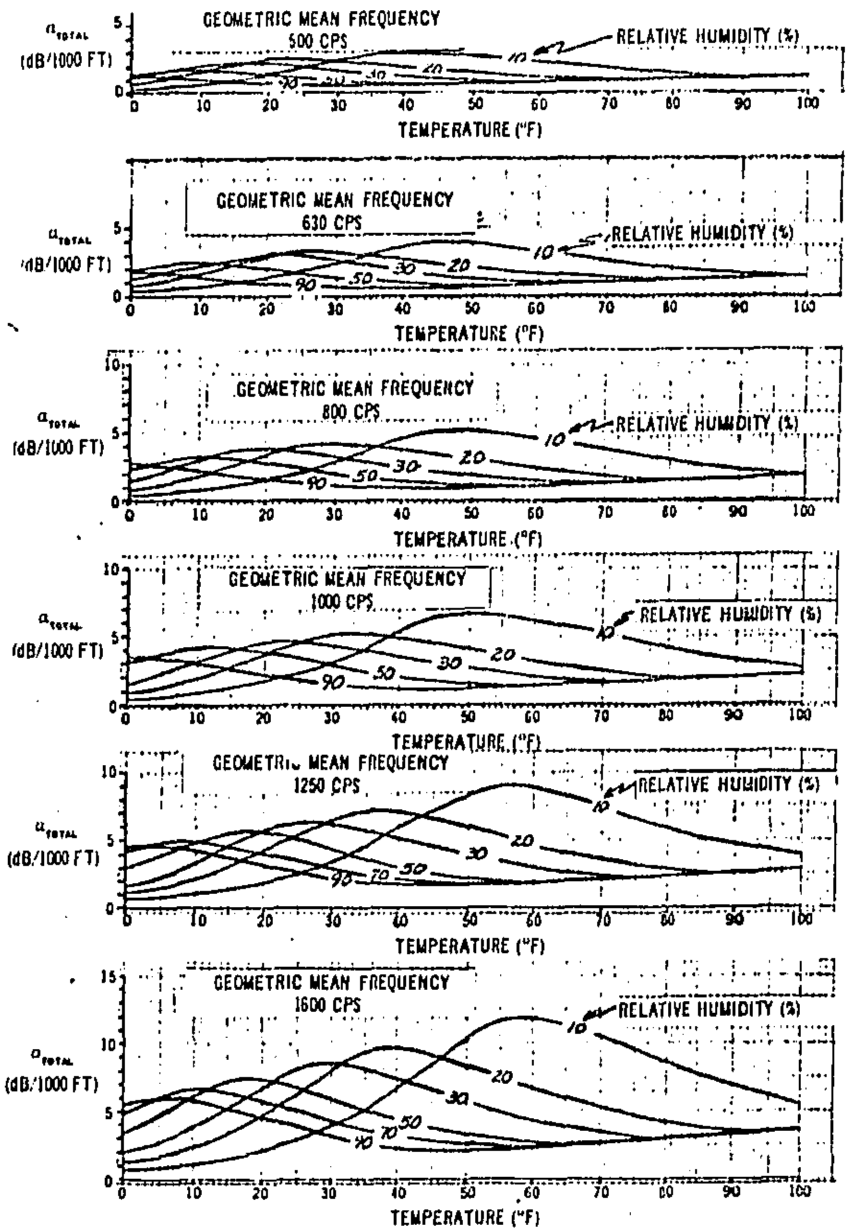


FIGURE 15 (CONT)

ATMOSPHERIC ABSORPTION COEFFICIENTS FOR 1/3RD OCTAVE BANDS OF NOISE FOR DIFFERENT TEMPERATURES AND HUMIDITIES

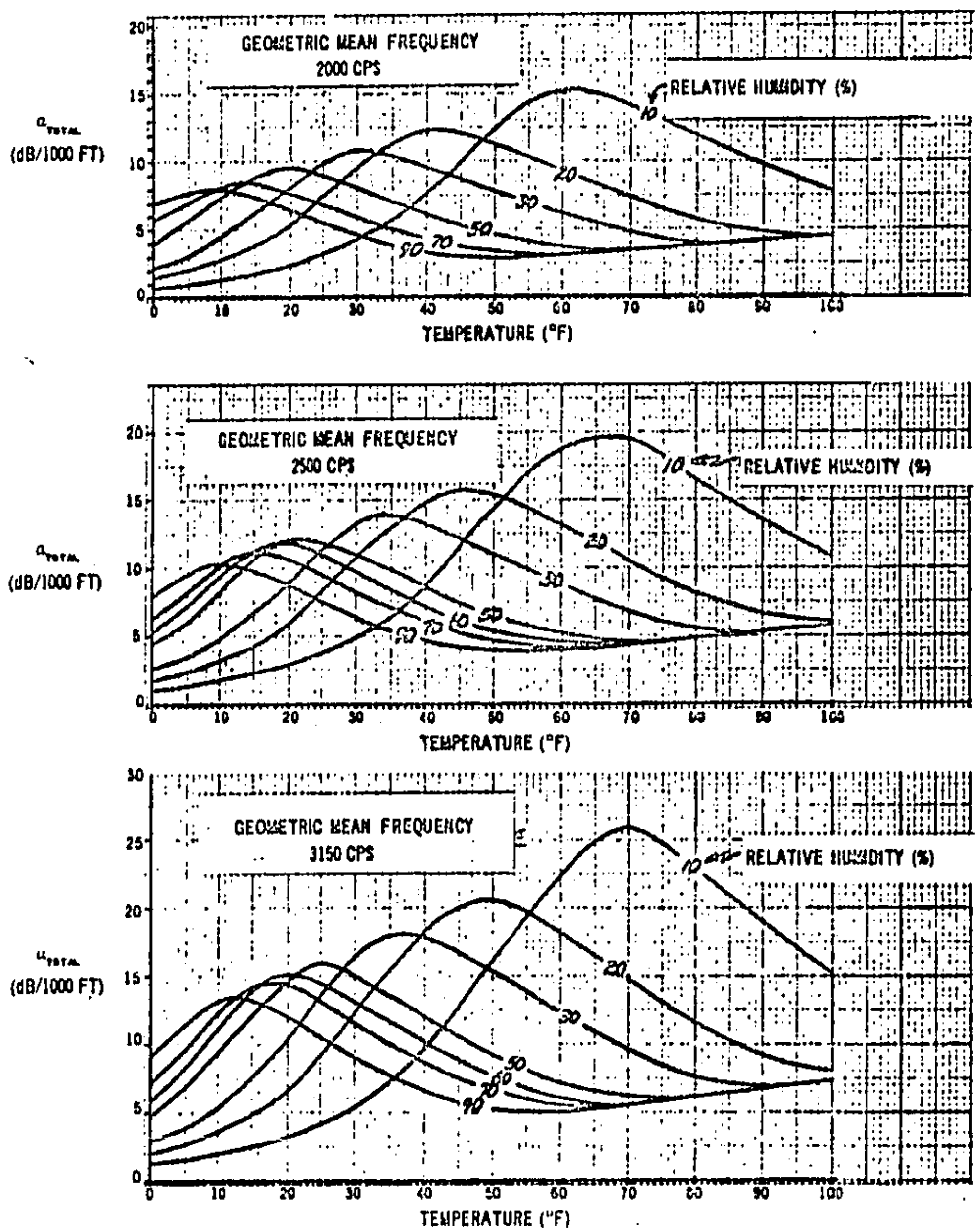
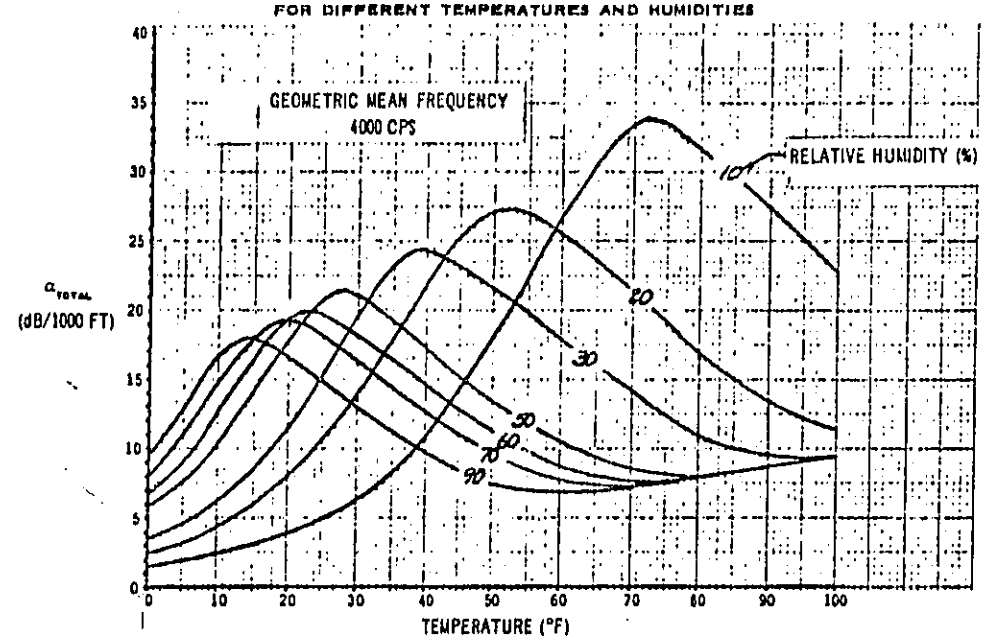


FIGURE 18 (CONT)

ATMOSPHERIC ABSORPTION COEFFICIENTS FOR 1/3 RD OCTAVE BANDS OF NOISE FOR DIFFERENT TEMPERATURES AND HUMIDITIES



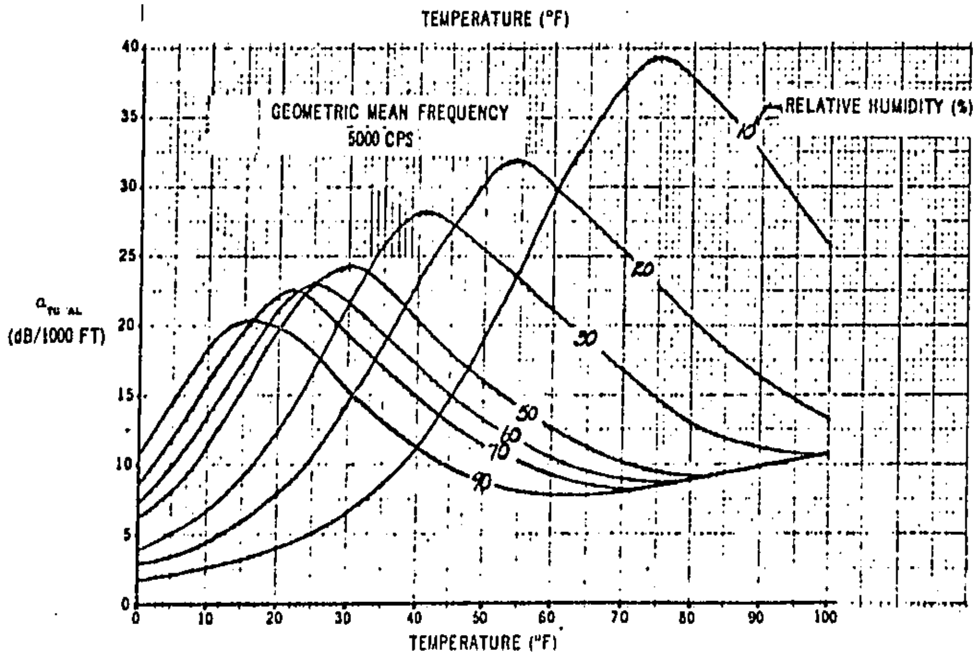


FIGURE 15 (CONT)

ATMOSPHERIC ABSORPTION COEFFICIENTS FOR 1/3 RD OCTAVE BANDS OF NOISE FOR DIFFERENT TEMPERATURES AND HUMIDITIES

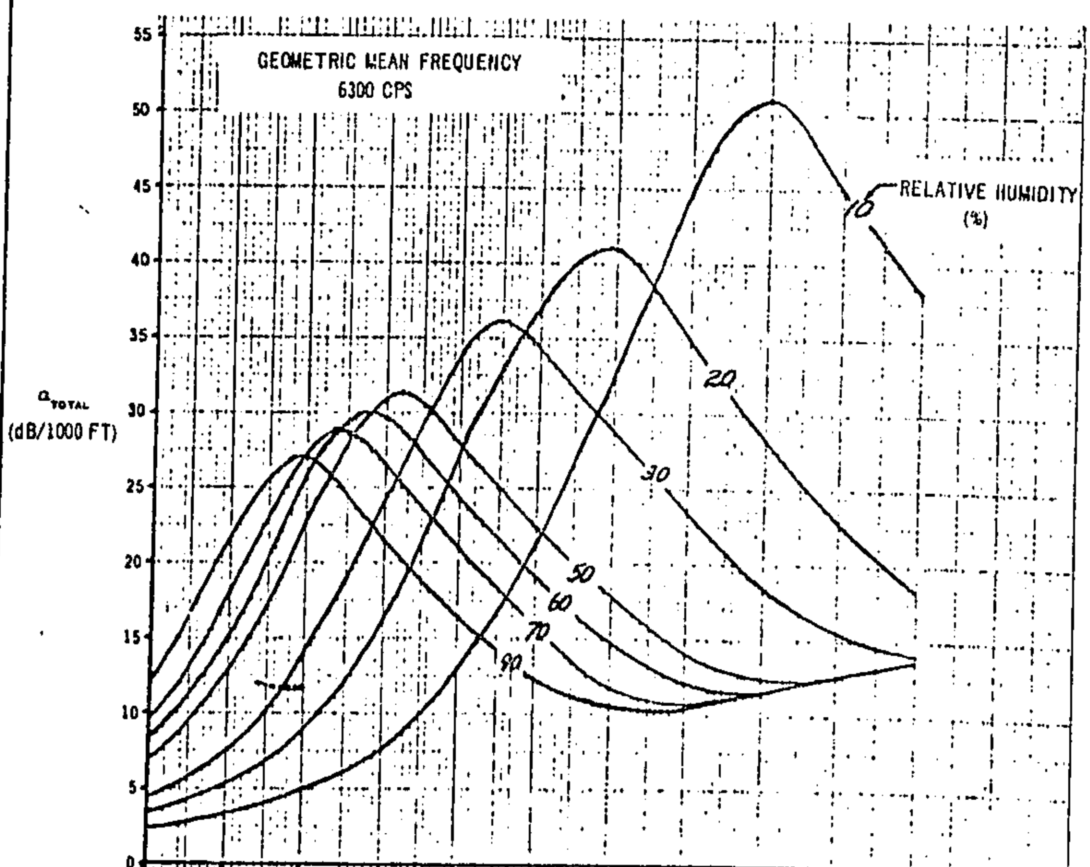


FIGURE 15 (CONT)

ATMOSPHERIC ABSORPTION COEFFICIENTS FOR 1/3RD OCTAVE BANDS OF NOISE
FOR DIFFERENT TEMPERATURES AND HUMIDITIES

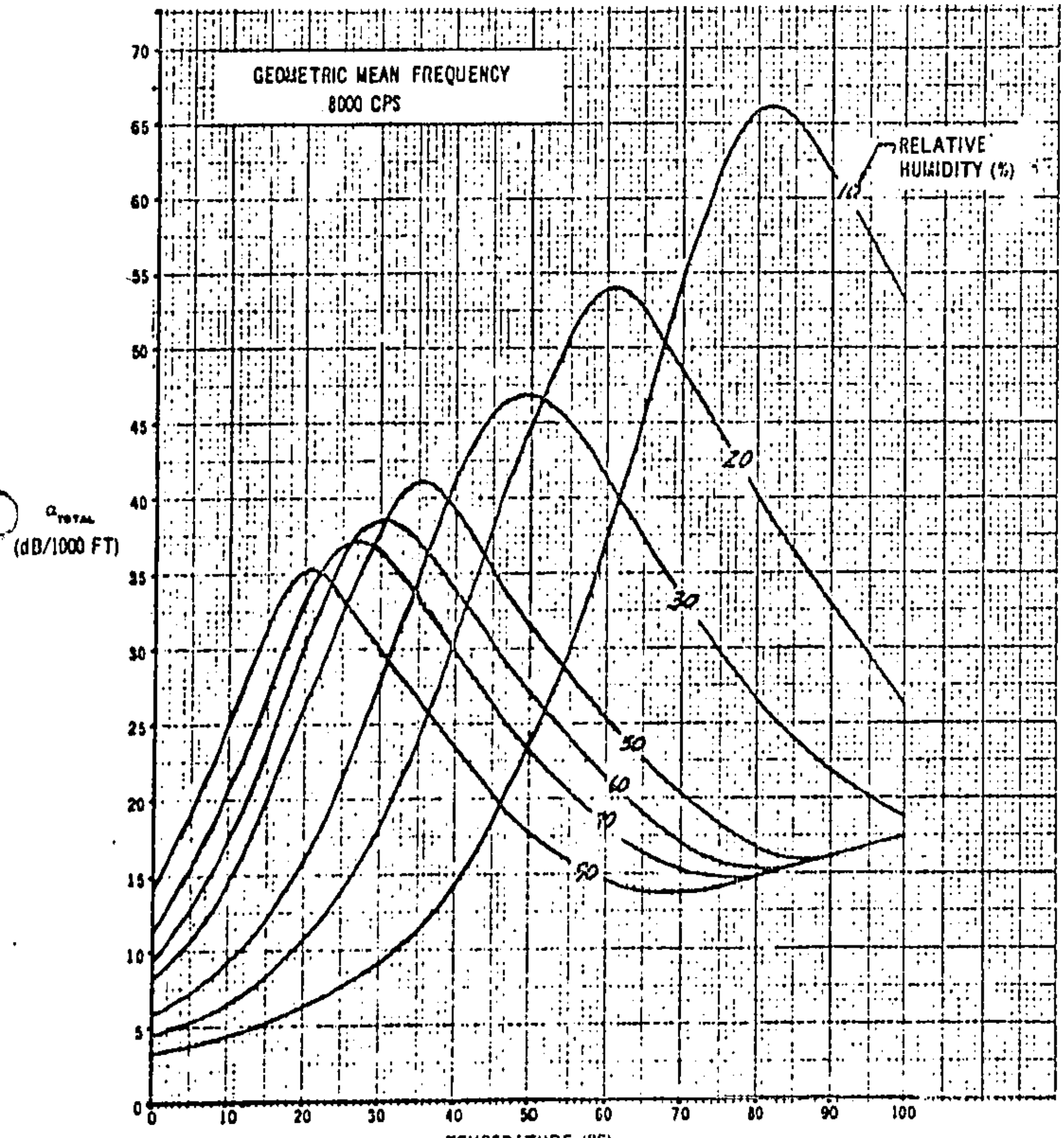


FIGURE 15 (CONCLUDED)

AEROSPACE RECOMMENDED PRACTICE

Society of Automotive Engineers, Inc.
TWO PENNSYLVANIA PLAZA, NEW YORK, N.Y. 10001

ARP 1071

Issued June 1972
Revised

DEFINITIONS AND PROCEDURES FOR COMPUTING THE EFFECTIVE PERCEIVED NOISE LEVEL FOR FLYOVER AIRCRAFT NOISE

1. INTRODUCTION

1.1 The introduction of different types of jet engines, some producing audible tones, have prompted studies to obtain an improved single-number measure of complex aircraft flyover noise which is related to subjective response. Previous studies resulted in specification of the noise in terms of the perceived noise level according to the definitions and procedures of ARP 865A.

1.2 Several judgment tests on aircraft flyover noise signals having different durations and spectra containing tonal components have shown the desirability of adjustments to the perceived noise level (as computed by the procedures of ARP 865A) to account for the signal time history and the presence of audible discrete frequency components in the sound spectrum.

1.3 The effective perceived noise level, EPNL, specified in units of EPNdB, is a single number measure calculated from objective acoustic measurements in accordance with the procedures defined in this document. It is calculated from a time sequence of tone-adjusted perceived noise levels which are calculated from one-third octave band noise spectra. The tone adjustments are determined from one-third octave band spectra, by a procedure which estimates the extent of discrete frequency (tone) components from irregularities in the shape of the one-third octave band noise spectra.

The development of the computational procedure for EPNL is based upon the results of a number of separate judgment tests. It is subject to revision as a result of additional judgment tests of complex flyover noise signals.

2. EXPLANATION OF TERMS

2.1 Perceived Noise Level, PNL: The perceived noise level of a given sound is a result of a calculation as specified in Paragraph 2.2 of SAE ARP 865A. The unit of perceived noise level is termed the PNdB.

NOTE: The procedure specified in SAE ARP 865A yields an approximation of the perceived noise level as determined by subjective experiment on a fundamental psychoacoustical basis; namely, that the perceived noise level of a given sound is numerically equal to the sound pressure level of a reference sound that is judged by listeners to have the same perceived noisiness as the given sound, the reference sound being a band of random noise one octave in width centered on 1000 Hz (cps).

2.2 Perceived Noise Level, PNL (k): PNL (k) is the perceived noise level calculated from one-third octave band levels determined at the k-th interval of time, where k is a number indicating the number of 0.5-second intervals elapsed from an arbitrary reference time zero of the flyover signal.

2.3 Tone-Corrected Perceived Noise Level, PNLT (k): PNLT (k) is the value of PNL (k) adjusted for the presence of tonal components, i.e. PNLT (k) = PNL (k) + C (k), as specified in Attachment 1 of this document.

Maximum Tone-Corrected Perceived Noise Level, PNLTM: The PNLTM is the maximum value of the PNLT (k) which occurs during an aircraft flyover noise event.

NOTE: The PNLTM will generally be different in value from the perceived noise level calculated from the maximum sound pressure levels occurring in each octave or one-third octave band during a flyover. (In accordance with Note 2, Step 2.2 of ARP 865A, the perceived noise level calculated from the maximum band levels is designated the composite perceived noise level, abbreviated PNLC.) These differences may be accounted for as follows:

(a) The PNLTM includes a correction for tonal components;

(b) PNLTM is calculated from a single one-third octave band spectrum, scanned within a very short time interval (not exceeding 50 milliseconds);

(c) Typically, the maximum sound pressure levels in the individual frequency bands will occur at different times during the flyover.

2.5 Tone Corrections: A complex noise signal may generally be said to contain a tonal component if the sound pressure level in a given frequency band, as measured using an appropriate narrow bandwidth filter, is appreciably greater than the sound pressure level in adjacent frequency bands. This characteristic may also be observed when there are several tones with several fundamental frequencies and harmonics or when the noise signal contains a random noise component with significant energy in a narrow band of frequency. This ARP is concerned with tones that are of sufficiently great amplitude that the flyover noise signal is capable of exciting the acoustic sensation of pitch. The manner of determining the presence of tones and the tone-correction factor is defined in Attachment 1.

NOTE 1: Narrow-band analysis of a flyover noise signal may reveal many tonal components that are not significantly audible since they may be masked by accompanying broad band noise or by other tonal components. Tone-correction factors generally are not applied unless the tones, identified by the procedures described in Attachment 1, are distinctly audible.

NOTE 2: The procedures for identification of audible tones described in Attachment 1 yields approximate values for the protrusion of tones above the broad band spectrum. Irregularities in measured one-third octave band noise spectra, due to factors other than tones, may result in incorrect estimates of the tone magnitude and, under some conditions, may identify a tone when none is actually present (a "pseudo" tone). Where it is suspected that an incorrect tone correction has been introduced, supplementary data analyses may be necessary, using filters with band-widths narrower than one-third of an octave. Sources of spectrum irregularities, other than tones, include reflections from the ground plane, fluctuations in sound propagation through the atmosphere, and background levels (ambient acoustical noise or electrical noise).

2.6 Duration: In a field situation, the duration of a flyover noise signal may be considered as the time interval in seconds during which the sound pressure levels of the flyover noise noticeably protrude above the sound pressure levels of the ambient noise at the measurement site. The duration, thus defined, is influenced by both the flyover noise signal and the ambient background noise level.

To remove the influence of the ambient noise levels in the computation of the EPNL, the duration, d, is defined as the interval in seconds between values of PNLT (k) which are 10 dB less than PNLTM.

3. CALCULATION PROCEDURE

The effective perceived noise level, EPNL, expressed in EPNdB, is calculated in accordance with the following procedure:

Step 1

Sound pressure levels in the 24 one-third octave bands having center frequencies from 50 to 10,000 Hz shall be determined for a continuous sequence of one-half second time intervals throughout the time period of the flyover noise.

NOTE 1: It is recommended that the overall electrical performance of the data acquisition and reduction system meet the requirements of the latest version of SAE ARP 796.

NOTE 2: The data reduction system may be composed of analog and digital elements meeting the performance characteristics of the latest version of SAE ARP 796.

NOTE 3: Measured spectra should be adjusted to compensate for background levels resulting from ambient acoustic noise or electrical noise in the data acquisition or reduction equipment. It is recommended that a one-third octave band spectral analysis be made of background noise levels (resulting from ambient acoustic noise and electrical noise in the data acquisition system) recorded at the same system gain setting as employed during recordings of the flyover noise signals from the aircraft. The spectral noise analysis for the flyover noise signal should then be compared to the spectral analysis of the background noise, and the measured one-third octave band levels, $L(i)_{flyover}$, should be adjusted to compensate for background noise levels $L(i)_{background}$ within the range of $3 < L(i)_{flyover} - L(i)_{background} < 10$. Values of $L(i)_{flyover}$ less than 3 dB greater than $L(i)_{background}$ should be deleted from calculation of PNLT or discrete frequency corrections.

Step 2

Perceived noise levels, PNL (k), shall be calculated for each one-third octave band spectra determined at k-th intervals in accordance with Paragraph 2.2 of SAE ARP 865A.

NOTE 1: In general, computed quantities, such as PNL (k) PNLM and C (k) values, may be computed to the nearest one-tenth of a dB.

Step 3

The presence of and corrections for tonal components in the spectrum are determined according to Attachment 1 of this document.

NOTE: When the tone corrections determined from one-third octave band spectra in accordance to Attachment 1 result in tone corrections which are suspected to be incorrect, additional analyses may be made with filter band widths, narrower than one-third octave band. Results of the narrow-band analysis may then be used to compute revised tone-corrections, C (k). Because procedures for narrow band frequency analysis of time-varying noise spectra are not standardized and may be subject to possible errors, the use of such procedures should be noted, and the procedure described, when employed.

Step 4

The tonal corrections, C (k), determined in Step 3, are to be added to the perceived noise levels, PNL (k), determined in Step 2 to determine PNLT (k). Thus:

$$PNLT(k) = PNL(k) + C(k)$$

Step 5

The effective perceived noise level, in EPNdB, is defined by the following expression:

$$EPNL = 10. \log \frac{1}{T} \int_{-\infty}^{\infty} 10^{\frac{PNLT}{10}} dt$$

where PNLT is the instantaneous perceived noise level and T is a normalizing constant, set equal to 10 seconds. In practice, PNLT is not available directly as an integrable function. It is computed from one-third octave band sound pressure levels determined at discrete one-half second intervals. The basic working definition for EPNL is obtained by replacing the above integral definition with the following summation expression:

$$EPNL = 10 \log \sum_{K=0}^{2d} 10^{\frac{PNLT(k)}{10}} -13$$

In this expression, the integration is approximated by a summation process which extends over that time period of the flyover signal between the first and last times at which PNLT (k) is within 10 dB of PNLTM; d is the duration in seconds between the first and last values of PNLT (k) which are 10 dB less than PNLTM.

NOTE 1: When 10 dB-down points fall between the calculated PNLT (k) values, as is the usual case, the points to be used for the summation should be established by and include the first and last points for which PNLT (k) $\geq$ (PNLTM - 10). The duration time, d, should be taken as 0.5 seconds time the number of points included in the summation. Thus, for flyover noise signals having multiple maximum values, maxima, with some minimum values between successive maxima falling more than 10 dB below PNLTM, the summation process should include all PNLT (k) values within the initial and final values of PNLT (k) which are within 10 dB of PNLTM.

NOTE 2: A factor, D, accounting for the effect of the signal time history and duration may be calculated as follows:

$$D = EPNL - PNLTM$$

ATTACHMENT 1

CALCULATION OF DISCRETE FREQUENCY CORRECTIONS FOR ONE-THIRD OCTAVE BAND NOISE SPECTRA

Step 1:

Compute: $s(j, i) = L(j) - L(i)$ where:

i = 1/3 octave frequency band number, ranging from $i = 19$, corresponding to 80 Hz, up to $i = 39$, corresponding to 8,000 Hz.

$j = i + 1$, up to $j = 40$, corresponding to 10,000 Hz.

$L(i)$ = sound pressure level in the i-th 1/3 octave frequency band at the k-th time interval.

$s(j, i)$ = numerical difference between successive band sound pressure levels, with $s(j, i) = 0$ for $i < 19$.

Step 2:

Designate (by encircling or other means) those values of $s(j, i)$ where:

$$| s(j, i) - s(j-1, i-1) | > 5 \text{ dB}$$

Step 3:

A. If the encircled $s(j, i)$ is positive and algebraically greater than $s(j-1, i-1)$ encircle $L(j)$.

B. If the encircled $s(j, i)$ is zero or negative and algebraically less than $s(j-1, i-1)$, encircle $L(i)$.

Step 4:

A. For encircled values of $L(i)$ located between adjacent non-encircled values, $L(i-1)$ and $L(i+1)$:

$$\text{Set } L'(i) = \frac{L(i+1) + L(i-1)}{2}$$

If the level in the highest band, $L(40)$ is encircled:

Set $L'(40) = L(39) + s(39, 38)$ if $L(39)$ and $L(38)$ are not encircled;

Set $L'(40) = L(39) + \frac{s(39, 37)}{2}$ if $L(38)$ is encircled, but $L(37)$ is not;

Set $L'(40) = L(39) + \frac{s(39, 36)}{3}$ if $L(37)$ and $L(38)$ are encircled, but $L(36)$ is not.

B. For two successive encircled values, $L(i)$ and $L(i+1)$,:

$$\text{Set } L'(i) = \frac{2\,L(i-1) + L(i+2)}{3}$$

$$\text{and } L'(i+1) = \frac{L(i-1) + 2\,L(i+2)}{3}$$

If the levels in the two highest frequency bands are encircled:

Set $L'(39) = L(38) + s(38, 37)$
and $L'(40) = L(38) + 2\ s\ (38, 37)$, if $L(37)$ and $L(38)$ are not encircled;

Set $L'(39) = L(38) + \frac{s(38, 36)}{2}$ and

$L'(40) = L(38) + s(38, 36)$, if

$L(37)$ is encircled but $L(36)$ is not;

Set $L'(39) = L(38) + \frac{s(38, 35)}{3}$ and

$L'(40) = L(38) + \frac{2\ s(38, 35)}{3}$ if

$L(36)$ and $L(37)$ are encircled, but $L(35)$ is not.

Step 5:

For each encircled band level determine:

$$F(i) = L(i) - L'(i) > 0$$

Where F values greater than 5 dB occur in adjacent bands, $F(i)$, $F(i+1)$, and provided

$\left| s(i+2, i-1) \right| < 5$ for 2 adjacent bands,

Set $F' = 10 \log \left(\text{antilog} \frac{F(i)}{10} + \text{antilog} \frac{F(i+1)}{10} \right)$

Where one of two adjacent F values occur in a band outside the frequency range 500 - 5000 Hz, the values shall be halved, and the F' value ascribed to the 500 - 5000 Hz range.

Step 6:

Determine the tonal correction C from the following equations, where F indicates either F or F' as determined in Step 5:

$C = 0$	$F < 3$	for 1/3 octave bands between 500 and 5000 Hz.
$C = \frac{F}{3}$	$3 \leq F < 20$	
$C = 6.7$	$20 \leq F$	
$C = 0$	$F < 6$	for 1/3 octave bands in the range 50 - 10,000 Hz but outside the range 500 - 5000 Hz.
$C = \frac{F}{6}$	$6 \leq F < 20$	
$C = 3.3$	$20 \leq F$	

Step 7:

Select the maximum value of C determined in Step 6 for the k-th time interval. This value defines the tone correction, $C(k)$, that is to be used in Paragraph 3, Step 4, to obtain PNLT(k).

NOTE: Table A-1 provides an example of the calculation procedure according to Steps 1 through 7.

TABLE A-I

An Example of the Calculation Procedure for Determining A Discrete Frequency Correction for One-Third Octave Band Frequency Spectrum

Step		3	1+2	4	5	5	6
Band	f(i)	L'(i)	S(j,i)	L(i)	F(i)	F'(i)	C
19	80	74					
20	100	66	- 8				
21	125	A 74	+ 8	75	-1.0		0
22	160	84	+10				
23	200	86	+ 2				
24	250	B 87	+ 1	83	+4.0		0
25	315	80	- 7				
26	400	A 84	+ 4	82	+2.0		0
27	500	84	0				
28	630	83	- 1				
29	800	82	- 1				
30	1000	83	+ 1				
31	1250	85	+ 2				
32	1600	A 95	+10	84.3	+10.7	14.0	4.7*
33	2000	B 95	0	83.7	+11.3		
34	2500	83	-12				
35	3150	A 84	+ 1	82	+ 2.0		0
36	4000	81	- 3				
37	5000	78	- 3				
38	6300	75	- 3				
39	8000	73	- 2				
40	10,000	A 77	+ 4	71	+ 6.0		1.0

* In accord with Step 7, the discrete frequency correction is 4.7 dB.

TAD-494.7

AEROSPACE RECOMMENDED PRACTICE

LAND SEA AIR SPACE

Society of Automotive Engineers, Inc.
TWO PENNSYLVANIA PLAZA, NEW YORK, N.Y. 10001

ARP 865A

Issued 10-15-64
Revised 8-15-69

DEFINITIONS AND PROCEDURES FOR COMPUTING THE PERCEIVED NOISE LEVEL OF AIRCRAFT NOISE

1. INTRODUCTION

The introduction of commercial jet aircraft operations as well as the general increase in air traffic has resulted in an international concern over aircraft noise. The perceived noise level is a single number rating of the noise based upon objective acoustic measurements which is related to the relative subjective response to the noise. The perceived noise level, as defined in this document, is based only on the noise spectra measured in octave or one-third octave bands of frequency. As such, it is most accurate in rating broadband sounds of similar time duration which do not contain strong discrete frequency components.

When additional factors such as the duration and the presence of discrete frequency components are to be taken into account, the effective perceived noise level (EPNL) may be a preferred measure.

2. CALCULATION OF PERCEIVED NOISE LEVEL IN PNdB FROM MEASURED NOISE DATA

2.1 Explanation of Terms:

2.1.1 Perceived Noise Level in PNdB - Perceived noise level of a given sound in PNdB is the result of a calculation as specified in paragraph 2.2.

> NOTE: This procedure gives an approximation of the perceived noise level as determined by subjective experiment on a fundamental psychoacoustical basis: namely, that perceived noise level of a given sound is numerically equal to the sound pressure level of a reference sound that is judged by listeners to have the same perceived noisiness as the given sound, the reference sound being a band of random noise one octave in width centered on 1000 Hz (cps).

2.1.2 Noy - A unit of perceived noisiness. The numerical value of the perceived noisiness of a sound within a given frequency band, in noys, is related to the band pressure level. This relationship is given in Table I. Table II provides an alternate means of calculating the appropriate noy value by means of equations. (The equations in Table II may be the preferred method for computer computation of noy values.)

> NOTE 1: In order to avoid confusion, attention is drawn to the fact that noy values given herein are the same as given in Ref. 1 but differ from those given in Refs. 2, 3, 4, and 5. The differences between the values given here and those of Refs. 2 and 3 result from minor changes made to facilitate computer computations; the changes are not based on new psychoacoustic test data and are generally not large enough to necessitate re-calculation of perceived noise levels previously calculated by the tables given in Refs. 2 and 3.

References:

1. R. A. Pinker: Computation of Perceived Noise Level: Mathematical Formulation of the Noy Tables, NGTE Note NT. 684, February 1968.

2. SAE ARP 865, dated 10-15-64.

3. K. D. Kryter and K. S. Pearsons: Modification of Noy Table, JASA, Vol. 36, 1964, p. 394.

4. K. D. Kryter and K. S. Pearsons: Some Effects of Spectral Content and Duration on Perceived Noise Level, JASA, Vol. 35, 1963, p. 866-886.

5. K. D. Kryter: Scaling Human Reactions to the Sound From Aircraft, JASA, Vol. 31, 1959, p. 1415-1429.

NOTE 2: The values of Table I and II may be used for calculating noy values for either octave or one-third octave bands. The difference in octave or one-third octave band computation arises in the summation described in Step 2 of Section 2.2.

NOTE 3: Tables I and II present information for preferred one-third octave frequency measurements (Ref: USAS S1.6 1967, Preferred Frequencies for Acoustical Measurements). In calculating perceived noise levels based on the older octave band frequencies (Ref: ASA Z24.10-1953), little error will be incurred by using the values of Tables I and II as follows:

Octave Band Limits in Hz.	Preferred Frequency Octave Band Center in Hz.
37.5 - 75	50
75 - 150	100
150 - 300	200
300 - 600	400
600 - 1200	800
1200 - 2400	1600
2400 - 4800	3150
4800 - 10,000	6300

2.2 Calculation Procedure - Perceived noise level (PNL) in PNdB is calculated according to the following procedure:

Step 1 - The sound pressure level in each one-third octave frequency band (or full octave frequency band) is converted to a noy value by reference to Table I, entering the Table at the appropriate band center frequency (or by use of the equations and constants given in Table II at the appropriate band center frequency).

NOTE 1: Unless specifically designated otherwise, the perceived noise level is to be calculated from frequency band sound pressure levels read at the same instant in time. Such a calculated perceived noise level should be referred to as the instantaneous perceived noise level, or simply the perceived noise level, abbreviated PNL. The maximum value of the instantaneous perceived noise levels occurring in a set of instantaneous perceived noise levels calculated during successive time intervals is designated the maximum perceived noise level, abbreviated PNLM, or PNL (max).

NOTE 2: For some applications, an aircraft flyover noise signal may be described by calculating a perceived noise level value using the maximum sound pressure levels occurring in each octave (or one-third octave) frequency band, even though the maximum sound pressure levels in the frequency bands do not occur at the same instant of time. The perceived noise level calculated from such maximum band levels should be designated as the composite perceived noise level, abbreviated PNLC, or PNL (comp).

Step 2 - The noy values found in Step 1 are combined in the manner described in the following formulas:

Octave bands:

$$\underline{N} = n_{max} + 0.3 \quad [\Sigma n - n_{max}]$$

One-third octave bands

$$\underline{N} = n_{max} + 0.15 \quad [\Sigma n - n_{max}]$$

where n_{max} is the number of noys in the band having the greatest noy value, and Σ n is the sum of the noy values in all the bands.

Step 3 - N is converted into the perceived noise level (PNL) in PNdB by the following expression:

$$PNL = 40 + 33.22 \log_{10} \underline{N}$$

NOTE: For N values of 1.0 or greater, the PNL can be found from Table I by treating the quantity in the 1000 Hz column as the noy value and reading SPL as PNL.

PREPARED BY
SAE COMMITTEE A-21, AIRCRAFT NOISE MEASUREMENT

TABLE I – NOYS AS A FUNCTION OF SOUND PRESSURE LEVEL

SPL	⅓ OCTAVE BAND CENTER FREQUENCIES IN Hz (c/s)																							
	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
4																			0.10					
5																		0.10	0.11	0.10				
6																		0.11	0.12	0.11	0.10			
7																		0.12	0.14	0.13	0.11			
8																		0.14	0.16	0.14	0.13			
9																	0.10	0.15	0.17	0.16	0.14			
10																	0.11	0.17	0.19	0.18	0.16	0.10		
11																	0.12	0.19	0.22	0.21	0.18	0.12		
12																0.10	0.14	0.22	0.24	0.24	0.21	0.14		
13																0.11	0.16	0.24	0.27	0.27	0.24	0.16		
14																0.13	0.18	0.27	0.30	0.30	0.27	0.19		
15															0.10	0.14	0.21	0.30	0.33	0.33	0.30	0.22		
16										0.10	0.10	0.10	0.10	0.10	0.11	0.16	0.24	0.33	0.35	0.35	0.33	0.25		
17										0.11	0.11	0.11	0.11	0.11	0.13	0.18	0.27	0.35	0.38	0.38	0.35	0.30	0.10	
18									0.10	0.13	0.13	0.13	0.13	0.13	0.15	0.21	0.30	0.38	0.41	0.41	0.38	0.33	0.12	
19									0.11	0.14	0.14	0.14	0.14	0.14	0.17	0.24	0.33	0.41	0.45	0.45	0.41	0.36	0.14	
20									0.13	0.16	0.16	0.16	0.16	0.16	0.20	0.27	0.36	0.45	0.49	0.49	0.45	0.39	0.17	
21								0.10	0.14	0.18	0.18	0.18	0.18	0.18	0.23	0.30	0.39	0.49	0.53	0.53	0.49	0.42	0.21	0.10
22								0.11	0.16	0.21	0.21	0.21	0.21	0.21	0.25	0.33	0.42	0.53	0.57	0.57	0.53	0.45	0.25	0.11
23								0.13	0.19	0.24	0.24	0.24	0.24	0.24	0.30	0.36	0.46	0.57	0.62	0.62	0.57	0.50	0.30	0.13
24							0.10	0.14	0.21	0.27	0.27	0.27	0.27	0.27	0.33	0.40	0.50	0.62	0.67	0.67	0.62	0.55	0.33	0.15
25							0.11	0.16	0.24	0.30	0.30	0.30	0.30	0.30	0.35	0.43	0.55	0.67	0.73	0.73	0.67	0.60	0.35	0.17
26							0.13	0.18	0.27	0.33	0.33	0.33	0.33	0.33	0.38	0.48	0.60	0.73	0.79	0.79	0.73	0.65	0.39	0.20
27						0.10	0.14	0.21	0.30	0.35	0.35	0.35	0.35	0.35	0.41	0.52	0.65	0.79	0.85	0.85	0.79	0.71	0.42	0.23
28						0.11	0.16	0.24	0.33	0.38	0.38	0.38	0.38	0.38	0.45	0.57	0.71	0.85	0.92	0.92	0.85	0.77	0.46	0.26
29						0.13	0.18	0.27	0.35	0.41	0.41	0.41	0.41	0.41	0.49	0.63	0.77	0.92	1.00	1.00	0.92	0.84	0.50	0.30
30					0.10	0.14	0.21	0.30	0.39	0.45	0.45	0.45	0.45	0.45	0.53	0.69	0.84	1.00	1.07	1.07	1.00	0.92	0.55	0.33
31					0.11	0.16	0.24	0.33	0.41	0.49	0.49	0.49	0.49	0.49	0.57	0.75	0.92	1.07	1.15	1.15	1.07	1.00	0.60	0.37
32					0.13	0.18	0.27	0.36	0.45	0.53	0.53	0.53	0.53	0.53	0.62	0.83	1.00	1.15	1.23	1.23	1.15	1.07	0.65	0.41
33					0.14	0.21	0.30	0.39	0.49	0.57	0.57	0.57	0.57	0.57	0.67	0.91	1.07	1.23	1.32	1.32	1.23	1.15	0.71	0.45
34				0.10	0.16	0.24	0.33	0.42	0.53	0.62	0.62	0.62	0.62	0.62	0.73	1.00	1.15	1.32	1.41	1.41	1.32	1.23	0.77	0.50
35				0.11	0.18	0.27	0.36	0.46	0.57	0.67	0.67	0.67	0.67	0.67	0.79	1.07	1.23	1.41	1.51	1.51	1.41	1.32	0.84	0.55
36				0.13	0.21	0.30	0.40	0.50	0.62	0.73	0.73	0.73	0.73	0.73	0.85	1.15	1.32	1.51	1.62	1.62	1.51	1.41	0.92	0.61
37				0.15	0.24	0.33	0.43	0.55	0.67	0.79	0.79	0.79	0.79	0.79	0.92	1.23	1.41	1.62	1.74	1.74	1.62	1.51	1.00	0.67
38				0.17	0.27	0.37	0.48	0.60	0.73	0.85	0.85	0.85	0.85	0.85	1.00	1.32	1.51	1.74	1.86	1.86	1.74	1.62	1.10	0.74
39			0.10	0.20	0.30	0.41	0.52	0.65	0.79	0.92	0.92	0.92	0.92	0.92	1.07	1.41	1.62	1.86	1.99	1.99	1.86	1.74	1.21	0.82
40			0.12	0.23	0.33	0.45	0.57	0.71	0.85	1.00	1.00	1.00	1.00	1.00	1.15	1.51	1.74	1.99	2.14	2.14	1.99	1.86	1.34	0.90
41			0.14	0.26	0.37	0.50	0.63	0.77	0.92	1.07	1.07	1.07	1.07	1.07	1.23	1.62	1.86	2.14	2.29	2.29	2.14	1.99	1.46	1.00
42			0.16	0.30	0.41	0.55	0.69	0.84	1.00	1.15	1.15	1.15	1.15	1.15	1.32	1.74	1.99	2.29	2.45	2.45	2.29	2.14	1.63	1.10
43			0.19	0.33	0.45	0.61	0.76	0.92	1.07	1.23	1.23	1.23	1.23	1.23	1.41	1.86	2.14	2.45	2.63	2.63	2.45	2.29	1.79	1.21
44		0.10	0.22	0.37	0.50	0.67	0.83	1.00	1.15	1.32	1.32	1.32	1.32	1.32	1.52	1.99	2.29	2.63	2.81	2.81	2.63	2.45	1.99	1.34
45		0.12	0.26	0.42	0.55	0.74	0.91	1.08	1.24	1.41	1.41	1.41	1.41	1.41	1.62	2.14	2.45	2.81	3.02	3.02	2.81	2.63	2.14	1.45
46		0.14	0.30	0.46	0.61	0.82	1.00	1.16	1.33	1.52	1.52	1.52	1.52	1.52	1.74	2.29	2.63	3.02	3.23	3.23	3.02	2.81	2.29	1.63
47		0.16	0.34	0.52	0.67	0.90	1.08	1.25	1.42	1.62	1.62	1.62	1.62	1.62	1.87	2.45	2.51	3.23	3.46	3.46	3.23	3.02	2.45	1.74
48		0.19	0.38	0.58	0.74	1.00	1.17	1.34	1.53	1.74	1.74	1.74	1.74	1.74	2.00	2.63	3.02	3.46	3.71	3.71	3.46	3.23	2.63	1.87
49	0.10	0.22	0.43	0.65	0.82	1.08	1.26	1.45	1.64	1.87	1.87	1.87	1.87	1.87	2.14	2.81	3.23	3.71	3.97	3.97	3.71	3.46	2.81	2.00

TABLE I CONTINUED

SPL	1/3 OCTAVE BAND CENTER FREQUENCIES IN Hz (c/s)																							
	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
50	.12	.26	.49	.72	.90	1.17	1.36	1.56	1.76	2.00	2.00	2.00	2.00	2.00	2.30	3.02	3.46	3.97	4.26	4.26	3.97	3.71	3.02	2.40
51	.14	.30	.55	.80	1.00	1.26	1.47	1.68	1.89	2.14	2.14	2.14	2.14	2.14	2.46	3.23	3.71	4.26	4.56	4.56	4.26	3.97	3.23	2.63
52	.17	.34	.62	.90	1.09	1.36	1.59	1.80	2.03	2.30	2.30	2.30	2.30	2.30	2.64	3.46	3.97	4.56	4.89	4.89	4.56	4.26	3.46	2.81
53	.21	.39	.70	1.00	1.19	1.47	1.71	1.94	2.17	2.46	2.46	2.46	2.46	2.46	2.83	3.71	4.26	4.89	5.24	5.24	4.89	4.56	3.71	3.02
54	.25	.45	.79	1.09	1.28	1.58	1.85	2.09	2.33	2.64	2.64	2.64	2.64	2.64	3.03	3.97	4.56	5.24	5.61	5.61	5.24	4.89	3.97	3.23
55	.30	.51	.89	1.19	1.35	1.71	2.00	2.25	2.50	2.83	2.83	2.83	2.83	2.83	3.25	4.26	4.89	5.61	6.01	6.01	5.61	5.24	4.26	3.46
56	.34	.59	1.00	1.29	1.50	1.85	2.15	2.42	2.69	3.03	3.03	3.03	3.03	3.03	3.48	4.56	5.24	6.01	6.44	6.44	6.01	5.61	4.56	3.71
57	.39	.67	1.09	1.40	1.63	2.00	2.33	2.61	2.88	3.25	3.25	3.25	3.25	3.25	3.73	4.89	5.61	6.44	6.90	6.90	6.44	6.01	4.89	3.97
58	.45	.77	1.19	1.53	1.77	2.15	2.51	2.81	3.10	3.48	3.48	3.48	3.48	3.48	4.00	5.24	6.01	6.90	7.39	7.39	6.90	6.44	5.24	4.26
59	.51	.87	1.29	1.66	1.92	2.33	2.71	3.03	3.32	3.73	3.73	3.73	3.73	3.73	4.29	5.61	6.44	7.39	7.92	7.92	7.39	6.90	5.61	4.56
60	.59	1.00	1.40	1.81	2.09	2.51	2.93	3.26	3.57	4.00	4.00	4.00	4.00	4.00	4.59	6.01	6.90	7.92	8.49	8.49	7.92	7.39	6.01	4.89
61	.67	1.10	1.53	1.97	2.26	2.71	3.16	3.51	3.83	4.29	4.29	4.29	4.29	4.29	4.92	6.44	7.39	8.49	9.09	9.09	8.49	7.92	6.44	5.24
62	.77	1.21	1.66	2.15	2.45	2.93	3.41	3.78	4.11	4.59	4.59	4.59	4.59	4.59	5.28	6.90	7.92	9.09	9.74	9.74	9.09	8.49	6.90	5.61
63	.87	1.32	1.81	2.34	2.65	3.16	3.69	4.06	4.41	4.92	4.92	4.92	4.92	4.92	5.66	7.39	8.49	9.74	10.4	10.4	9.74	9.09	7.39	6.01
64	1.00	1.45	1.97	2.54	2.88	3.41	3.98	4.39	4.73	5.28	5.28	5.28	5.28	5.28	6.06	7.92	9.09	10.4	11.2	11.2	10.4	9.74	7.92	6.44
65	1.11	1.60	2.15	2.77	3.12	3.69	4.30	4.71	5.09	5.66	5.66	5.66	5.66	5.66	6.50	8.49	9.74	11.2	12.0	12.0	11.2	10.4	8.49	6.90
66	1.22	1.75	2.34	3.01	3.39	3.98	4.64	5.07	5.45	6.06	6.06	6.06	6.06	6.06	6.96	9.09	10.4	12.0	12.8	12.8	12.0	11.2	9.09	7.39
67	1.35	1.92	2.54	3.28	3.68	4.30	5.01	5.46	5.85	6.50	6.50	6.50	6.50	6.50	7.46	9.74	11.2	12.8	13.8	13.8	12.8	12.0	9.74	7.92
68	1.49	2.11	2.77	3.57	3.99	4.64	5.41	5.88	6.27	6.96	6.96	6.96	6.96	6.96	8.00	10.4	12.0	13.8	14.7	14.7	13.8	12.8	10.4	8.49
69	1.65	2.32	3.01	3.89	4.33	5.01	5.84	6.33	6.73	7.46	7.46	7.46	7.46	7.46	8.57	11.2	12.8	14.7	15.8	15.8	14.7	13.8	11.2	9.09
70	1.82	2.55	3.28	4.23	4.69	5.41	6.31	6.81	7.23	8.00	8.00	8.00	8.00	8.00	9.19	12.0	13.8	15.8	16.9	16.9	15.8	14.7	12.0	9.74
71	2.02	2.79	3.57	4.60	5.09	5.84	6.81	7.33	7.75	8.57	8.57	8.57	8.57	8.57	9.85	12.8	14.7	16.9	18.1	18.1	16.9	15.8	12.8	10.4
72	2.23	3.07	3.89	5.01	5.52	6.31	7.36	7.90	8.32	9.19	9.19	9.19	9.19	9.19	10.6	13.8	15.8	18.1	19.4	19.4	18.1	16.9	13.8	11.2
73	2.46	3.37	4.23	5.45	5.99	6.81	7.94	8.50	8.93	9.85	9.85	9.85	9.85	9.85	11.3	14.7	16.9	19.4	20.8	20.8	19.4	18.1	14.7	12.0
74	2.72	3.70	4.60	5.94	6.50	7.36	8.57	9.15	9.59	10.6	10.6	10.6	10.6	10.6	12.1	15.8	18.1	20.8	22.3	22.3	20.8	19.4	15.8	12.8
75	3.01	4.06	5.01	6.46	7.05	7.94	9.19	9.85	10.3	11.3	11.3	11.3	11.3	11.3	13.0	16.9	19.4	22.3	23.9	23.9	22.3	20.8	16.9	13.8
76	3.32	4.45	5.45	7.03	7.65	8.57	9.85	10.6	11.0	12.1	12.1	12.1	12.1	12.1	13.9	18.1	20.8	23.9	25.6	25.6	23.9	22.3	18.1	14.7
77	3.67	4.89	5.94	7.66	8.29	9.19	10.6	11.3	11.8	13.0	13.0	13.0	13.0	13.0	14.9	19.4	22.3	25.6	27.4	27.4	25.6	23.9	19.4	15.8
78	4.06	5.37	6.45	8.33	9.00	9.85	11.3	12.1	12.7	13.9	13.9	13.9	13.9	13.9	16.0	20.8	23.9	27.4	29.4	29.4	27.4	25.6	20.8	16.9
79	4.49	5.90	7.03	9.07	9.76	10.6	12.1	13.0	13.6	14.9	14.9	14.9	14.9	14.9	17.1	22.3	25.6	29.4	31.5	31.5	29.4	27.4	22.3	18.1
80	4.96	6.48	7.66	9.85	10.6	11.3	13.0	13.9	14.6	16.0	16.0	16.0	16.0	16.0	18.4	23.9	27.4	31.5	33.7	33.7	31.5	29.4	23.9	19.4
81	5.48	7.11	8.33	10.6	11.3	12.1	13.9	14.9	15.7	17.1	17.1	17.1	17.1	17.1	19.7	25.6	29.4	33.7	36.1	36.1	33.7	31.5	25.6	20.8
82	6.06	7.81	9.07	11.3	12.1	13.0	14.9	16.0	16.9	18.4	18.4	18.4	18.4	18.4	21.1	27.4	31.5	36.1	38.7	38.7	36.1	33.7	27.4	22.3
83	6.70	8.57	9.87	12.1	13.0	13.9	16.0	17.1	18.1	19.7	19.7	19.7	19.7	19.7	22.6	29.4	33.7	38.7	41.5	41.5	38.7	36.1	29.4	23.9
84	7.41	9.41	10.7	13.0	13.9	14.9	17.1	18.4	19.4	21.1	21.1	21.1	21.1	21.1	24.3	31.5	36.1	41.5	44.4	44.4	41.5	38.7	31.5	25.6
85	8.19	10.3	11.7	13.9	14.9	16.0	18.4	19.7	20.8	22.6	22.6	22.6	22.6	22.6	26.0	33.7	38.7	44.4	47.6	47.6	44.4	41.5	33.7	27.4
86	9.05	11.3	12.7	14.9	16.0	17.1	19.7	21.1	22.4	24.3	24.3	24.3	24.3	24.3	27.9	36.1	41.5	47.6	51.0	51.0	47.6	44.4	36.1	29.4
87	10.0	12.1	13.9	16.0	17.1	18.4	21.1	22.6	24.0	26.0	26.0	26.0	26.0	26.0	29.9	38.7	44.4	51.0	54.7	54.7	51.0	47.6	38.7	31.5
88	11.1	13.0	14.9	17.1	18.4	19.7	22.6	24.3	25.8	27.9	27.9	27.9	27.9	27.9	32.0	41.5	47.6	54.7	58.6	58.6	54.7	51.0	41.5	33.7
89	12.2	13.9	16.0	18.4	19.7	21.1	24.3	26.0	27.7	29.9	29.9	29.9	29.9	29.9	34.3	44.4	51.0	58.6	62.7	62.7	58.6	54.7	44.4	36.1
90	13.5	14.9	17.1	19.7	21.1	22.6	26.0	27.9	29.7	32.0	32.0	32.0	32.0	32.0	36.8	47.6	54.7	62.7	67.2	67.2	62.7	58.6	47.6	38.7
91	14.9	16.0	18.4	21.1	22.6	24.3	27.9	29.9	31.8	34.3	34.3	34.3	34.3	34.3	39.4	51.0	58.6	67.2	72.0	72.0	67.2	62.7	51.0	41.5
92	16.0	17.1	19.7	22.6	24.3	26.0	29.9	32.0	34.2	36.8	36.8	36.8	36.8	36.8	42.2	54.7	62.7	72.0	77.2	77.2	72.0	67.2	54.7	44.4
93	17.1	18.4	21.1	24.3	26.0	27.9	32.0	34.3	36.7	39.4	39.4	39.4	39.4	39.4	45.3	58.6	67.2	77.2	82.7	82.7	77.2	72.0	58.6	47.6
94	18.4	19.7	22.6	26.0	27.9	29.9	34.3	36.8	39.4	42.2	42.2	42.2	42.2	42.2	48.5	62.7	72.0	82.7	88.6	88.6	82.7	77.2	62.7	51.0
95	19.7	21.1	24.3	27.9	29.9	32.0	36.8	39.4	42.2	45.3	45.3	45.3	45.3	45.3	52.0	67.2	77.2	88.6	94.9	94.9	88.6	82.7	67.2	54.7
96	21.1	22.6	26.0	29.9	32.0	34.3	39.4	42.2	45.3	48.5	48.5	48.5	48.5	48.5	55.7	72.0	82.7	94.9	102	102	94.9	88.6	72.0	58.6
97	22.6	24.3	27.9	32.0	34.3	36.8	42.2	45.3	48.5	52.0	52.0	52.0	52.0	52.0	59.7	77.2	88.6	102	109	109	102	94.9	77.2	62.7
98	24.3	26.0	29.9	34.3	36.8	39.4	45.3	48.5	52.0	55.7	55.7	55.7	55.7	55.7	64.0	82.7	94.9	109	117	117	109	102	82.7	67.2
99	26.0	27.9	32.0	36.8	39.4	42.2	48.5	52.0	55.7	59.7	59.7	59.7	59.7	59.7	68.6	88.6	102	117	125	125	117	109	88.6	72.0

TABLE I CONTINUED

	1/3 OCTAVE BAND CENTER FREQUENCIES IN Hz (c/s)																							
SPL	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
100	27.9	29.9	34.3	39.4	42.2	45.3	52.0	55.7	59.7	64.0	64.0	64.0	64.0	64.0	73.5	94.9	109	125	134	134	125	117	94.9	77.2
101	29.9	32.0	36.8	42.2	45.3	48.5	55.7	59.7	64.0	68.6	68.6	68.6	68.6	68.6	78.8	102	117	134	144	144	134	125	102	82.7
102	32.0	34.3	39.4	45.3	48.5	52.0	59.7	64.0	68.6	73.5	73.5	73.5	73.5	73.5	84.4	109	125	144	154	154	144	134	109	88.6
103	34.3	36.8	42.2	48.5	52.0	55.7	64.0	68.6	73.5	78.8	78.8	78.8	78.8	78.8	90.5	117	134	154	165	165	154	144	117	94.9
104	36.8	39.4	45.3	52.0	55.7	59.7	68.6	73.5	78.8	84.4	84.4	84.4	84.4	84.4	97.0	125	144	165	177	177	165	154	125	102
105	39.4	42.2	48.5	55.7	59.7	64.0	73.5	78.8	84.4	90.5	90.5	90.5	90.5	90.5	104	134	154	177	189	189	177	165	134	109
106	42.2	45.3	52.0	59.7	64.0	68.6	78.8	84.4	90.5	97.0	97.0	97.0	97.0	97.0	111	144	165	189	203	203	189	177	144	117
107	45.3	48.5	55.7	64.0	68.6	73.5	84.4	90.5	97.0	104	104	104	104	104	119	154	177	203	217	217	203	189	154	125
108	48.5	52.0	59.7	68.6	73.5	78.8	90.5	97.0	104	111	111	111	111	111	128	165	189	217	233	233	217	203	165	134
109	52.0	55.7	64.0	73.5	78.8	84.4	97.0	104	111	119	119	119	119	119	137	177	203	233	249	249	233	217	177	144
110	55.7	59.7	68.6	78.8	84.4	90.5	104	111	119	128	128	128	128	128	147	189	217	249	267	267	249	233	189	154
111	59.7	64.0	73.5	84.4	90.5	97.0	111	119	128	137	137	137	137	137	158	203	233	267	286	286	267	249	203	165
112	64.0	68.6	78.8	90.5	97.0	104	119	128	137	147	147	147	147	147	169	217	249	286	307	307	286	267	217	177
113	68.6	73.5	84.4	97.0	104	111	128	137	147	158	158	158	158	158	181	233	267	307	329	329	307	286	233	189
114	73.5	78.8	90.5	104	111	119	137	147	158	169	169	169	169	169	194	249	286	329	352	352	329	307	249	203
115	78.8	84.4	97.0	111	119	128	147	158	169	181	181	181	181	181	208	267	307	352	377	377	352	329	267	217
116	84.4	90.5	104	119	128	137	158	169	181	194	194	194	194	194	223	286	329	377	404	404	377	352	286	233
117	90.5	97.0	111	128	137	147	169	181	194	208	208	208	208	208	239	307	352	404	433	433	404	377	307	249
118	97.0	104	119	137	147	158	181	194	208	223	223	223	223	223	256	329	377	433	464	464	433	404	329	267
119	104	111	128	147	158	169	194	208	223	239	239	239	239	239	274	352	404	464	497	497	464	433	352	286
120	111	119	137	158	169	181	208	223	239	256	256	256	256	256	294	377	433	497	533	533	497	464	377	307
121	119	128	147	169	181	194	223	239	256	274	274	274	274	274	315	404	464	533	571	571	533	497	404	329
122	128	137	158	181	194	208	239	256	274	294	294	294	294	294	338	433	497	571	611	611	571	533	433	352
123	137	147	169	194	208	223	256	274	294	315	315	315	315	315	362	464	533	611	655	655	611	571	464	377
124	147	158	181	208	223	239	274	294	315	338	338	338	338	338	388	497	571	655	702	702	655	611	497	404
125	158	169	194	223	239	256	294	315	338	362	362	362	362	362	416	533	611	702	752	752	702	655	533	433
126	169	181	208	239	256	274	315	338	362	388	388	388	388	388	446	571	655	752	806	806	752	702	571	464
127	181	194	223	256	274	294	338	362	388	416	416	416	416	416	478	611	702	806	863	863	806	752	611	497
128	194	208	239	274	294	315	362	388	416	446	446	446	446	446	512	655	752	863	925	925	863	806	655	533
129	208	223	256	294	315	338	388	416	446	478	478	478	478	478	549	702	806	925	991	991	925	863	702	571
130	223	239	274	315	338	362	416	446	478	512	512	512	512	512	588	752	863	991	1062	1062	991	925	752	611
131	239	256	294	338	362	388	446	478	512	549	549	549	549	549	630	806	925	1062	1137	1137	1062	991	806	655
132	256	274	315	362	388	416	478	512	549	588	588	588	588	588	676	863	991	1137	1219	1219	1137	1062	863	702
133	274	294	338	388	416	446	512	549	588	630	630	630	630	630	724	925	1062	1219	1306	1306	1219	1137	925	752
134	294	315	362	416	446	478	549	588	630	676	676	676	676	676	776	991	1137	1306	1399	1399	1306	1219	991	806
135	315	338	388	446	478	512	588	630	676	724	724	724	724	724	832	1062	1219	1399	1499	1499	1399	1306	1062	863
136	338	362	416	478	512	549	630	676	724	776	776	776	776	776	891	1137	1306	1499	1606	1606	1499	1399	1137	925
137	362	388	446	512	549	588	676	724	776	832	832	832	832	832	955	1219	1399	1606	1721	1721	1606	1499	1219	991
138	388	416	478	549	588	630	724	776	832	891	891	891	891	891	1024	1306	1499	1721	1844	1844	1721	1606	1306	1062
139	416	446	512	588	630	676	776	832	891	955	955	955	955	955	1098	1399	1606	1844	1975	1975	1844	1721	1399	1137
140	446	478	549	630	676	724	832	891	955	1024	1024	1024	1024	1024	1176	1499	1721	1975			1975	1844	1499	1219
141	478	512	588	676	724	776	891	955	1024	1098	1098	1098	1098	1098	1261	1606	1844					1975	1606	1306
142	512	549	630	724	776	832	955	1024	1098	1176	1176	1176	1176	1176	1351	1721	1975						1721	1399
143	549	588	676	776	832	891	1024	1098	1176	1261	1261	1261	1261	1261	1448	1844							1844	1499
144	588	630	724	832	891	955	1098	1176	1261	1351	1351	1351	1351	1351	1552	1975							1975	1606
145	630	676	776	891	955	1024	1176	1261	1351	1448	1448	1448	1448	1448	1664									1721
146	676	724	832	955	1024	1098	1261	1351	1448	1552	1552	1552	1552	1552	1783									1844
147	724	776	891	1024	1098	1176	1351	1448	1552	1664	1664	1664	1664	1664	1911									1975
148	776	832	955	1098	1176	1261	1448	1552	1664	1783	1783	1783	1783	1783	2048									
149	832	891	1024	1176	1261	1351	1552	1664	1783	1911	1911	1911	1911	1911										
150	891	955	1098	1261	1351	1448	1664	1783	1911	2048	2048	2048	2048	2048										

TABLE II
DEFINITIONS AND PROCEDURES FOR COMPUTING THE PERCEIVED NOISE LEVEL OF AIRCRAFT NOISE

The value N, in noys, given in Table I for a particular frequency band is related to the band sound pressure level, L, by the general basic equation

$$N = A \cdot 10^{M_j (L - L_k)} \quad \text{for}$$

$$N \leq 0.1 \text{ and } L \leq 150$$

where M_j, L_k and A depend upon the band center frequency and the magnitude of L.

For $L_1 \leq L < L_2$

$$N = 0.1 \; [10^{M_1 (L - L_1)}] \qquad 0.1 \leq N \leq 0.3$$

For $L_2 \leq L < L_3$

$$N = 10^{M_2 (L - L_3)} \qquad 0.3 \leq N \leq 1.0$$

For $L_3 \leq L < L_c$

$$N = 10^{M_3 (L - L_3)} \qquad 1.0 \leq N_1 \quad L \leq 150$$

For $L_c \leq L \leq 150$

$$N = 10^{M_4 (L - L_4)}$$

Note that for frequency bands having center frequencies from 400 to 6300 Hz inclusive, $L_3 = L_4$ and $M_3 = M_4$ (i.e. one set of values of L_k and M_j suffice to define noy values for $N \geq 1$ and $L \leq 150$). The values of M_j and L_k are tabulated in Table II.

TABLE II (Cont'd)

Band Center Frequency (Hz)	L_1	M_1	L_2	M_2	L_3	M_3	L_c	M_4	L_4
50	49	0.079520	55	0.058098	64	0.043478	91.01	0.030103	52
63	44	0.068160	51	0.058098	60	0.040570	85.88	0.030103	51
80	39	0.068160	46	0.052288	56	0.036831	87.32	0.030103	49
100	34	0.059640	42	0.047534	53	0.036831	79.85	0.030103	47
125	30	0.053013	39	0.043573	51	0.035336	79.76	0.030103	46
160	27	0.053013	36	0.043573	48	0.033333	75.96	0.030103	45
200	24	0.053013	33	0.040221	46	0.033333	73.96	0.030103	43
250	21	0.053013	30	0.037349	44	0.032051	74.91	0.030103	42
315	18	0.053013	27	0.034859	42	0.030675	94.63	0.030103	41
400	16	0.053013	25	0.034859	40	0.030103	100.00	0.030103	40
500	16	0.053013	25	0.034859	40	0.030103	100.00	0.030103	40
630	16	0.053013	25	0.034859	40	0.030103	100.00	0.030103	40
800	16	0.053013	25	0.034859	40	0.030103	100.00	0.030103	40
1000	16	0.053013	25	0.034859	40	0.030103	100.00	0.030103	40
1250	15	0.059640	23	0.034859	38	0.030103	100.00	0.030103	38
1600	12	0.053013	21	0.040221	34	0.029960	100.00	0.029960	34
2000	9	0.053013	18	0.037349	32	0.029960	100.00	0.029960	32
2500	5	0.047712	15	0.034859	30	0.029960	100.00	0.029960	30
3150	4	0.047712	14	0.034859	29	0.029960	100.00	0.029960	29
4000	5	0.053013	14	0.034859	29	0.029960	100.00	0.029960	29
5000	6	0.053013	15	0.034859	30	0.029960	100.00	0.029960	30
6300	10	0.068160	17	0.037349	31	0.029960	100.00	0.029960	31
8000	17	0.079520	23	0.037349	37	0.042285	44.29	0.029960	34
10,000	21	0.0596401	29	0.043573	41	0.042285	50.72	0.029960	37

[illegible]

FOR SMALL ENGINE POWERED EQUIPMENT

SAE J1046a

SAE Recommended Practice

1. Scope - This SAE Recommended Practice establishes the instrumentation and procedure to be used in measuring the maximum exterior sound level for engine powered equipment under 14.71 kw (20 bhp). It is intended to include equipment such as lawn mowers, snow blowers, tillers, etc. It is not intended to include equipment designed primarily for operation on highways or within factories and buildings, or vehicles such as motorcycles, snowmobiles, and pleasure motor boats that are covered by other SAE Standards or Recommended Practices.

This SAE Recommended Practice may also be used when measuring the maximum exterior sound level on similar equipment powered by electricity or other power sources.

2. Instrumentation - The following instrumentation shall be used for the measurement required:

2.1 A precision sound level meter which meets the Type 1 requirements of ANSI S1.4-1971, Specification for Sound Level Meters.

2.2 As an alternative to making direct measurements using a sound level meter, a microphone or sound level meter may be used with a magnetic tape recorder and/or a graphic level recorder or indicating meter, pro[illegible]ing the system meets the requirements of SAE J184.

2.3 A sound level calibrator (see paragraph 4.2.4).

2.4 The microphone shall be used with an acceptable windscreen. To be acceptable, the screen must not affect the microphone response more than ± 1 dB for frequencies from 20 to 4000 Hz and ± 1-1/2 dB for frequencies from 4000 to 10,000 Hz (see Paragraph 4.3).

2.5 An anemometer or other device for measurement of ambient wind speed.

2.6 An engine speed indicator (accuracy ± 1% of full range).

2.7 A thermometer for measurement of ambient temperature.

3. Procedure

3.1 Test Site - The test area shall consist of a flat open space free from the effects of any large reflecting surfaces such as a signboard, building, or hillside located for a minimum distance of 30.4 m (100 ft.) from the measurement zone. (See Fig. 1).

3.1.2 The entire surface of the measurement zone shall be: synthetic sur[illegible]e mounted to 19 mm (3/4") thickness exterior plywood or 13 mm (1[illegible] thickness marine plywood with suitable adhesive.

Acoustical properties tested per ASTM C423-66 after mounting on plywood shall be:

Hz	Sound Absorption Coefficients
125	.00 - .06
250	.07 - .12
500	.15 - .28
1000	.28 - .34
2000	.38 - .47
4000	.40 - .62

3.1.3 Not more than one person other than the equipment operator and the observer reading the meter shall be within 15 m (50 ft.) of the vehicle path or instrumentation, and that person shall be directly behind the observer who is reading the meter, on a line through the microphone and the observer.

3.1.4 The A-weighted sound level (including wind effects), due to sources other than the equipment being measured, shall be at least 10 dB lower than the level of the equipment being measured.

3.2 Equipment Operation

3.2.1 Operate the equipment at the combination of load and speed which produces the maximum sound level without violating the manufacturer's operation specifications.

3.2.2 RECOMMENDED LOADING TECHNIQUES.

3.2.2.1 Walk-Behind Mowing Equipment - Test as mobile equipment (paragraph 3.3.5). Run the engine or motor at the mower manufacturer's maximum specified speed. Set the blade at the closest available setting to a 51 mm (2 in.) cutting height. Engage the blade and self-propelling mechanism if available. Additional loading mechanism is not deemed necessary.

3.2.2.2 Riding, Mowing Equipment - Test as mobile equipment (paragraph 3.3.5). Run the engine or motor at the mower manufacturer's specified maximum speed. Set the blades at the closest available setting to a 51 mm (2 in.) cutting height and engage the blades. Obtain the maximum sound level with auxiliary load and/or by towing a load. (See paragraph 3.2.3.)

3.2.2.3 Walk-Behind Snow Blowers and Tillers - Test as equipment which is not traveling (paragraph 3.3.4). Run the engine or motor at the equipment manufacturer's specified maximum speed. Engage all mechanisms other than propelling. Load the equipment with an auxiliary load to obtain the maximum sound level. (See paragraph 3.2.3).

2.2.4 Garden Tractors with Attachments Other than Mowers - Test as paragraph 3.3.6. Run the engine(s) or motor(s) at the tractor manufacturer's specified maximum speed. With the attachments engaged, obtain the maximum sound level with an auxiliary load and/or by towing a load. (See paragraph 3.2.3.)

3.2.2.5 Miscellaneous Equipment - Run the engine(s) or motor(s) at the manufacturer's specified maximum speed. With the equipment engaged, obtain the maximum sound level with an auxiliary load and/or by ...ing a load. (See paragraph 3.2.3.)

3.2.3. Auxiliary Loading - The A-weighted sound level of the auxiliary load shall be at least 10dB less than the equipment being measured. The presence of the auxiliary load shall not affect the sound radiated to the microphone. Auxiliary loads may be applied by brake, generator, pump, or another similar device. As the equipment is loaded to obtain the maximum sound level, the engine speed may be somewhat less than the manufacturer's specified maximum due to normal engine governor regulation.

3.3 Measurements.

3.3.1 The microphone shall be located at the apex of the triangular measurement zone area, at a height of 1.2 m (4 ft.) above the ground plane. (See paragraph 3.1.1 and Fig. 1.)

3.3.2 The sound level meter shall be set for "slow" response and for the A-weighted network.

3.3.3 The ambient wind speed relative to the source and microphone, ambient temperature, maximum engine speed, test condition engine speed and ambient A-weighted sound level shall be measured and recorded.

3.3.4 For equipment which is not traveling, test as follows: with the operator in normal position, orient the equipment to obtain maximum so... level. Take measurements to nearest 0.5 db at 7.6 m (25 ft.) fro... the nearest surface of the equipment. Operate the equipment as specified in Section 3.2. Repeat the test at least three times, and more if necessary, to obtain two readings that are within one dB of each other. Report, to nearest 0.5 dB, the average of two highest readings which are within 1 dB of each other.

3.3.5 For mobile equipment, take measurements to nearest 0.5 dB at 7.6 m (25 ft.) from the nearest surface of the equipment along a path of straight line travel. Operate the equipment as specified in Section 3.2.

The applicable reading for each test run will be the highest sound level obtained from the equipment as it moves along the line of travel. The equipment shall be run at least three times in each direction. Report, to nearest 0.5 dB, the average of two highest readings from the loudest side which are within 1 dB of each other.

3.3.6 For equipment that can be operated in two modes, mobile and not traveling, test as specified in paragraphs 3.3.4 and 3.3.5. Report the higher value.

4. General Comments

...1 It is strongly recommended that persons technically trained and ex...ienced in the current techniques of sound measurement select the equipment and conduct the tests.

4.2 Proper use of all test instrumentation is essential to obtain valid measurements. Operating manuals or other literature furnished by the instrument manufacturer should be referred to for both recommended operation of the instrument and precautions to be observed. Specific items to be considered are:

4.2.1 The type of microphone, its directional response characteristics, and its orientation relative to the ground plane and source of noise.

4.2.2 The effects of ambient weather conditions on the performance of all instruments (for example, temperature, humidity, and barometric pressure). Instrumentation can be influenced by low temperature and caution should be exercised.

4.2.3 Proper signal levels, terminating impedances, and cable lengths on multi-instrument measurement systems.

4.2.4 Proper acoustical calibration procedure, to include the influence of extension cables, etc. Field calibration shall be made immediately before and after each test sequence. Internal calibration means is acceptable for field use, provided that external calibration is accomplished immediately before or after field use.

4.3 It is recommended that measurements be made only when wind speed is below 19 km/h (12 mph).

4.4 It is recommended that care be taken in selecting a test site and placing the plywood panels so that panel vibrations do not contribute to the sound level readings.

5. References - Suggested reference material is as follows:

5.1 ANSI S1.1 - 1960, Acoustical Terminology

5.2 ANSI S1.13 - 1971, Methods of Measurement of Sound Pressure Levels.

5.3 ANSI S1.4 - 1971, Specification for Sound Level Meters.

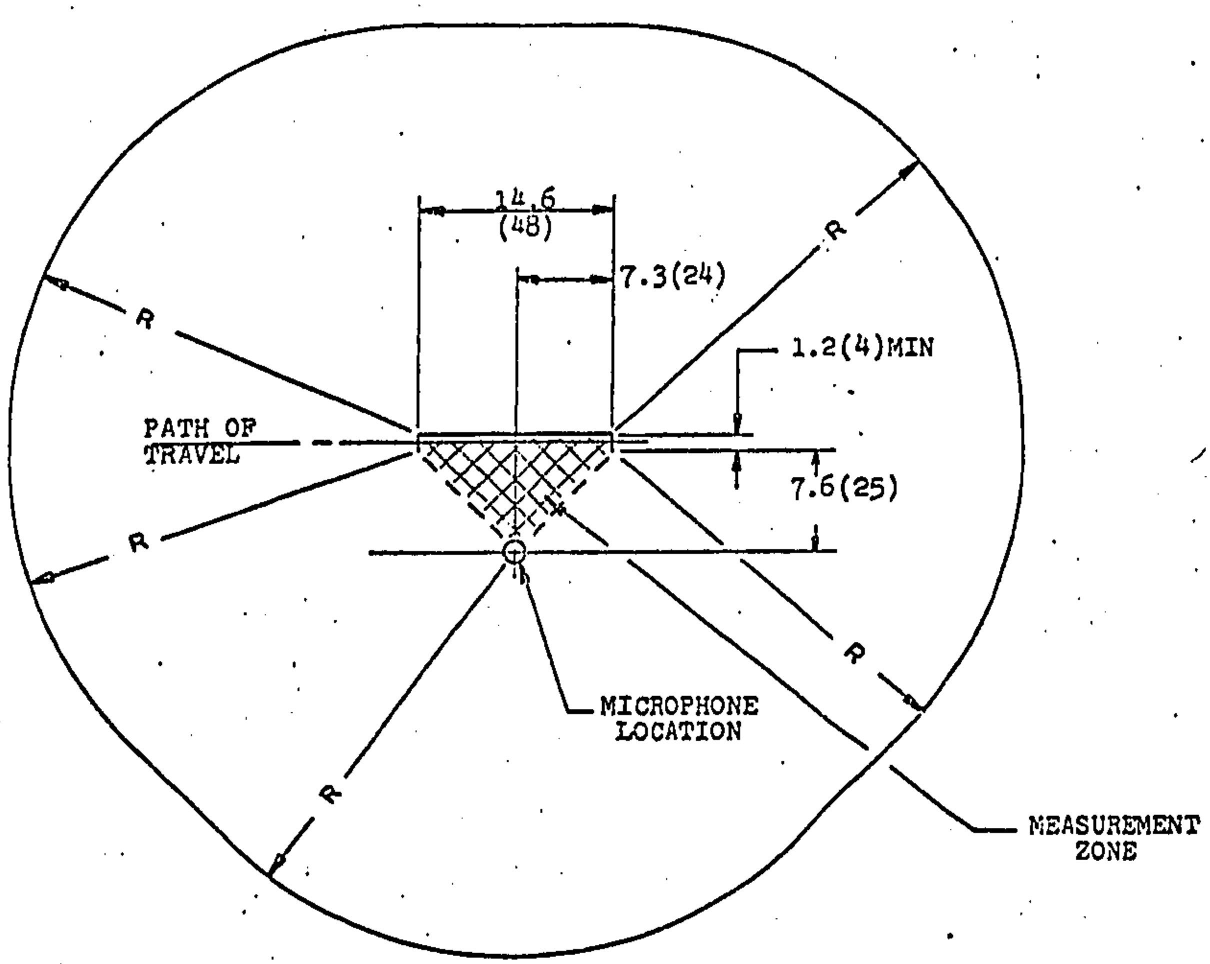
Applications for copies of these documents should be addressed to: American National Standards Institute, Inc., 1430 Broadway, New York, New York 10018.

5.4 SAE J184, Qualifying a Sound Data Acquisition System.

5.5 ASTM C 423-66, Method of Test for Sound Absorption of Acoustical Materials in Reverberation Rooms.

APPENDIX

To convert the sound level readings obtained at 7.6 m (25 ft.) to equivalent 15 m (50 ft.) readings, subtract 6 dB(A) from the 7.6 m (25 ft.) readings.



NOTE: DIMENSIONS ARE M(FT)

R = 30.4(100) MINIMUM

FIG. 1 - TEST SITE

INTRODUCTION

The Small Engine Powered Equipment Subcommittee was organized by the SAE Vehicle Sound Level Committee to develop a new sound level measurement procedure for small engine powered equipment. The scope of the subcommittee was to establish the instrumentation and procedure to be used in measuring the maximum exterior sound level for engine powered equipment under 20 hp. Members of the subcommittee include individuals from engine manufacturers, equipment manufacturers, and an acoustical consulting firm.

Early in 1971 SAE members in the construction equipment industry were developing a new sound level measurement procedure to replace SAE J952 Standard, Sound Levels for Engine Powered Equipment. Several members of the SAE Vehicle Sound Level Committee found the construction equipment industry measurement procedure unsatisfactory for small engine powered equipment sound level measurement. Two factors were a major concern of the SAE Vehicle Sound Level Committee in the development of a new sound level measurement procedure:

1. Distance between noise source and microphone.
2. Surface of the test site between the noise source and the microphone.

SUMMARY RESULTS

The SAE Small Engine Powered Equipment Subcommittee developed a new sound level measurement procedure for small engine powered equipment. Data was gathered in an effort to improve the test site used in the measurement of exterior sound level of small engine powered equipment such as mowers, riding mowers, garden tractors, snowblowers, etc. The procedure developed requires a shorter measurement distance and an artificial test surface. The new procedure provides accurate, repeatable sound level data. Also the method of loading the test equipment was recommended.

DISCUSSION

1. The problem areas that were considered in development of this sound level measurement procedure are:

   a. Measurement Distance:

   In the past, most SAE procedures for exterior sound level measurement have used the 50' measurement distance between the microphone and noise source. On most small engine powered equipment the noise source is very close to an absorptive ground or grass surface and has a low grazing angle between the noise source and the test site surface. The noise absorption characteristic of a test surface may vary with type of grass, density of grass, its length, and the soil conditions, along with the type of soil. Reducing the distance from the noise source to the microphone decreases the possibility of variation due to the attenuation of the test surface.

   The sound levels of small engine powered equipment are normally 5 to 15 dBA lower than larger equipment that used the 50' measuring distance. Reducing the measuring distance effectively will allow a higher background level on the test site area.

   Another consideration in the reduction of the measurement distance was that the cost of the artificial test surface area would be greatly reduced. The measurement zone was finally established, using a fixed location for the microphone 25' from the nearest surface of the equipment being tested.

   b. Test Site Surface:

   Preliminary investigations on a rotary mower tested by 7 different committee members and on their test sites showed a 6 dBA variation in measured sound level between the 7 measurements. The large variations in sound level readings could be test sites. To reduce the variation between measurements on different test sites, the committee decided to consider using an artificial surface for testing the equipment.

The committee thus sponsored and conducted 3 separate field tests. The first field test compared sound level measurements made over grass to measurements made over a polyurethane foam surface. The second field test combined a synthetic turf surface under the vehicle path and a polyurethane foam surface between the vehicle path and the microphone. The third field test compared grass to using all synthetic turf material on the test site. The final all synthetic turf material correlation was within 1.1 dBA to grass. This correlation held true with all various types of small engine powered equipment. Besides the good correlation between the artificial synthetic turf surface and grass, the surface has these other advantages:

1. The surface is more durable than grass and other materials, which is needed when making many tests.
2. Test site is portable and can also be used in winter weather.
3. This material can be used in indoor test facilities.

The subcommittee has concluded a series of tests on a rotary lawnmower sent around and tested at the subcommittee members various synthetic turf test sites and on grass. The variation in sound level measurements on grass was $3\frac{1}{2}$ dBA and the variation on tartan turf was $2\frac{1}{2}$ dBA.

Since the original approval of SAE J1046, the test site material manufacturer has discontinued his artificial turf product. The subcommittee has subsequently made tests on two Monsanto materials and approved one which most closely duplicated the original surface. These tests have shown a direct correlation between the sound absorption coefficients and the noise levels obtained by the equipment. Thus the physical description of the material was removed from the test site description and the tolerance on the sound absorption coefficient was expanded to include both the original material and the new material.

c. Recommended Loading Techniques

In SAE J952B Sound Levels for Engine Power Equipment, the equipment operations specified: "Operate the equipment at the combination of load and speed which produces the maximum sound level without violating the manufacturer's operation specification". The subcommittee decided this statement was vague and difficult to interpret, so recommended loading techniques were developed by the committee for various classes of equipment. However, these loading techniques do not necessarily result in normal or typical operating sound levels.

APPENDIX

1. The materials used for test sites that have been evaluated and approved by the subcommittee are:

   1. Tartan Turf, manufactured by 3M Co. (no longer in production).
   2. Astro Turf S20, manufactured by Monsanto Co., St. Louis, Mo.

Other materials may be used but have to be checked for qualifications per ASTM C423-66 for sound absorption coefficients.

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

(affiliée à l'Organisation Internationale de Normalisation — ISO)

RECOMMANDATION DE LA C E I

INTERNATIONAL ELECTROTECHNICAL COMMISSION

(affiliated to the International Organization for Standardization — ISO)

I E C RECOMMENDATION

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Sonomètres de précision

Precision sound level meters

Bureau Central de la Commission Electrotechnique Internationale

1, rue de Varembé

Genève, Suisse

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CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

PRECISION SOUND LEVEL METERS

FOREWORD

1) The formal decisions or agreements of the IEC on technical matters, prepared by Technical Committees on which all the National Committees having a special interest therein are represented, express, as nearly as possible, an international consensus of opinion on the subjects dealt with.

2) They have the form of recommendations for international use and they are accepted by the National Committees in that sense.

3) In order to promote this international unification, the IEC expresses the wish that all National Committees having as yet no national rules, when preparing such rules, should use the IEC recommendations as the fundamental basis for these rules in so far as national conditions will permit.

4) The desirability is recognized of extending international agreement on these matters through an endeavour to harmonize national standardization rules with these recommendations in so far as national conditions will permit. The National Committees pledge their influence towards that end.

PREFACE

This Recommendation has been prepared by IEC Technical Committee No. 29, Electro-Acoustics. Work was started at the meeting held in Rapallo in 1960, where a preliminary draft prepared by the French National Committee was discussed. A Secretariat draft was discussed at a meeting in Helsinki in 1961, and as a result of these discussions, a final draft was submitted to the National Committees for approval under the Six Months' Rule in March 1962.

The following countries voted explicitly in favour of publication:

Belgium	Norway
Czechoslovakia	Romania
Denmark	Sweden
France	Switzerland
Germany	United Kingdom
Hungary	Union of Soviet Socialist Republics
Japan	United States of America
Netherlands	

PRECISION SOUND LEVEL METERS

1. Scope

1.1 This Recommendation applies to sound level meters for high precision apparatus for laboratory use, or for accurate measurements in which stable, high fidelity and high quality apparatus is required.

1.2 This apparatus will be called:

"sonomètre de précision" in French;

"precision sound level meter" in English;

"точный шумомер" in Russian.

1.3 This Recommendation does not apply to apparatus for measuring discontinuous sounds or sound of very short duration.

2. Object

2.1 In view of the difficulty of establishing a quantitative measurement of a sensation and of the complexity of operation of the human ear, it is not possible, in the present state of the art, to design an objective noise measuring apparatus giving results which are absolutely comparable, for all types of noise, with those given by direct subjective methods.

2.2 However, it is considered essential to standardize an apparatus by which noises can be measured under closely defined conditions so that results obtained by users of such apparatus can be compared.

2.3 The object of the present Recommendation is therefore to specify the characteristics of an apparatus for accurately measuring certain weighted sound pressure levels. The weighting applied to each sinusoidal component of the sound pressure is given as a function of frequency by three standard reference curves, called A, B, C.

2.4 Sound level meters are used to measure a wide variety of noises, under many differing conditions, and for a variety of purposes. The noises may differ in level, spectrum and waveform, and these characteristics may vary with time in different ways. The noise may be mainly from a single source, or it may be a mixture from many sources. It may be measured outdoors in an open field, in a city among closely spaced hard-faced buildings, in a highly reverberant room, or in an anechoic chamber. It may be measured in order to estimate the hearing damage risk, to estimate annoyance, to rate the effectiveness of acoustical treatment, to compare competing products, or for many other purposes.

In each case the measurement technique must be chosen to suit the situation in order that a useful and valid result be obtained, because the quality of the measuring instrument does not alone determine the result. The quality can affect the consistency of readings obtained from day to day or obtained in repeated trials under similar conditions and it limits the absolute accuracy with which the sound pressure at the microphone is measured.

The instrument described in this Recommendation represents a practical combination of characteristics that will achieve a high degree of stability and accuracy. It is the present best compromise but as pointed out above, the manner of use will determine, in large part, the validity of any measurement made with an instrument that meets this specification. In particular, care must be exercised so that the presence of the observer does not invalidate the calibration.

2.5 In order to simplify the procedure for calibration and checking of the apparatus, the Recommendation is written primarily in terms of the free field response.

3. Definitions

3.1 For the definitions of the terms in this Recommendation, reference should be made to the International Electrotechnical Vocabulary, Publication 50(08), Electro-acoustics.

3.2 Sound level is defined by:

$$20 \log_{10} \frac{p_n}{p_o}$$

where p_n is the r.m.s. sound pressure due to the sound being measured, weighted in accordance with the curves A, B or C and p_o is the reference pressure (2.10^{-5} N/m² = 2.10^{-4} µ bar (dyn/cm²)).

3.3 Sound levels are expressed in decibels; the weighting curve used must always be stated (e.g. sound level A = x dB, or sound level = x dB (A)).

4. General technical characteristics

4.1 A sound level meter is generally a combination of a microphone, an amplifier, certain weightin networks, an attenuator and an indicating instrument having certain dynamic characteristics.

4.2 The sound level meter shall cover the frequency range as defined in the Appendix.

4.3 It shall include at least one of three weighting networks called A, B and C. The relative response versus frequency of the complete instrument with any one of these networks included, shall equal that specified in the table for the correspondingly labelled column, Curve A, Curve B or Curve C, within the tolerances indicated. When the apparatus has more than one network, it should be possible to take measurements on any of the networks provided. Although curves A, B and C take certain properties of the ear into account, they must be considered to be purely conventional.

The tolerances relate to the whole apparatus, i.e. they include the tolerances relating to the microphone, to the amplifiers, the weighting networks, the attenuators and the indicating instrument; they apply to the functioning of the apparatus in a free sound field in the direction specified by the manufacturer.

This specified direction shall be marked on the sound level meter itself, and the manufacturer shall state that the instrument is to be used for measurements in an essentially free field. The marking and statement shall not be required, however, if the direction specified leads to a calibration also proper for measurements in a diffuse sound field (this direction is usually between 60° and 80° from the axis of symmetry of the microphone) or if the sound level meter is sufficiently omnidirectional in sensitivity for a single calibration to be correct for measurements in both a free and a diffuse sound field.

4.4 When the microphone is situated in a free sound field of frequency 1 000 Hz (c/s) and is facing in the direction of calibration specified by the manufacturer, the reading of the sound level meter shall be the sound pressure level existing at the point before the introduction of the microphone, within a tolerance of ± 1 dB, under specified reference conditions. The microphone is to be connected to the sound level meter in the manner intended for normal use and the observer is to be in a position specified by the manufacturer as proper for the user.

4.5 If a flat response curve is provided, the manufacturer shall state the frequency range thereof and the tolerance limits.

4.6 It is recommended that the manufacturer should also indicate means for ensuring that the instrument reads correctly in a diffuse field within the tolerances given in the Appendix.

4.7 If the sound level meter is intended for use over a total range of more than 30 dB, it shall have more than one sensitivity range. It is recommended that the attenuator should be in 10 dB steps. Each range shall overlap its neighbour by at least 5 dB.

4.8 If a microphone extension cable or other arrangement is necessary in order to meet this specification, then it must be supplied as part of the apparatus.

5. Microphone characteristics

5.1 The microphone shall be of the omnidirectional pressure type.

5.2 The variation of the sensitivity of the microphone over an angle of ± 90° from an angle of incidence specified by the manufacturer (generally the axis of symmetry of the microphone) shall not exceed the values given in Table I.

TABLE I

Permissible tolerances on microphone sensitivity over an angle of ± 90°

Frequencies Hz (c/s)	Permissible tolerances dB	
31.5 - 1 000	1	−1
1 000 - 2 000	1	−2
2 000 - 4 000	1	−3
4 000 - 8 000	1	−6
8 000 - 12 500	1	−10

At any angle less than 30° from this angle of incidence, the variations of sensitivity shall not exceed the values given in Table II.

TABLE II

Permissible tolerances on microphone sensitivity over an angle less than 30°

Frequencies Hz (c/s)	Permissible tolerances dB	
up to 2 000	0.5	−0.5
2 000 - 4 000	0.5	−1
4 000 - 8 000	0.5	−1.5
8 000 - 12 500	0.5	−2

The limits may be symmetrical provided the total spread is not exceeded.
This variation of sensitivity shall be measured with the microphone mounted in the manner in which it is to be used as part of the sound level meter, the observer being in a position specified by the manufacturer as proper for the user.

5.3 The sensitivity of the microphone shall not change by more than ± 0.5 dB for a variation of ± 10% in the static pressure.

6. Characteristics of the indicating instrument

6.1 The indicating instrument shall be of the square-law type.

6.2 The scale of the indicating instrument shall be graduated in steps of 1 dB, over a range of at least 15 dB.

6.3 It is recommended that the scale of the indicating instrument should be graduated from — 5 to + 10 dB.

6.4 The error introduced by a change of range shall be less than 0.5 dB.

6.5 The accuracy of the graduations shall be ± 0.2 dB, except for the lower part of the scale which overlaps the adjacent attenuator setting, for which a tolerance of ± 0.5 dB is permitted. It shall also be possible to read to the same accuracy.

6.6 The sound level meter as a whole shall possess the following dynamic characteristic, which shall be designated as *Fast*.

6.6.1 If a pulse of sinusoidal signal having a frequency of 1 000 Hz (c/s) and duration of 0.2 s is applied, the maximum reading shall be 1 ± 1 dB less than the reading for a steady signal of the same frequency and amplitude.

6.6.2 If a sinusoidal signal, at any frequency between 100 and 12 500 Hz (c/s), is suddenly applied and thereafter held constant, the maximum reading shall exceed the final steady reading by 0.6 ± 0.5 dB.

6.7 The sound level meter may also be provided with the following dynamic characteristic, which may be designated as *Slow*.

6.7.1 If a pulse of sinusoidal signal having a frequency 1 000 Hz (c/s) and duration of 0.5 s is applied, the maximum reading shall be 4 ± 1 dB less than the reading for a steady signal of the same frequency and amplitude.

6.7.2 If a sinusoidal signal, at any frequency between 100 and 12 500 Hz (c/s), is suddenly applied and thereafter held constant, the maximum reading shall exceed the final steady reading by $0.6 \pm {}^{1}_{0.5}$ dB.

6.7.3 The steady reading for any sinusoidal signal between 31.5 and 12 500 Hz (c/s) shall not differ from the corresponding *Fast* reading by more than 0.1 dB.

6.8 The characteristics specified in Sub-clauses 6.6 and 6.7 shall be maintained for all weightings and sensitivity ranges of the sound level meter.

6.9 The dynamic characteristic used shall be stated in the test report.

7. Amplifier characteristics

7.1 For electrical calibration it is recommended that a resistance of known value should be inserted in series with the earth lead of the microphone, and that convenient means be provided for connection to it.

7.2 If the sound level meter is battery operated, a suitable means shall be provided to ensure that adequate battery voltages are maintained, so that the accuracy of the sound level meter remains within the specified tolerances.

7.3 If the sound level meter can also be used with a cable between the microphone and the amplifier, the corrections corresponding to this method of use shall be stated by the manufacturer.

7.4 If the microphone is replaced by an equivalent electrical impedance, the basic noise voltage level shall be at least 5 dB below the voltage corresponding to the minimum sound level measurable, whichever of the weighting curves be used.

7.5 When the microphone is replaced by an equivalent electrical impedance and when the sound level meter is exposed to a sound field greater than 20 dB above the minimum the instrument is intended to measure, the reading of the sound level meter shall be at least 20 dB below that which would be obtained in normal operation. This condition shall be fulfilled for the whole range of the scale of the indicating instrument, whatever the sound level, for all weighting curves and for all frequencies between 20 and 12 500 Hz (c/s).

An extension cable may be used to permit the amplifier to be removed from the intense sound field, but, if so, the sound level meter shall be suitably marked to indicate the maximum sound level to which the amplifier may be exposed. This test shall be made with bands of noise not wider than one octave.

7.6 The influence of vibrations shall be reduced to a minimum. This influence shall be indicated by the manufacturer for the complete apparatus, including microphone, and for frequencies between 20 and 5 000 Hz (c/s), in terms of the sound level that would produce a reading equal to that produced by an acceleration of 1 g_n. This indication shall be quoted for each response curve provided.

7.7 The effects of magnetic and electrostatic fields shall be reduced to a minimum. They shall also be indicated by the manufacturer for the complete apparatus, including microphone, in terms of the sound level corresponding to a magnetic field of 79.58 A/m (1 Oe) at 50 or 60 Hz (c/s) in a direction which gives maximum indication. This indication shall be quoted for each response curve provided.

7.8 The temperature range over which the calibration of the complete apparatus, including microphone, is not affected by more than 0.5 dB shall be specified by the manufacturer. If the effect of temperature is greater than 0.5 dB, the corrections to be applied shall be stated by the manufacturer. These corrections shall apply over the temperature range — 10° to 50 °C.

The manufacturer shall state the temperature limits which may not be exceeded without risk of permanent damage to the apparatus.

7.9 The manufacturer shall state the range of humidity over which the complete apparatus, including microphone, is intended to operate. Any effect of humidity shall be less than 0.5 dB; between 0 and 90% relative humidity.

7.10 The amplifier shall have a power-handling capacity of at least 12 dB greater than that corresponding to the maximum reading of the indicating instrument.

7.11 When provision is made for connecting external apparatus having a specified impedance, for example headphones, to the sound level meter, this connection shall not affect the indication by more than 0.5 dB; otherwise the indicating instrument shall be automatically disconnected.

8. Calibration and verification of the characteristics of the sound level meter

8.1 The complete sound level meter shall be calibrated at frequencies covering the range 20 to 12 500 Hz (c/s), in a sound field consisting of sensibly plane progressive waves, arriving at the microphone in the direction of incidence specified by the manufacturer. The observer shall be in the position specified by the manufacturer for normal use of the sound level meter. If it is necessary to use an extension cable as mentioned in Sub-clause 7.3 to satisfy these requirements, this fact shall be stated.

8.2 The sensitivity of the complete apparatus for a diffuse sound field is defined as the root-mean-square value of the sensitivities for all orientations in a free field, taking account, for each orientation, of the area of the corresponding surface element. For this purpose it will generally suffice to measure the sensitivity at angles of incidence of 0°, 30°, 60°, 90°, 120°, 150° and 180° from an axis of symmetry of the microphone and to calculate the random-incidence response by the following formula:

$$S^2 = K_1 S^2_0 + K_2 S^2_{30} + K_3 S^2_{60} \dots + K_7 S^2_{180}$$

where S is the random incidence sensitivity (given for example in millivolts per newton per square metre or in millivolts per microbar (millivolts per dyne per square centimetre).

S_0, S_{30}, S_{60} .... S_{180} are the sensitivities at the respective angles.

$K_1 = K_7 = 0.018$

$K_2 = K_6 = 0.129$

$K_3 = K_5 = 0.224$

$K_4 = 0.258$

The random incidence sensitivity should be determined at least at the frequencies 250, 500, 1 000, 2 000, 4 000, 8 000 and 12 500 Hz (c/s).

8.3 These measurements shall be used to verify that the requirements of Sub-clause 5.2 are met. If it is necessary to use an extension cable as mentioned in Sub-clause 7.3 to satisfy these requirements, this fact shall be marked on the sound level meter.

8.4 The requirements relating to the dynamic characteristics of the indicating instrument (Sub-clauses 6.6 and 6.7) shall be checked at a steady reading of the indicating instrument 4 dB less than the full scale reading.
It is also recommended that they be checked for an indication 5 dB above the minimum indication of the indicating instrument.
This check shall be made using an electrical signal, preferably in series with the microphone, for all the response curves provided.

8.5 The verification of the square law of addition (value indicated = square root of the sum of the mean-square values of the individual components) shall be effected by using a two-tone generator, or a similar arrangement for providing two non-harmonic frequencies, first successively and then simultaneously.
The measurements shall be made for different combinations of non-harmonic frequencies and different positions of the level switch. For this purpose, an electrical signal of frequency f_1, the root-mean square value of which is adjusted to give a certain reading x on the indicating instrument, shall be applied at the microphone input to the amplifier.

The signal f_1 shall then be replaced by a signal f_2, fulfilling the conditions previously specified and the r.m.s. value of the signal f_2 shall be adjusted to give the same reading x on the indicating instrument.

The two signals, f_1 and f_2 shall then be applied simultaneously, the two signals being equally attenuated in such a manner as to restore the reading x. The attenuation required shall be 3 ± 0.1 dB for each signal. The adjustment of the attenuation of each signal shall not affect the other. This test shall be made for a value of the reading $x = 4$ dB below the full scale reading of the indicating instrument.

8.6 The verification of the scale calibration of the indicating instrument (Sub-clause 6.5) shall be effected by an electrical method at frequencies of 31.5, 1 000 and 8 000 Hz (c/s).

8.7 The accuracy of the indications on the attenuator shall be verified by applying to the amplifier sinusoidal input voltages of adjustable amplitude and of frequencies 31.5, 1 000 and 8 000 Hz (c/s). The error shall always be less than 0.5 dB with respect to a reading corresponding to a sound pressure level of 80 dB.

8.8 The complete apparatus shall be calibrated in absolute values at some frequency specified by the manufacturer, called *reference frequency*. This shall be preferably 1 000 Hz (c/s) but shall at least always lie between 200 and 1 000 Hz (c/s). The accuracy of the apparatus at the reference frequency, including errors due to free field approximation and those due to the actual electro-acoustical measurements, shall always be within $\pm$ 1 dB, with respect to a reading corresponding to a sound pressure level of 80 dB.

This tolerance shall apply for standard reference conditions of 20 °C, 65% relative humidity and an atmospheric pressure of 1 000 millibars.

8.9 For sound level meters designed for the measurement of sound pressure levels greater than 100 dB, the sound level meter, with the microphone replaced by an equivalent electrical impedance, shall be subjected to substantially sinusoidal sounds, or to bands of noise having a bandwidth less than one octave, at a sound-pressure level of 100 dB at each frequency, or at each octave band, between 20 and 12 500 Hz (c/s).

When sine waves are used, the frequency shall be changed at a rate not in excess of 1 octave per 10 s. The attenuator shall be set so that 100 dB corresponds to full-scale reading of the indicating instrument. No special antivibration or other special protective measures for the apparatus shall be used. The maximum resulting reading of the indicating instrument shall be stated if it is not at least 20 dB below the full-scale reading.

The test may be repeated at higher settings if appropriate, and the manufacturer shall state the highest setting at which the instrument has been tested and found to produce no microphonics greater than 20 dB below full scale, as prescribed above. It is permissible to conduct certain tests at levels above 100 dB over a limited frequency range but any such limitation shall be reported.

9. Rating plate

The apparatus shall carry the markings:

— *precision sound level meter*;

— the manufacturer's name;

— the type and the serial number;

— the serial number of the microphone.

10. Descriptive leaflet

10.1 Each sound level meter shall be accompanied by a descriptive leaflet which includes at least the following information in addition to that given on the rating plate:

- the type of microphone (electrostatic, moving coil, etc.);
- the angles of incidence specified in Sub-clause 4.3 and 5.2;
- an indication of the range of sound levels which it is designed to measure;
- the reference sound-pressure level specified in Sub-clause 3.2;
- the response curves specified in Sub-clause 4.3;
- the law of addition specified in Sub-clause 6.1;
- the dynamic characteristics *(Fast-Slow)* specified in Sub-clauses 6.6 and 6.7;
- the influence of vibration, magnetic and electrostatic fields, temperature and humidity on the indications of the complete apparatus, including a statement of the frequency, or frequency ranges and the levels, at which the tests were made;
- the limits of temperature and humidity beyond which permanent damage may be caused to the apparatus and the microphone;
- any correction to the calibration required by the use of a microphone extension cable;
- the calibration procedure necessary to maintain the accuracy specified in Sub-clause 8.8. Devices used for this purpose are internal amplifier calibrators and closed coupler calibrators. When such means are employed, the manufacturer shall explain the principles involved and their limitations;
- the position in which the observer should be situated for normal use of the sound level meter.

10.2 It is recommended that the following information should be also included in the descriptive leaflet:

- the impedance of the microphone and, if necessary, its variation with frequency;
- the sensitivity as a function of frequency for the angle of incidence specified by the manufacturer, as specified in Sub-clause 8.1;
- the directional characteristics at the frequencies specified in Sub-clause 5.2;
- the random-incidence calibration calculated by the method specified in Sub-clause 8.2 with the microphone mounted in the manner in which it is to be used.

APPENDIX

RELATIVE RESPONSES AND ASSOCIATED TOLERANCES FOR FREE FIELD CONDITIONS

The tolerance limit is zero at the reference frequency

Frequency Hz (c/s)	Curve A dB	Curve B dB	Curve C dB	Tolerance limits dB	
10	− 70.4	− 38.2	− 14.3	5	− ∞
12.5	− 63.4	− 33.2	− 11.2	5	− ∞
16	− 56.7	− 28.5	− 8.5	5	− ∞
20	− 50.5	− 24.2	− 6.2	5	− 5
25	− 44.7	− 20.4	− 4.4	5	− 5
31.5	− 39.4	− 17.1	− 3.0	3	− 3
40	− 34.6	− 14.2	− 2.0	3	− 3
50	− 30.2	− 11.6	− 1.3	3	− 3
63	− 26.2	− 9.3	− 0.8	3	− 3
80	− 22.5	− 7.4	− 0.5	2	− 2
100	− 19.1	− 5.6	− 0.3	1	− 1
125	− 16.1	− 4.2	− 0.2	1	− 1
160	− 13.4	− 3.0	− 0.1	1	− 1
200	− 10.9	− 2.0	0	1	− 1
250	− 8.6	− 1.3	0	1	− 1
315	− 6.6	− 0.8	0	1	− 1
400	− 4.8	− 0.5	0	1	− 1
500	− 3.2	− 0.3	0	1	− 1
630	− 1.9	− 0.1	0	1	− 1
800	− 0.8	0	0	1	− 1
1 000	0	0	0	1	− 1
1 250	0.6	0	0	1	− 1
1 600	1.0	0	− 0.1	1	− 1
2 000	1.2	− 0.1	− 0.2	1	− 1
2 500	1.3	− 0.2	− 0.3	1	− 1
3 150	1.2	− 0.4	− 0.5	1	− 1
4 000	1.0	− 0.7	− 0.8	1	− 1
5 000	0.5	− 1.2	− 1.3	1.5	− 1.5
6 300	− 0.1	− 1.9	− 2.0	1.5	− 2
8 000	− 1.1	− 2.9	− 3.0	1.5	− 3
10 000	− 2.5	− 4.3	− 4.4	2	− 4
12 500	− 4.3	− 6.1	− 6.2	3	− 6
16 000	− 6.6	− 8.4	− 8.5	3	− ∞
20 000	− 9.3	− 11.1	− 11.2	3	− ∞

These responses are based on frequencies calculated from $1\,000 \times 10^{n/10}$, where n is a positive or negative integer.

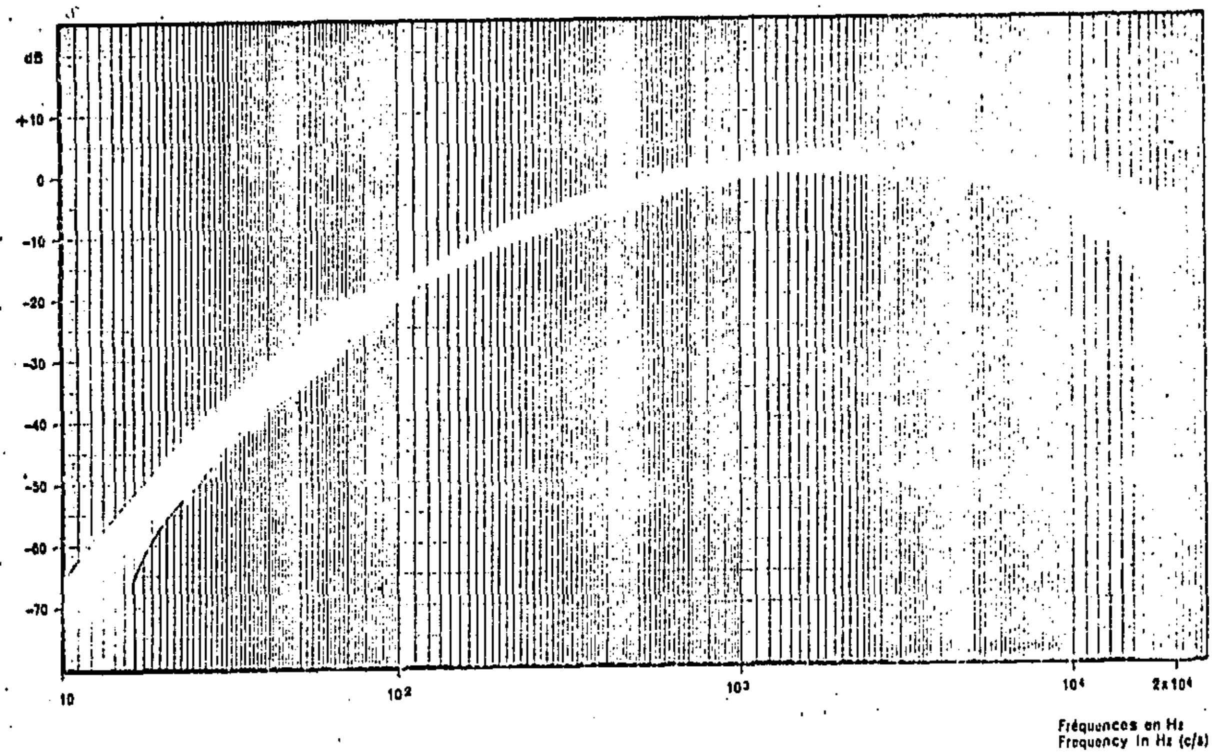

FIG. 1. — Courbe de pondération A.
Weighting curve A.

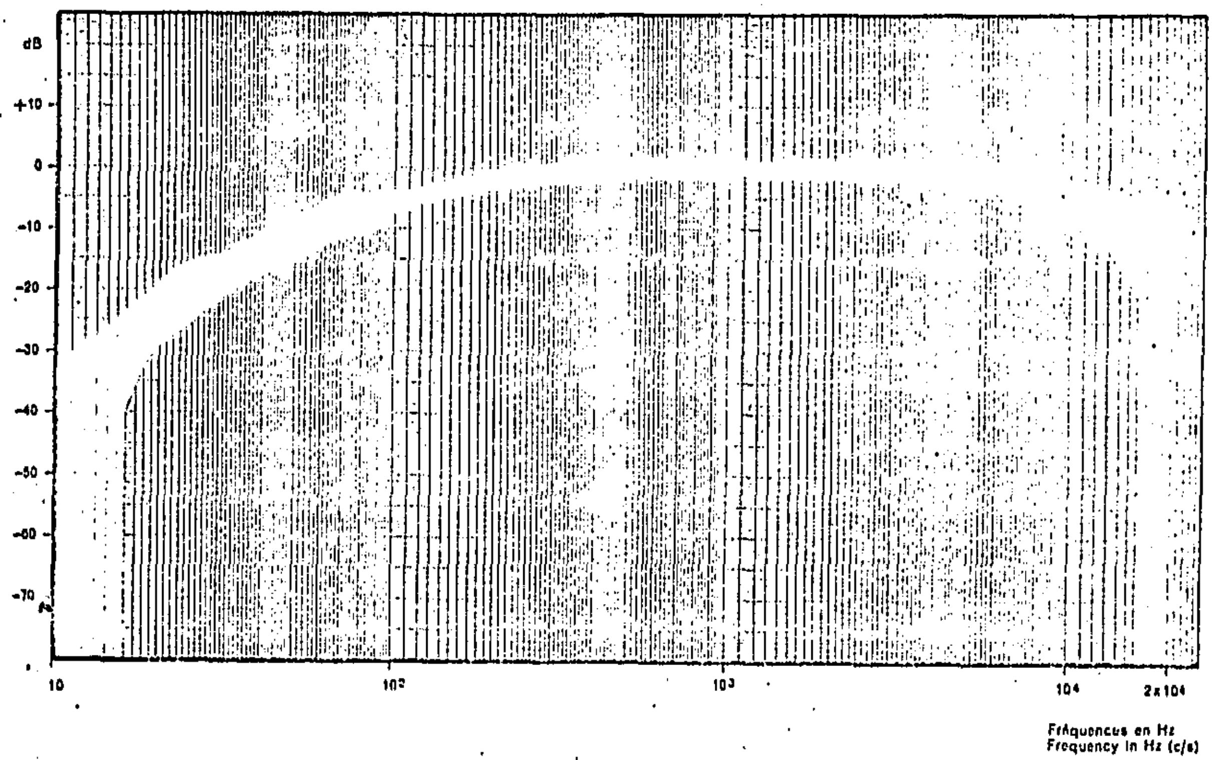

Fig. 2. — Courbe de pondération B.
Weighting curve B.

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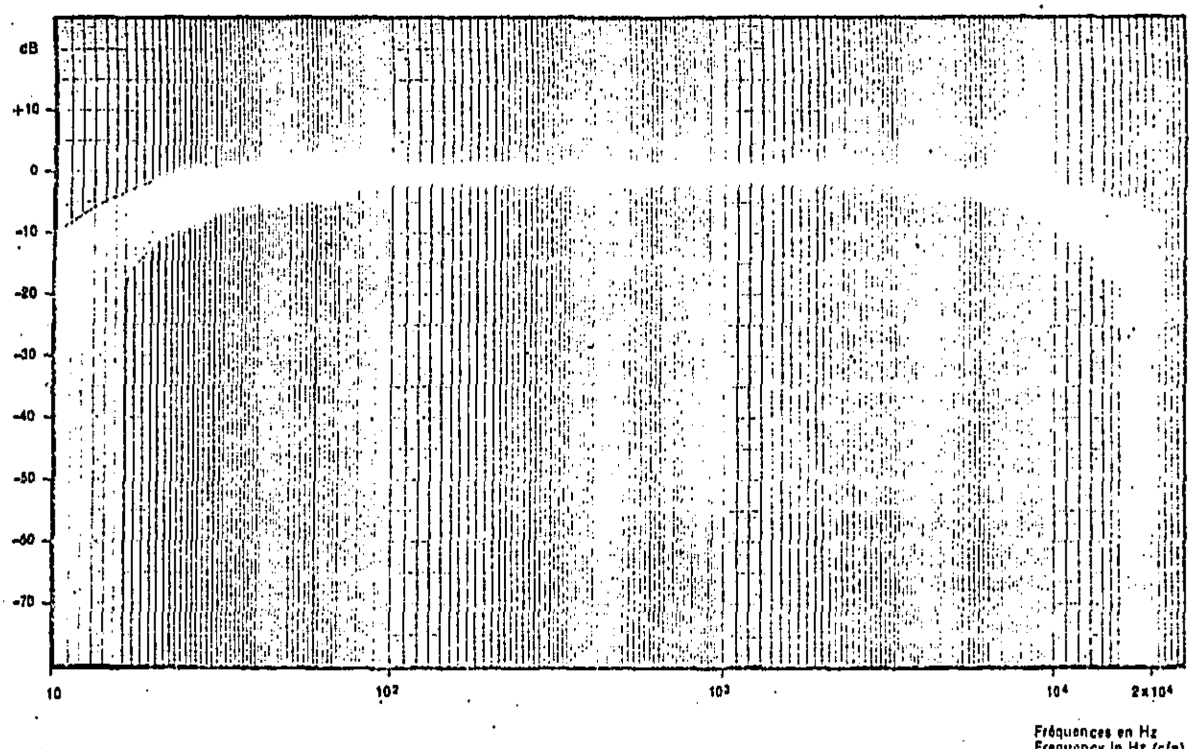

FIG. 3. — Courbe de pondération C.
Weighting curve C.

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

(affiliée à l'Organisation Internationale de Normalisation — ISO)

RECOMMANDATION DE LA CEI

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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Filtres de bandes d'octave, de demi-octave et de tiers d'octave destinés à l'analyse des bruits et des vibrations

Octave, half-octave and third-octave band filters intended for the analysis of sounds and vibrations

Bureau Central de la Commission Electrotechnique Internationale

1, rue de Varembé

Genève, Suisse

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

OCTAVE, HALF-OCTAVE AND THIRD-OCTAVE BAND FILTERS INTENDED FOR THE ANALYSIS OF SOUNDS AND VIBRATIONS

FOREWORD

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PREFACE

This Recommendation has been prepared by I E C Technical Committee No. 29, Electro-acoustics.

A draft was discussed at the meetings held in Rapallo in 1960, in Helsinki in 1961, in Baden-Baden in 1962 and in Aix-les-Bains in 1964. As a result of this latter meeting, a final draft was submitted to the National Committees for approval under the Six Months' Rule in November 1964.

The following countries voted explicitly in favour of publication:

Australia	Italy
Austria	Japan
Belgium	Netherlands
Canada	Norway
Czechoslovakia	Romania
Denmark	Sweden
Finland	Switzerland
France	Turkey
Germany	United Kingdom
Israel	

The United States National Committee cast a negative vote on the ground that they believe the recommendations contained in this Publication strongly discourage filter design approaching the ideal for noise analysis. For example, if the frequency response of a Butterworth filter is centered within the tolerance, the effective bandwidth is 7% greater than it should be.

OCTAVE, HALF-OCTAVE AND THIRD-OCTAVE BAND FILTERS INTENDED FOR THE ANALYSIS OF SOUNDS AND VIBRATIONS

1. Scope

This Recommendation applies to band filters commonly known as octave, half-octave and third-octave band filters of the passive or active type, the latter including amplifier elements, e.g. tubes, valves and/or transistors.

It specifies the most important characteristics of these filters together with the corresponding tolerances.

2. Object

The object of the present Recommendation is to specify the characteristics of band-pass filters to be used in sound and vibration analysis for which octave and third-octave band-pass filters are preferred.

To permit a comparison of the results of measurements in which band filters are used, it is necessary to use filters having certain well defined characteristics, such as limiting frequencies (cut-off frequencies), selectivity, attenuation, terminating impedances.

3. Pass-bands

The pass-bands shall be so chosen that the mid-band frequencies f_m (geometrical means between the upper and lower limiting frequencies) correspond to the preferred frequencies, given in Table I, defined by ISO Publication R266, Preferred Frequencies for Acoustical Measurements.

For example, according to Table I, an octave band filter might have one of the following mid-band frequencies:

16; 31.5; 63; 125; 250; 500; 1 000; 2 000; 4 000; 8 000; 16 000 Hz (c/s).

A set of filters may comprise all the band-pass filters specified or only a selection thereof.

4. Terminating Impedances

To ensure proper operation, the terminating impedances between which the filter is inserted shall be purely resistive and constant, preferably with a value of 600 ohms.

Terminations may, in practice, have a variety of values, provided that they are compatible with the design of the filter.

It is recommended that it be always possible to use a 600 ohms termination and that a high impedance termination preferably above 10 000 ohms should also be available.

The attenuation values shall remain within their tolerances if the terminating impedances differ by ± 5% from their nominal values.

5. Maximum permissible voltage

The manufacturer shall indicate the maximum voltage which may be applied at the input of the filters without risk of abnormal operation or deterioration.

For a 600 ohms filter, the peak value of the permissible e.m.f. applied via a 600 ohms resistor to the input shall be at least 2.2 V (i.e. $2 \times 0.775\sqrt{2}$). This value corresponds, for a sinusoidal voltage, to an input power of 1 mW at the input terminals of the filter within its pass-band. All the electrical characteristics (pass-band, attenuation etc.) specified in this Recommendation shall be appropriate for the maximum voltage indicated by the manufacturer.

6. Bandwidth, attenuation and selectivity

6.1 *Effective bandwidth*

6.1.1 The effective bandwidth of a given transmission system is the bandwidth of an ideal system which:

a) has a uniform transmission in its pass-band equal to the maximum transmission of the system under consideration;

b) transmits the same power as the system under consideration when both systems receive identical signals at the input having a uniform energy distribution at all frequencies (white noise).

6.1.2 The effective bandwidth shall be given by the manufacturer.

6.1.3 The frequency response of the filter should preferably so lie within the given tolerances that the effective bandwidth as above defined is within ± 10% of the nominal pass-band, i.e. octave, half-octave or third-octave.

The minimum insertion loss (corresponding to maximum transmission) in the pass-band should be used as the reference for calculating the effective bandwidth.

6.2 *Attenuation in the pass-band*

6.2.1 The nominal insertion loss in the pass-band shall be indicated by the manufacturer and marked on the apparatus. This loss shall be the same for all the filters of a set of filters.

6.2.2 The variation Δ of the attenuation, with respect to the nominal insertion loss, for the limiting frequencies f_1 and f_2, shall satisfy the following relation:

$$-0.5\ \text{dB} \leq \Delta \leq 6\ \text{dB}.$$

Note. — The frequencies f_1 and f_2 are linked to the mid-band frequency f_m by the following relations:

Octave band filters:

$$f_m = \sqrt{f_1 f_2}$$

where $f_2 = 2 f_1$ and $f_1 = f_m/\sqrt{2} \approx 0.7071\, f_m$

$f_2 = f_m \sqrt{2} \approx 1.4142\, f_m$.

Half-octave band filters:

$$f_m = \sqrt{f_1 f_2}$$

where $f_2 = f_1 \sqrt{2} \approx 1.4142\, f_1$

and $f_1 = f_m / \sqrt[4]{2} \approx 0.8409\, f_m$

$f_2 = f_m \sqrt[4]{2} \approx 1.1892\, f_m$.

Third-octave band filters:

$$f_m = \sqrt{f_1 f_2}$$

where $f_2 = f_1 \sqrt[3]{2} \approx 1.2599 f_1$
and $f_1 = f_m / \sqrt[6]{2} \approx 0.8909 f_m$
$f_2 = f_m \sqrt[6]{2} \approx 1.1225 f_m$.

6.2.3 In the case of octave band filters, for frequencies lying a quarter octave above and below f_m, the variation Δ of the attenuation, with respect to the nominal insertion loss, shall satisfy the following relation:

$$-0.5 \text{ dB} \leq \Delta \leq 1 \text{ dB}.$$

6.2.4 In the case of half-octave band filters, for frequencies lying one-eighth octave above and below f_m, the variation Δ of the attenuation, with respect to the nominal insertion loss, shall satisfy the following relation:

$$-0.5 \text{ dB} \leq \Delta \leq 1 \text{ dB}.$$

6.2.5 In the case of third-octave band filters, for frequencies lying one-twelfth octave below and above f_m, the variation Δ of the attenuation, with respect to the nominal insertion loss, shall satisfy the following relation:

$$-0.5 \text{ dB} \leq \Delta \leq 1 \text{ dB}.$$

6.3 *Attenuation outside the pass-band*

6.3.1 For frequencies as defined below with respect to f_m, the variation Δ of the attenuation, with respect to the nominal insertion loss, shall satisfy the following relations:

For octave band filters:

$$\Delta \geq 18 \text{ dB}$$

at $f = 0.5 f_m$
and $f = 2 f_m$.

For half-octave band filters:

$$\Delta \geq 18 \text{ dB}$$

at $f = f_m / \sqrt{2} \approx 0.7071 f_m$
and $f = f_m \sqrt{2} \approx 1.4142 f_m$.

For third-octave band filters:

$$\Delta \geq 13 \text{ dB}$$

at $f = f_m / \sqrt[3]{2} \approx 0.7937 f_m$
and $f = f_m \sqrt[3]{2} \approx 1.2599 f_m$.

6.3.2 For frequencies higher than $4 f_m$ and lower than $f_m/4$, the variation Δ of the attenuation, with respect to the nominal insertion loss, shall satisfy the following relation:

$\Delta \geq 40$ dB for octave band filters;
$\Delta \geq 50$ dB for half-octave and third-octave band filters.

6.3.3 For frequencies higher than $8 f_m$ and lower than $f_m/8$, the variation Δ of the attenuation, with respect to the nominal insertion loss, shall satisfy the following relation:

$$\Delta \geq 60 \text{ dB}.$$

6.3.4 In addition to the attenuation requirements for each filter given above, the attenuation for any filter set shall be maintained over the entire frequency range from one-third of the lowest mid-band frequency to three times the highest mid-band frequency of the set.

6.4 *Over-all tolerances*

The over-all tolerances for the frequency response may be shown on a graph with the frequency on a logarithmic scale as abscissa and the attenuation on a linear decibel scale as ordinate.

The limits defined individually in the Sub-clauses 6.2.2 to 6.3.3 inclusive should be plotted on the graph and joined by two straight lines, one for the upper and one for the lower limits.

These limits are also summarized in Table II: Variation A of the attenuation, with respect to the nominal insertion loss.

7. Non-linearity distortion (harmonic distortion)

7.1 The attenuation A_m, measured at the mid-band frequency f_m, shall be constant within ± 0.5 dB, whatever the input voltage, for all values up to the maximum permissible voltage defined in Clause 5.

7.2 The requirements of Clause 6 shall be met for any input voltage up to the maximum permissible voltage as defined in Clause 5, when the total output voltage (including any products of distortion) is measured.

8. Effect of battery voltage

If the filter is battery-operated, means shall be provided to ensure that adequate battery voltages are maintained so that the performance of the filter remains within the specified tolerances.

9. Influence of magnetic and electrostatic fields

The influence of magnetic and electrostatic fields shall be reduced to a minimum. An assessment of this influence shall be indicated by the manufacturer, the filter being terminated by its proper impedances as indicated in Clause 4.

Note. — The measurement shall be made for each of the pass-bands defined in Clause 3 for a magnetic field of 10 A/m (≈ 0.13 Oe) of a frequency of 50 Hz(c/s) or 60 Hz(c/s) as specified by the manufacturer, in a direction corresponding to the maximum voltage measured at the output terminals. The values given by the manufacturer shall be the electrical voltages measured at the output terminals under the previously mentioned conditions, for each of the bands if necessary, i.e. if the interfering voltage varies from one band to the other.

10. Influence of vibration and ambient sound fields

For each of the pass-bands provided in a set of filters, the manufacturer shall state the maximum output voltage that results when the filter is vibrated with an acceleration of 1 g_n = 9.80 665 m/s² (peak) at a frequency which ranges over the whole pass-band under consideration. A similar specification for a stated sound pressure level shall also be given.

11. Influence of temperature

The temperature range over which the insertion loss A_m, measured at the mid-band frequency f_m, is not affected by more than 0.5 dB shall be specified by the manufacturer. If this influence exceeds 0.5 dB, the correction to be applied shall be specified by the manufacturer. The correction shall apply to the temperature range of – 10 °C to + 50 °C. The manufacturer shall indicate the temperature limits which cannot be exceeded without risk of permanent damage to the apparatus.

12. Influence of humidity

The manufacturer shall specify the range of humidity over which the apparatus will function correctly. The influence of humidity on the insertion loss A_m, measured at the mid-band frequency f_m, shall be less than 0.5 dB for relative humidities up to 90%.

TABLE I

Frequencies conforming with ISO Publication R266

The table may be extended in either direction by successive multiplication or division by 1000. The letter x indicates in each column the geometric mid-band frequencies of the filter.

Preferred frequencies	1/1 octave	1/2 octave	1/3 octave	Preferred frequencies	1/1 octave	1/2 octave	1/3 octave	Preferred frequencies	1/1 octave	1/2 octave	1/3 octave
16	x	x	x	160			x	1 600			x
18				180		x		1 800			
20			x	200			x	2 000	x	x	x
22.4		x		224				2 240			
25			x	250	x	x	x	2 500			x
28				280				2 800		x	
31.5	x	x	x	315			x	3 150			x
35.5				355		x		3 550			
40			x	400			x	4 000	x	x	x
45		x		450				4 500			
50			x	500	x	x	x	5 000			x
56				560				5 600		x	
63	x	x	x	630			x	6 300			x
71				710		x		7 100			
80			x	800			x	8 000	x	x	x
90		x		900				9 000			
100			x	1 000	x	x	x	10 000			x
112				1 120				11 200		x	
125	x	x	x	1 250			x	12 500			x
140				1 400		x		14 000			
160			x	1 600			x	16 000	x	x	x

Note. — The exact preferred frequencies calculated from 1 000 × $10^{3n/10}$ for octave band filters, 1 000 × $10^{3n/20}$ for half-octave band filters and 1 000 × $10^{n/10}$ for third-octave band filters where n is a positive or negative integer, or zero, should be used for the design of filters rather than the nominal values given in the table.

For normal acoustical measurements, the difference between the nominal and the exact frequencies is negligible.

TABLE II

Variation Δ of the attenuation, with respect to the nominal insertion loss

Frequency range			Attenuation dB
Octave filters	Half-octave filters	Third-octave filters	
From $\frac{f_m}{\sqrt[4]{2}} = 0.8409\, f_m$ To $f_m \sqrt[4]{2} = 1.1892\, f_m$	From $\frac{f_m}{\sqrt[8]{2}} = 0.9170\, f_m$ To $f_m \sqrt[8]{2} = 1.0905\, f_m$	From $\frac{f_m}{\sqrt[12]{2}} = 0.9439\, f_m$ To $f_m \sqrt[12]{2} = 1.0595\, f_m$	$-0.5 \leq \Delta \leq 1$
* From $\frac{f_m}{\sqrt{2}} = 0.7071\, f_m$ To $f_m \sqrt{2} = 1.4142\, f_m$	* From $\frac{f_m}{\sqrt[4]{2}} = 0.8409\, f_m$ To $f_m \sqrt[4]{2} = 1.1892\, f_m$	* From $\frac{f_m}{\sqrt[6]{2}} = 0.8909\, f_m$ To $f_m \sqrt[6]{2} = 1.1225\, f_m$	$-0.5 \leq \Delta \leq 6$
At $\frac{f_m}{2}$ and $2 f_m$	At $\frac{f_m}{\sqrt{2}} = 0.7071\, f_m$ And $f_m \sqrt{2} = 1.4142\, f_m$	—	≥ 18
—	—	At $\frac{f_m}{\sqrt[3]{2}} = 0.7937\, f_m$ And $f_m \sqrt[3]{2} = 1.2599\, f_m$	≥ 13
Below $\frac{f_m}{4}$ And above $4 f_m$	—	—	≥ 40
—	Below $\frac{f_m}{4}$ And above $4 f_m$	Below $\frac{f_m}{4}$ And above $4 f_m$	≥ 50
Below $\frac{f_m}{8}$ And above $8 f_m$	Below $\frac{f_m}{8}$ And above $8 f_m$	Below $\frac{f_m}{8}$ And above $8 f_m$	≥ 60

* These are the band defining frequencies.

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

(affiliée à l'Organisation Internationale de Normalisation — ISO)

RECOMMANDATION DE LA C.E.I.

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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Recommandations relatives aux sonomètres

Recommendations for sound level meters

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

RECOMMENDATIONS FOR SOUND LEVEL METERS

FOREWORD

1) The formal decisions or agreements of the I.E.C. on technical matters, prepared by Technical Committees on which all the National Committees having a special interest therein are represented, express, as nearly as possible, an international consensus of opinion on the subjects dealt with.

2) They have the form of recommendations for international use and they are accepted by the National Committees in that sense.

3) In order to promote this international unification, the I.E.C. expresses the wish that all National Committees having as yet no national rules, when preparing such rules, should use the I.E.C. recommendations as the fundamental basis for these rules in so far as national conditions will permit.

4) The desirability is recognized of extending international agreement on these matters through an endeavour to harmonize national standardization rules with these recommendations in so far as national conditions will permit. The National Committees pledge their influence towards that end.

PREFACE

These recommendations have been prepared by Technical Committee No. 29, Electroacoustics. Work was started at a meeting held in Paris in 1957, when a preliminary draft prepared by the French National Committee was discussed. A second draft was discussed at a meeting held in Stockholm in 1958, and as a result of these discussions a final draft was submitted to the National Committees for approval under the Six Month's Rule in September 1959.

The following 18 countries voted explicitly in favour of publication of this draft:

Austria	Japan
Belgium	Netherlands
Czechoslovakia	Norway
Denmark	Poland
Finland	Romania
France	Sweden
Germany	Switzerland
Hungary	United Kingdom
India	Union of Soviet Socialist Republics

The United States National Committee cast a negative vote on this occasion as it could not accept the tolerances with regard to the directional characteristics of the microphone. Consequently, this problem was re-discussed at a meeting held in Rapallo in April 1960, and as a result, an amendment to Clause 5.2 was submitted to the National Committees under the Two Month's Procedure in August 1960.

The following 13 countries voted explicitly in favour of this amendment:

Austria	Netherlands
Belgium	Norway
Czechoslovakia	Sweden
Finland	Switzerland
Hungary	United Kingdom
India	United States of America
Italy	

However, five countries, viz, Denmark, France, Germany, Poland and the U.S.S.R., were not in favour of this amendment.

Scrutiny of the results of both votes by the Chairman and Secretariat of T.C. 29 showed that there had evidently been a misunderstanding as to how these tolerances were to be interpreted. As the point is of relatively minor importance it has been decided to include both series of tolerances in Clause 5.2 of these recommendations, with an explanation of their different applications, so as not to delay publication unnecessarily.

The present recommendations apply only to sound level meters for general purposes; further recommendations applying to precision sound level meters are in preparation.

RECOMMENDATIONS FOR SOUND LEVEL METERS

1. Scope

These recommendations apply to sound level meters for general purposes.

They do not apply to apparatus for measuring sounds of very short duration or discontinuous sounds.

Note: Further recommendations applying to precision sound level meters are in preparation.

2. Object

2.1 In view of the difficulty of establishing a quantitative measurement of a sensation and of the complexity of operation of the human ear, it is not possible in the present state of the art to design an objective noise measuring apparatus giving results which are absolutely comparable, for all types of noise, with those given by direct subjective methods.

2.2 However, it is considered essential to standardize an apparatus by which noises can be so measured that users of this apparatus throughout the world may compare their results.

2.3 The object of the present recommendations is therefore to specify the characteristics of an apparatus to measure certain weighted sound pressure levels. The weighting applied to each sinusoidal component of the sound pressure is given as a function of frequency by three standard reference curves, called A, B and C.

2.4 In practice, measurements may have to be made under very different conditions, ranging from the free field of a single source to a completely diffuse field.

2.5 In order to simplify the procedure for the calibration and checking of the apparatus, these recommendations are written primarily in terms of the free field response.

2.6 This apparatus will be called:
"sonomètre" in French,
"sound level meter" in English,
"шумомер" in Russian.

3. Definitions

3.1 For the definitions of the terms employed, reference should be made to the International Electrotechnical Vocabulary, Group 08, Electro-acoustics (I.E.C. Publication 50 (08)).

3.2 The weighted sound level is defined by:

$$20 \log_{10} \frac{p_a}{p_o}$$

where p_a is the r.m.s. sound pressure due to the sound being measured weighted in accordance with the curves A, B or C and p_o is the reference pressure (2.10^{-5} N/m² = 2.10^{-4} dyne/cm²).

Note: This definition is in accordance with ISO Recommendation R 131.

3.3 The weighted sound levels are expressed in decibels; the weighting curve used shall always be stated (e.g. sound level A = x dB or sound level = x dB (A)).

4. General technical characteristics

4.1 A sound level meter is generally a combination of a microphone, an amplifier, certain weighting networks, an attenuator and an indicating instrument having certain dynamic characteristics.

4.2 The sound level meter shall cover the frequency range 31.5 to 8 000 Hz (c/s).

4.3 It shall include at least one of the three different response curves called A, B and C. These curves shall pass through the points given in Table II, page 21, within the tolerances indicated.

Although these weightings approximate very roughly certain properties of the ear, they are to be considered merely as conventional. The tolerances permitted are relatively large. The tendency is to narrow them and if a manufacturer is able to offer closer tolerances this fact should be stated.

The tolerances relate to the whole apparatus, i.e. they include the tolerances relating to the microphone, the amplifier, the weighting networks, the attenuator, if present, and the indicating instrument; they apply to the functioning of the apparatus in a free sound field in a particular direction which shall be specified by the manufacturer.

It is recommended that the manufacturer should also indicate means for ensuring that the meter reads correctly in a diffuse sound field.

4.4 If the sound level meter is designed to use more than one of the three weighting curves A, B and C, defined in Clause 4.3, it shall allow measurements to be made with any of the curves, at all sound levels within the range of the apparatus.

4.5 If the sound level meter is intended for use over a total interval of more than 30 dB it shall have more than one sensitivity range. It is recommended that the attenuator be in 10 dB steps. Each range shall overlap its neighbour by at least 5 dB.

5. Microphone characteristics

5.1 The microphone shall be of the omnidirectional type.

5.2 The variation of the sensitivity of the microphone over an angle up to ± 90° from the direction specified by the manufacturer for this purpose in Clause 4.3, shall not exceed the values given in Table I.

TABLE I

Permissible tolerances on microphone sensitivity over an angle of ± 90°

Frequency Hz (c/s)	Permissible tolerances dB	
	A	B
31.5-500	± 1	± 1
1 000	± 1.5	+ 1 − 2
2 000	± 4	+ 1 − 6
4 000	± 8	+ 1 − 8
8 000	± 15	+ 1 − 15

Two series of permissible tolerances for microphone sensitivity over an angle of ± 90° are given according to whether the measurements are made with the microphone mounted on the sound level meter case or with the microphone alone, physically spearated from the sound level meter proper, but electrically connected thereto.

The values given in *Column A* refer to measurements made with the microphone mounted on the sound level meter as for use, any observer being effectively outside the sound field.

The values given in *Column B* refer to measurements made on the microphone alone, physically separated from the sound level meter proper, but electrically connected thereto, any observer being effectively outside the sound field.

6. Characteristics of the indicating instrument

6.1 The indicating instrument shall be of the square-law type.

6.2 The scale of the indicating instrument shall be graduated in steps of 1 dB, if possible over an interval of at least 15 dB.

6.3 It is recommended that the scale of the indicating instrument be graduated from − 5 to + 10 dB.

6.4 The error introduced by a change of range shall be less than 1 dB.

6.5 For the first five divisions of the scale of the indicating instrument, the accuracy of the graduation shall be ± 1 dB. For the other divisions, the accuracy shall be ± 0.5 dB. It shall also be possible to read to the same accuracy.

6.6 The sound level meter shall possess the following overall dynamic characteristics, which may be designated as *Fast:*

6.6.1 If a pulse of sinusoidal signal having a frequency of 1 000 Hz (c/s) and a duration of 0.2 second is applied, the maximum reading shall be 1 dB less than the reading for a steady signal of the same frequency and amplitude; tolerances are allowed such that the maximum reading may be equal to the steady reading, or at the most 4 dB lower.

6.6.2 If a sinusoidal signal, at any frequency between 31.5 and 8 000 Hz (c/s), is suddenly applied and thereafter held constant, the maximum reading shall exceed the final steady reading by 0.6 ± 0.5 dB.

6.7 The sound level meter may also be provided with the following overall dynamic characteristics which may be designated as *Slow:*

6.7.1 If a pulse of sinusoidal signal of frequency 1 000 Hz (c/s) and duration 0.5 second is applied, the maximum reading shall be 4 ± 2 dB less than the reading for a steady signal of the same frequency and amplitude.

6.7.2 If a sinusoidal signal, at any frequency between 31.5 and 8 000 Hz (c/s), is suddenly applied and thereafter held constant, the maximum reading shall exceed the final steady reading by 0.6 (+ 1, − 0.5) dB.

6.7.3 The steady reading for any sinusoidal signal between 31.5 and 8 000 Hz (c/s) shall not differ from the corresponding *Fast* reading by more than 0.1 dB.

6.8 The characteristics specified in Clauses 6.6 and 6.7 shall be maintained for all weightings and all settings of the attenuator.

6.9 It is recommended that the dynamic characteristic used be stated in the test report.

7. Amplifier characteristics

7.1 For electrical calibration it is recommended that a resistance of known value be inserted in series with the earth lead of the microphone, and that convenient means be provided for connection to it.

7.2 If the sound level meter is battery operated, a suitable means shall be provided for checking the battery voltages under load.

7.3 If the sound level meter can also be used with a cable between microphone and amplifier, the corrections corresponding to this method of use shall be stated by the manufacturer.

7.4 When the microphone is replaced by an equivalent electrical impedance, the basic noise voltage shall be at least 5 dB lower than the voltage corresponding to the minimum sound level measurable, whichever of the weighting curves be used.

7.5 When the microphone is replaced by an equivalent electrical impedance and when the sound level meter is placed in a sound field, the reading of the sound level meter shall be at least 10 dB below that which would be obtained in normal operation. This condition shall be fulfilled for the whole range of the scale of the indicating instrument, whatever the sound level, for all frequencies between 31.5 and 8 000 Hz (c/s).

7.6 The effects of vibration shall be reduced as far as possible.

7.7 The effects of magnetic and electrostatic fields shall be reduced as far as possible.

7.8 The temperature range over which the calibration of the complete apparatus, including the microphone, is not affected by more than 1 dB shall be specified by the manufacturer. If the effect of temperature is greater than 1 dB the corrections to be applied shall be stated by the manufacturer.

7.9 The range of humidity over which the complete apparatus, including the microphone, is intended to operate shall be specified by the manufacturer.

7.10 The amplifier shall have a power handling capacity at least 10 dB greater than that corresponding to the maximum reading of the indicating instrument.

7.11 When provision is made to connect external apparatus having a specified impedance to the sound level meter, for example headphones, this connection shall not affect the indication by more than 1 dB; otherwise the indicating instrument shall be disconnected automatically.

8. Calibration and checking of the characteristics of the sound level meter

8.1 The complete sound level meter shall be calibrated at frequencies covering the range 31.5 to 8 000 Hz (c/s), in a sound field consisting of sensibly plane progressive waves, arriving at the microphone in the direction of incidence specified by the manufacturer. Any observer shall be effectively outside the sound field. If it is necessary to use the extension cable mentioned in Clause 7.3 to satisfy the requirements, this fact shall be stated.

8.2 It is also useful to determine the sensitivity of the complete apparatus for a diffuse sound field. This sensitivity is defined as the root-mean-square value of the free-field sensitivities for all orientations. For this purpose it is sufficient to measure the sensitivity of the microphone at angles of incidence of 0°, 30°, 60°, 90°, 120°, 150° and 180° from the direction specified in Clause 4.3 and to calculate the sensitivity for a diffuse sound field by the following formula:

$$S^2 = K_1 S_0^2 + K_2 S_{30}^2 + K_3 S_{60}^2 \ldots\ldots\ldots\ldots + K_7 S_{180}^2$$

where S = sensitivity for a diffuse sound field (given for example in mV/dyne/cm²)

$S_0, S_{30}, S_{60}, \ldots\ldots\ldots\ldots S_{180}$ = sensitivities at the respective angles.

$K_1 = K_7 = 0.018,$

$K_2 = K_6 = 0.129,$

$K_3 = K_5 = 0.224,$

$K_4 = 0.258.$

The sensitivity for a diffuse sound field shall be determined at least at the frequencies 250, 500, 1 000, 2 000, 4 000 and 8 000 Hz (c/s).

8.3 Conformity with the requirements relating to the dynamic characteristics of the indicating instrument (Clauses 6.6 and 6.7) shall be checked at a steady reading of the indicating instrument 4 dB less than the full-scale reading.

This check shall be made by applying an electrical signal to the amplifier, preferably in series with the microphone, for all the weighting curves provided.

8.4 The verification of the quadratic law of addition (value indicated = square root of the sum of the mean-square values of the individual components) shall be effected by using a two-tone generator, or a similar arrangement for providing two non-harmonic frequencies first successively and then simultaneously. The measurements shall be made for different combinations of non-harmonic frequencies and different positions of the level switch. For this purpose an electrical signal of frequency f_1, the root-mean-square value of which is adjusted to give a certain reading x on the indicator, shall be applied at the microphone input to the amplifier. The signal f_1 shall then be replaced by a signal f_2, fulfilling the conditions previously specified, and the r.m.s. value of the signal f_2 shall be adjusted to give the same reading x on the indicating instrument.
The two signals of frequency f_1 and f_2, with the r.m.s. values previously used, shall then be applied simultaneously and the reading y of the indicating instrument noted. Under these conditions the following relation shall obtain:

$$y = x + 3 \text{ dB}$$

It is recommended that this relation should be satisfied to within $\pm$ 0.25 dB. This test shall be made for a value of the reading x = 7 dB below the full-scale reading of the indicating instrument.

8.5 The scale calibration of the indicating instrument (Clause 6.5) shall be checked by an electrical method at frequencies of 31.5, 1 000 and 8 000 Hz (c/s).

8.6 The accuracy of the indications on the attenuator shall be checked by applying sinusoidal voltages of adjustable amplitude and of frequencies 31.5, 1 000 and 8 000 Hz (c/s). In each case the error shall be less than 1 dB with respect to a reading of 80 dB.

9. Marking

9.1 The apparatus shall carry the marking *Sound Level Meter*.

9.2 It shall also be marked at least with

- the manufacturer's name
- the type
- the serial number
- an indication of the range of sound pressure levels that it is designed to measure.

10. Descriptive leaflet

10.1 Each sound level meter shall be accompanied by a descriptive leaflet which includes the following information:

- the type of microphone (electrostatic, moving coil, etc.) its serial number and other manufacturing references,
- the angle of incidence specified in Clause 4.3,
- the response curves given in Clause 4.3,
- the dynamic characteristics *(Fast-Slow)* given in Clauses 6.6 and 6.7,

— the effects of vibration, magnetic and electrostatic fields, temperature and humidity on the indications on the sound level meter,

— the limits of temperature and humidity beyond which permanent damage may be caused to the apparatus

— any correction to the calibration required by the use of a microphone extension cable.

10.2 It is recommended that the following information be also included in the descriptive leaflet:

— the impedance of the microphone,

— the sensitivity of the microphone as a function of frequency for the angle of incidence specified by the manufacturer, as in Clause 4.3,

— the directional characteristics of the microphone at the frequencies given in Clause 5.2,

— the sensitivity for a diffuse sound field calculated by the method given in Clause 8.2,

— a warning that the presence of an observer in the sound field in proximity to the microphone may affect the accuracy of the measurements, particularly at the higher frequencies.

TABLE II

Response of the sound level meter in a free field relative to the true sound pressure level for the angle of incidence specified in Clause 4.3

Frequency Hz (c/s)	Curve A dB	Curve B dB	Curve C dB	Tolerances dB	
10	−70.5	−38.5	−14.5	5	−∞
12.5	−63.4	−33.4	−11.4	5	[illegible]
16	−56.7	−28.7	−8.6	5	−∞
20	−50.4	−24.4	−6.3	5	−∞
25	−44.6	−20.5	−4.5	5	−∞
31.5	−39.2	−17.2	−3.0	5	−5
40	−34.5	−14.2	−2.0	4.5	−4.5
50	−30.2	−11.7	−1.3	4	−4
63	−26.1	−9.4	−0.8	4	−4
80	−22.3	−7.4	−0.5	3.5	−3.5
100	−19.1	−5.7	−0.3	3.5	−3.5
125	−16.1	−4.3	−0.2	3	−3
160	−13.2	−3.0	−0.1	3	−3
200	−10.8	−2.1	0	3	−3
250	−8.6	−1.4	0	3	−3
315	−6.5	−0.9	0	3	−3
400	−4.8	−0.5	0	3	−3
500	−3.2	−0.3	0	3	−3
630	−1.9	−0.1	0	3	−3
800	−0.8	0	0	2.5	−2.5
1 000	0	0	0	2	−2
1 250	0.6	0	0	2.5	−2.5
1 600	1.0	−0.1	−0.1	3	−3
2 000	1.2	−0.2	−0.2	3	−3
2 500	1.2	−0.3	−0.3	4	−3
3 150	1.2	−0.5	−0.5	5	−3.5
4 000	1.0	−0.8	−0.8	5.5	−4
5 000	0.5	−1.2	−1.3	6	−4.5
6 300	−0.1	−2.0	−2.0	6	−5
8 000	−1.1	−3.0	−3.0	6	−6
10 000	−2.4	−4.2	−4.3	6	−∞
12 500	−4.2	−6.0	−6.0	6	−∞
16 000	−6.5	−8.3	−8.4	6	−∞
20 000	−9.2	−11.0	−11.1	6	−∞

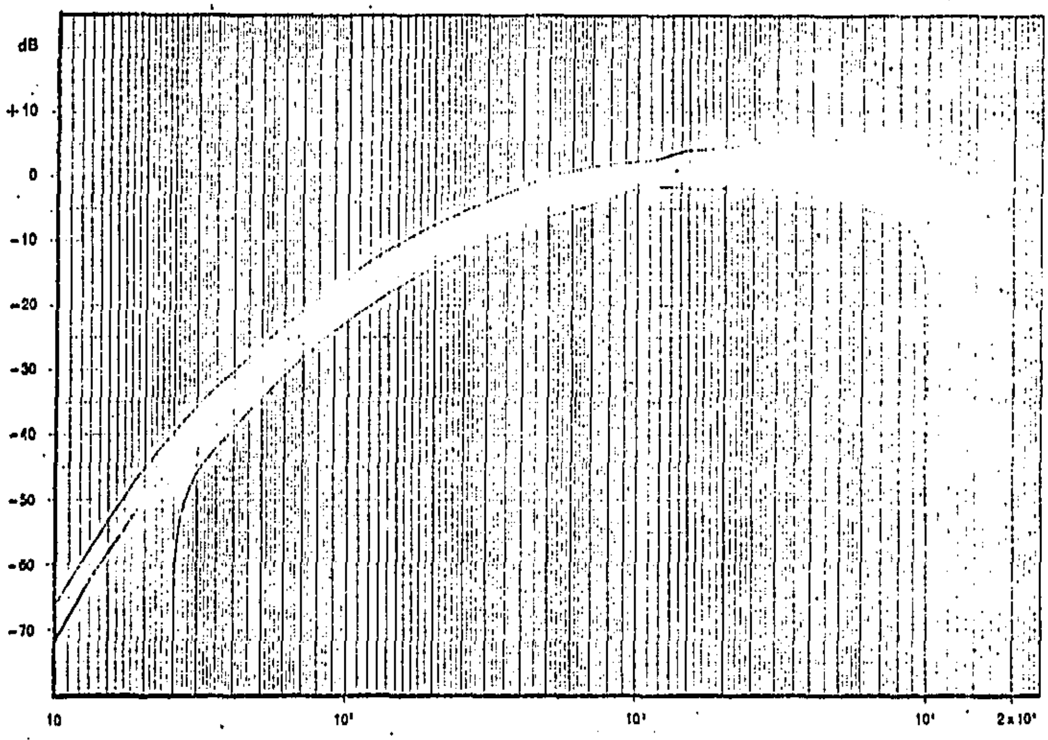

Fig. 1. Courbe de pondération A.
Weighting curve A.

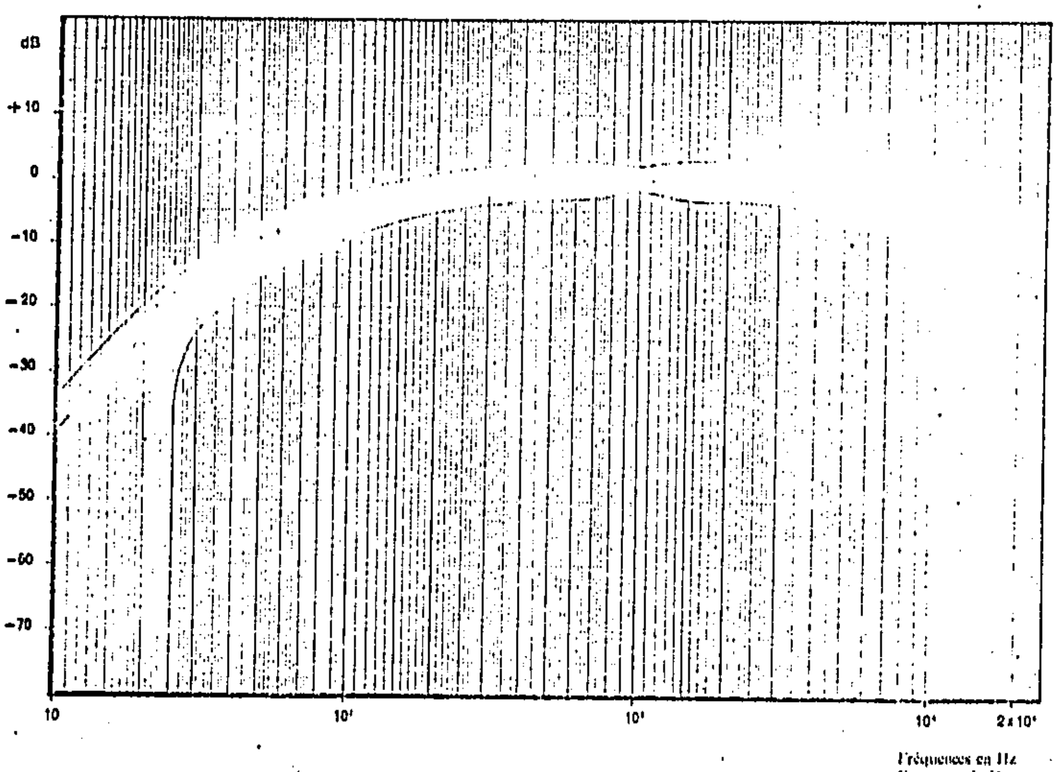

Fig. 2. Courbe de pondération B.
Weighting curve B.

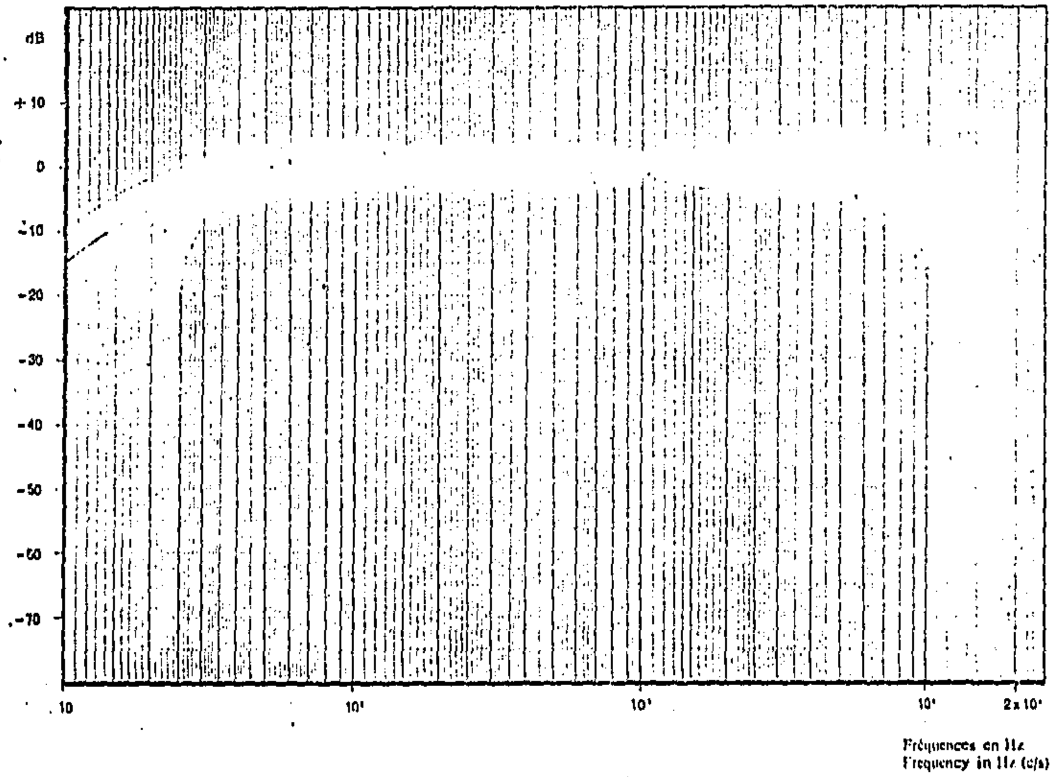

Fig. 3. Courbe de pondération C.
Weighting curve C.

12/27/73

(1)

(FROM NTID 300.13 TRANSPORTATION NOISE ... 12/31/71)

- 1st gen. 4-eng. lo-bypass engine A/C constitute 30% of total operations
  - contribute ~~[illegible]~~ 69% of total noise impact area (NEF-30 + higher)

NEF ≥ 40, residential use incompatible with airport noise

for NEF 30; 1450 sq mi in U.S. (1970)

e.g. – consider a fleet of

10	707's	110 actual
15	727's	104 actual
8	DC-10's	98 actual

if we allowed the 1/2 figure to represent the total no. of A/Ps, the 8 DC-10's would be a good start toward that 1/2

a.) i.e. 8 of 33 is about 1/4, by treating only 9 of the 727's, operator could meet the 1/2 figure ~~by~~ without doing a thing to the 707's.

b.) if we required at least half of each type to be properly engine/nacelled, then he would have to do 8 727's and 5 707's

now, note the difference in FNL for the two conditions!

a

Type	90-Day N	Noise Level Actual
3 u	179	110
2 u	9/15(211): 84	104
2 t	9/15(211): 127	96
1	147	98

NFL =

b

Type	90-day N	Noise Level Actual
3 u	189	110
3 t	140	101
2 u	7/15: 98	104
2 t	8/15: 112	96
1	147	98

u untreated t – treated

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Performing Organization: US ARMY MATERIEL COMMAND INTERN TRAINING CENTER, RED RIVER ARMY DEPOT, TEXARKANA, TEX. 75501

Title: AN EVALUATION OF HIGH LEVEL NOISE AND ITS REDUCTION IN A 3000 BTU/HR GASOLINE-ENGINE-POWERED FIELD REFRIGERATION UNIT.

Author(s): WILLIAM C. BROWN.

Responsible Individual: DR GEORGE D. C. CHIANG
Telephone Number: AV 829-3535

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JEAN DRAKE (214) 838-2573 838-2168 829-3535 829-3535 AV

Abstract: THIS REPORT DESCRIBES THE RESULTS OF RESEARCH INTENDED TO DETERMINE THE SOURCES OF HIGH LEVEL AIRBORNE NOISE TRANSMITTED FROM A 3000 BTU/HR MOBILE REFRIGERATION UNIT USING AN AIR-COOLED ENGINE AS THE PRIME MOVER. AN ELECTRIC MOTOR WAS ADAPTED TO POWER THE UNIT AND THE MAJOR NOISE PRODUCING COMPONENTS OF THE SYSTEM (COMPRESSOR, MOTOR, FAN) WERE ANALYZED SEPARATELY TO DETERMINE THEIR CONTRIBUTION TO THE OVERALL NOISE.

Conclusions: UNACCEPTABLE NOISE LEVELS ARE PRODUCED BY THE 3000 BTU/HR PORTABLE REFRIGERATION UNIT.

Recommendations: NUMEROUS RECOMMENDATIONS RELATED TO REDUCTION OF NOISE LEVELS ARE CONTAINED IN THIS DOCUMENT. THEY ARE TOO LENGTHY TO LIST HERE.

~~MR HUNT 274-8620~~

Date Published: 04/7[illegible]
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Abstract: AS MODERN ELECTRONIC CIRCUIT NETWORKS INCREASE RAPIDLY IN SIZE, AND THEIR CONTENTS ARE BECOMING MORE SOPHISTICATED, THE NEED FOR EMPLOYING THE POWERFUL TOOL OF COMPUTER SIMULATION TO ELECTRONIC CIRCUIT NETWORK DESIGN AND ANALYSIS BECOMES MORE APPARENT. COMPUTER SIMULATION OFFERS SEVERAL ADVANTAGES TO THE DESIGNERS OF ELECTRONIC CIRCUITS. THIS REPORT IS THE RESULT OF A SURVEY ON A FEW COMPUTER-AIDED ELECTRONIC CIRCUIT ANALYSIS PROGRAMS. THE CHARACTERISTIC FEATURES AND ANALYSIS CAPABILITIES OF EACH PROGRAM ARE DISCUSSED IN DETAIL. THE COMMON ASPECTS AMONG THE PROGRAMS ARE TABULATED FOR EASY COMPARISON. THE ACTUAL COMPUTER PROGRAM EXECUTIONS OF TWO EXAMPLE CIRCUIT NETWORKS ARE INCLUDED. THE PROGRAMS SURVEYED ARE ECAP, ECAP-II, CIRCUS, CIRCUS-II, SCEPTRE, ASTAP, BELAC, SYSCAP, CORNAP AND SCAP.

Conclusions: SELECTION OF AN OPTIMUM CIRCUIT ANALYSIS PROGRAM DEPENDS UPON THE COMPUTER SYSTEM AVAILABLE TO A POTENTIAL USER, AND UPON HIS PARTICULAR NEEDS FOR THE PROGRAM.

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Performing Organization: US ARMY MATERIEL COMMAND INTERN TRAINING CENTER, RED RIVER ARMY DEPOT, TEXARKANA, TEX. 75501

Title: AN ALTERNATE INVENTORY CONTROL POLICY FOR THE UNITED STATES ARMY DIRECT EXCHANGE SYSTEM.

Author(s): TIMOTHY D. SISLEY.

Responsible Individual: T. F. HOWIE
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ANSI S1.13-1971

American National Standard

methods for the measurement of sound pressure levels

S1.13-1971

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S1.13-1971

Partial Revision
of S1.2-1962 (R1971)

American National Standard Methods for the Measurement of Sound Pressure Levels

Secretariat

Acoustical Society of America

Approved July 14, 1971

American National Standards Institute, Inc

American National Standard

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Foreword

(This Foreword is not a part of American National Standard Methods for the Measurement of Sound Pressure Levels, S1.13-1971.)

This standard comprises a part of a group of definitions, standards, and specifications for use in acoustical work. It has been developed under the Standards Committee method of procedure, under the sponsorship of the Acoustical Society of America.

American National Standards Committee S1, under whose jurisdiction this standard was developed, has the following scope:

> Standards, specifications, methods of measurement and test, and terminology in the fields of physical acoustics, including architectural acoustics, electroacoustics, sonics and ultrasonics, and underwater sound, but excluding those aspects which pertain to safety, tolerance and comfort.

Various subcommittees have been organized to take care of the committee's program, and this standard was developed by Working Group S1-51.

This standard is a revision of Section 2 of American National Standard Method for the Physical Measurement of Sound, S1.2-1962 (R 1971).

Suggestions for improvement gained in the use of this standard will be welcome. They should be sent to the American National Standards Institute, 1430 Broadway, New York, N.Y. 10018.

Standards Committee S1, Acoustics, had the following personnel at the time it approved this standard:

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W. W. Lang, Vice-Chairman
Avril Brenig, Secretary

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W. Rudmose
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Working Group S1-51, Noise Measurement, which developed this standard had the following membership:

William W. Lang, *Chairman*

Peter K. Baade
Tony F. W. Embleton
Reg A. Kaenel
George C. Maling, Jr
Alan H. Marsh

Contents

SECTION PAGE

American National Standard Methods for the Measurement of Sound Pressure Levels

Introduction

(The material in this Introduction is intended for purposes of background and orientation.)

This standard is concerned with the measurement of sound pressure levels in air under a variety of conditions. The sound to be measured is frequently undesired (that is, noise). The basic purpose of this standard is to establish uniform procedures for obtaining sound pressure level data.

Sound pressure levels to be measured fall into two broad categories: those that are due to a specific source and those that characterize an ambient environment where the sound is usually generated by many sources. It is not always possible to make a clear distinction between these two categories. For example, the ambient noise in a community is often generated by many different sources, but primary concern may be focused on one particular source. In neighborhood A, the noise generated by the source may be masked by the ambient noise, while in neighborhood B, it may be audible. The ambient noise thus is important as a reference level for the evaluation of the noise from a particular source.

Even if the ambient noise has a low level, the measurement of sound pressure level does not always suffice for the quantitative evaluation of a source because the magnitude of the sound pressure level will depend upon the distance from the source, the directivity of the source, and the acoustic environment. For this reason, the total acoustic power radiated by a source of sound may provide a better measure of source output. Since acoustic power is usually calculated from measured values of sound pressure which depend on the acoustic environment, it is necessary to design and calibrate the measurement environment carefully if the accuracy required for sound ratings and comparisons is to be achieved. All aspects of the determination of sound power of sources are covered by other American National Standards. This standard specifically excludes those sound pressure level measurements which are obtained in order to permit calculation of the sound power radiated by a source.

Primary interest in this standard is focused on sound pressure level data which are obtained for their own sake. Since the human ear is a pressure-sensitive device, sound pressure level data are frequently sufficient to satisfy the purposes of the measurements.

This standard deals exclusively with objective methods of measurement. In many situations, it is desirable to make quantitative assessments of the subjective effects of noise on human beings. The measurements described here yield the physical data that are required for assessing the effects of noise but the assessment techniques themselves (for example, methods for calculating loudness, noise ratings with respect to the conservation of hearing, speech interference and noisiness, predictions of structural failure) are not included.

This standard describes three methods that can be used for measuring sound pressure levels (see Table 1). One method uses a relatively simple, portable instrument; the other two methods require more extensive instrumentation, but yield more detailed information. The choice of the method to be used for a specific measurement program will depend on the objectives of the program.

The techniques for measuring airborne sound pressure levels are summarized in Fig. 1. In planning a series of sound pressure measurements, it is imperative that the purpose of the measurements be kept clearly in mind. In Fig. 1, the purposes of a program of sound pressure level measurements are shown to be either for characterizing a sound source or an ambient sound field. In either case, if the objective is to obtain data on which engineering changes to the source (or sound field) are to be based, band pressure levels are required. On the other hand, if the purpose of the measurements is to obtain a quantity that relates the magnitude of the sound stimulus to an estimate of the effect of the noise on man, a simpler measurement (such as a weighted sound pressure level) may be all that is necessary.

The three different methods for sound pressure level measurements described in this standard are summarized in Table 1. The method to be selected depends upon the thoroughness of the description required for the purposes of the measurements. A thorough description requires an analysis of the sound pressure levels in narrow frequency bands from measurements made at suitable microphone locations over an appropriate time interval with the best available instrumentation. In other situations, a simplified measuring procedure may be entirely adequate for the purposes of the measurements.

The *survey method* that utilizes a hand-held sound-level meter is the least time-consuming but provides comparatively little information, that is, the weighted sound pressure level. No effort is made to control the acoustic environment; that is, the environment is in an "as is" condition, indoors or outdoors.

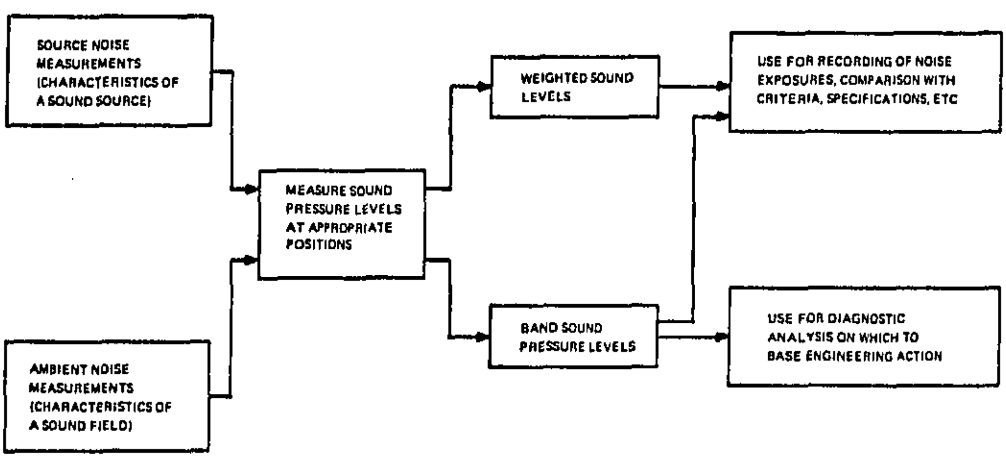
The *field method* utilizes equipment for frequency-band analysis and the acoustic environment may be modified to make it approach known conditions of measurement, or it may be in an "as is" condition either indoors or outdoors. For example, if measurements on a single machine are to be made in a machine shop, the environment may be left "as is" in a reverberant condition so that the room has an effect on the sound pressure levels at the various microphone positions. Alternatively, the environment may be controlled to a degree by covering some of the room surfaces with sound absorptive materials. The effect of the room on the sound pressure level measurements may then be reduced.

The *laboratory method* requires the use of the best

Table 1
Three Methods for Sound Pressure Measurements Described in This Standard

Measurement Method	Instrumentation	Environment	Location
Survey	Sound-level meter	"As is"; not controlled	Indoors or outdoors
Field	Instruments that meet requirements of applicable American National Standards	"As is" or semi-controlled with minor changes to add absorptive materials, remove reflecting objects, etc	Indoors or outdoors
Laboratory	Laboratory instruments that meet requirements of American National Standards	Controlled environment: anechoic or semi-anechoic room	Laboratory (indoors)

Fig. 1
Classification of Airborne Noise Measurements According to Purpose



available, laboratory-grade instrumentation. The frequency-band analysis is carried out under carefully controlled environmental conditions in a laboratory so that the effect of the room on the sound pressure level measurements may be precisely determined. The laboratory method is primarily used for source measurements.

The two types of noise encountered in practice are given below:

(1) Steady Noise
  Without audible discrete tones
  With audible discrete tones
(2) Nonsteady Noise
  Fluctuating noise
  Intermittent noise
  Impulsive noise
    Isolated bursts
    Quasi-steady noise

Steady noise is relatively constant over a long period of time and may or may not contain audible discrete tones. If none of the frequencies is audibly distinguishable from the others, the noise is wide-band and "unpitched." Nonsteady noise may be either fluctuating (that is, does not remain at any constant level during the period of observation), intermittent (that is, returns to the ambient level during the period of observation) or impulsive. These different types of noise require different measurement techniques which are described in detail in this standard.

The particular method selected for measuring noise thus depends upon:

(1) The nature and location of the noise source(s)

(2) The use to be made of the results of the measurements

(3) The type of noise to be measured

(4) The time and equipment available for the measurements, and

(5) The skill of the individual conducting the measurements

Before making a decision on measurement method and instrumentation system, the individual who intends to carry out a program of sound pressure level measurements should ask himself the following general questions:

(1) What do I want to know?

(2) What will I do with the data obtained?

(3) How accurate do I expect the data to be?

The answers to these questions and consideration of the five preceding items should provide guidance on the method to be chosen for the measurements and the instrumentation system to be selected.

This standard classifies the purposes of the measurements, identifies different kinds of commonly encountered noises, describes techniques for measuring and reporting steady and nonsteady noises as well as the instrumentation systems suitable for such measurements, and includes general guidelines for noise measurements in the field and in the laboratory.

1. Scope and Purpose

1.1 Scope

1.1.1 General recommendations are given to assist in the development of noise measurement techniques that are satisfactory for use under various environmental conditions.

1.1.2 The measurement of sound produced by sources which radiate directly into the air is given first priority. The airborne sound pressures may be partially attributable to sound transmission along structural pathways and reradiation from solid (or fluid) bodies.

1.1.3 Primary consideration is given to the measurement of sound created as a by-product of the principle function of the source. The methods may also be applied to other sources which are intended to generate sound. For example, measurements may be desired of the sound pressure generated by an alarm device operating in the presence of multiple noise sources.

1.1.4 This standard does not consider sound pressure level measurements which are obtained for the purpose of determining the sound power radiated by a source.

1.2 Purpose. The purpose of this standard is to provide uniform guidelines for measuring and reporting sound pressure levels observed under different environmental conditions. This standard is applicable to the many different types of sound pressure level measurements commonly encountered in practice. This standard is intended to assist in the preparation of test codes for: 1) determining compliance with a specification, ordinance, or acoustical criterion, and 2) obtaining information to assess the effects of noise on people or equipment.

2. Definitions

ambient noise. The all-encompassing noise associated with a given environment, being usually a composite of sounds from many sources near and far.

discrete tone. A sound wave whose instantaneous sound pressure varies essentially as a simple sinusoidal function of time.

fluctuating noise. A noise whose sound pressure level varies significantly but does not equal the ambient environmental level more than once during the period of observation.

impulsive noise. A noise characterized by brief excursions of sound pressure (acoustic impulses) which significantly exceed the ambient noise. The duration of a single impulse is usually less than one second.

intermittent noise. A noise whose sound pressure level equals the ambient environmental level two or more times during the period of observation. The period of time during which the level of the noise remains at an essentially constant value different from that of the ambient is on the order of one second or more.

nonsteady noise. A noise whose sound pressure level shifts significantly during the period of observation.

period of observation. The time interval during which acoustical data are obtained. The period of observation is determined by the characteristics of the noise being measured and should be at least ten times as long as the response time of the instrumentation. The greater the variation in indicated sound level, the longer must be the observation time for a given expected precision of the measurement.

sound level (noise level). Weighted sound pressure level obtained by the use of a metering characteristic and the weightings A, B, C (or other) as specified in the referenced standards (see Section 12). The weighting employed must be indicated. Unit: decibel (dB).

sound pressure level. Twenty times the logarithm to the base 10 of the ratio of the pressure of a sound to the reference sound pressure. Unless otherwise specified, the effective (rms) pressure is to be understood. The reference sound pressure is 20 $\mu N/m^2$. Unit: decibel (dB).

steady noise. A noise whose sound pressure level remains essentially constant (that is, fluctuations are negligibly small) during the period of observation.

3. Acoustic Environments

3.1 General. The sound pressure observed in the vicinity of the source may be influenced by the acoustic environment in which the source is operating. Small changes in orientation of the source may result in appreciable changes in the sound pressure level. It is imperative that the influence of the environment on the measurement of sound pressure level be considered.

3.2 Types of Measurements

3.2.1 Ambient Noise Measurements. Measurements of ambient noise are commonly made both outdoors and indoors. The observed sound pressure is usually a superposition of the sound pressures generated by many sources at different locations. In this type of measurement, it is the total sound pressure that is of interest rather than the sound pressure generated by any of the individual sources operating in the environment. A statistical description of the combined noise level produced by all of the sources operating simultaneously is frequently of interest. Typical ambient environments are given in *Table 2*.

3.2.2 Source Measurements. This type of measurement involves the determination of the sound pressure level produced by a source, located either outdoors or indoors. The source of interest will frequently be operating in the presence of other sources. The other sources establish the ambient noise. Typical sources are also listed in Table 2.

3.2.3 Example. The noise levels of a large city are frequently controlled by vehicular traffic (ambient environmental noise). If interest is focused on individual vehicles in the traffic, source measurements are necessary.

3.3 Environmental Factors Influencing Ambient Noise Measurements

3.3.1 Outdoors. The sound pressure levels measured outdoors will be influenced by:

(1) Sound absorption by the surface of the ground

Table 2
Typical Ambient Environments and Sources

Ambient Environment	Source
Outdoors	
Highway	Pneumatic tools
Residential neighborhood	Industrial machines
Airport	Stationary engines
	Equipment used by utilities: transformers, regulators, etc
	Ground vehicles
	Aircraft
	Boats and ships
Indoors	
Factories	Hand tools
Offices	Appliances
Schools	Industrial machines
Hospitals	Household equipment
Dwellings	

(2) Shape of the land contours

(3) Scattering from and absorption by objects such as buildings, trees, and people

(4) Inhomogeneities in the atmosphere (turbulence, wind gradients, and temperature gradients)

(5) Air absorption (ambient temperature and humidity)

(6) Time of day

3.3.2 Indoors. The sound pressure levels measured inside buildings will be influenced by:

(1) Sound reflection and absorption by the interior surfaces

(2) Reflections from and absorption by objects within the building, such as furniture and people

(3) External noise sources and the transmission characteristics of the structure

(4) Air absorption (ambient temperature and humidity)

3.4 Environmental Factors Influencing Source Measurements

3.4.1 General. Accurate measurements of sources are complicated because the pattern of sound radiation depends upon several environmental factors.

3.4.1.1 Radiation in a Free Field. At large distances from a source in a reflection-free, homogeneous, nondissipative space, the sound pressure varies inversely with the distance from the source; that is, the sound pressure level will decrease six decibels each time the distance from the acoustic center of the source is doubled. If the source is large compared with the wavelength of the sound it radiates, the general trend of pressure will be to decrease as the distance from the source is increased, but sound pressure maxima and minima may occur in the vicinity of the source.

3.4.1.2 Effect of a Reflecting Plane. When the sound source is located near a reflecting plane, sound waves reflected from the plane will interfere with those coming directly from the source. The general trend of the pressure will be to decrease as the distance from the source is increased and sound pressure maxima and minima will occur due to interference.

3.4.1.3 Radiation Within a Room. When a sound source radiates into a room, the sound will be reflected back and forth many times from the room surfaces; these reflections create complicated sound field. At any point within the room, the sound pressure may be considered to be the resultant of two coincident sound fields: the direct sound field which comes directly from the source without being first reflected, and the reverberant sound field. The reverberant sound field is itself the superposition of many sound waves which may interfere to produce spatial and temporal variations in sound pressure.

3.4.2 Optimal Conditions Outdoors. To realize optimal conditions outdoors for sound pressure measurements above a reflecting plane, the following requirements shall be met:

3.4.2.1 Extent of Reflecting Plane. A hard, smooth, massive plane surface shall extend from the source under test at least a distance $\lambda/2$ beyond the farthest microphone position, where λ is the wavelength of the sound at the lowest frequency of interest.

3.4.2.2 Absorption Coefficient of Reflecting Plane. The normal-incidence sound absorption coefficient of the reflecting plane shall not exceed 0.1 over the frequency range of interest (concrete or asphalt surfaces usually meet this requirement).

3.4.2.3 Obstacles and Reflecting Surfaces. No obstacles or reflecting surfaces with major dimensions greater than $\lambda/4$ (other than the ground) shall be within 5λ of the source, or within 5λ or $5r$ of the microphone positions, whichever is the greater, where λ is the wavelength of sound at the lowest frequency of interest and r is the distance from the farthest measurement position to the center of the source.

3.4.2.4 Atmospheric Conditions. The atmosphere shall be homogeneous to a height of 10 m above the ground or to the height of the source, whichever is greater, with a uniform negative temperature gradient and with no wind gradients. If measurements must be made under conditions with positive temperature gradients (thermal inversions), the positive temperature gradient shall not exceed 2°C per 300 m of height and the wind gradient shall not exceed 3 m/s per 300 m of height. Measurements shall not be made when the wind speed exceeds 6 m/s.

3.4.3 Optimal Conditions Indoors. Optimal conditions exist indoors in a free-field or anechoic room. Within the frequency range of interest, the sound waves reflected from the surfaces of the room make a negligible contribution (that is, less than 0.2 dB) to the sound pressure level at the point of observation. To realize free-field conditions in an enclosure, the test room shall meet the following requirements:

3.4.3.1 Size of Test Room. The dimensions of the anechoic room shall be large enough so that the microphones can be placed in the far radiation field of the sound source under test and at least $\lambda/4$ distant from the absorptive surfaces of the anechoic room, where λ is the wavelength of sound at the lowest frequency of interest.

NOTE: A useful rule of thumb is that the far radiation field exists under optimal conditions at distances greater than four times the largest source dimension. This does not imply that distances less than four times the largest source dimension are necessarily in the near field.

3.4.3.2 Absorption Coefficient of Test Room. The average normal-incidence sound absorption coefficient of all surfaces of the anechoic room should be equal to or greater than 0.99 over the frequency range of interest. The absorptive treatment shall be uniformly distributed over all of the surfaces. Most anechoic rooms with absorptive wedges at least 1 m long meet this criterion at frequencies above 100 Hz.

3.4.3.3 Obstacles and Reflecting Surfaces. Sound reflecting surfaces and obstructions other than the microphone and those associated with the sound source under test shall be absent from the room.

3.4.3.4 Free Field Above a Reflecting Plane. A semi-anechoic room with a free field over a reflecting plane shall incorporate all of the features described in 3.4.3.1, 3.4.3.2, and 3.4.3.3 except that the floor is a hard, smooth, massive plane surface. The average normal-incidence sound absorption coefficient of the floor shall not exceed 0.1 over the frequency range of interest. A concrete floor meets this requirement.

3.4.4 Other Indoor Environments. For many sources, it is either desirable or necessary to make measurements under conditions which are not optimal. For example, an indoor environment may have only a small amount of sound absorption. It may be desirable to leave the environment as it is while determining the sound levels in the environment when a particular source is in operation. Or, alternatively, it may be desirable to make the environment more closely approximate the optimal conditions described in 3.4.3 by introducing absorptive treatment.

3.4.4.1 Requirements. When conditions indoors are not optimal, useful measurements can be made without excessive errors due to sound reflections from walls or other surfaces provided that:

(1) The room has an adequate volume

(2) The source is located sufficiently far from the walls and other reflecting surfaces

(3) The measurement positions are relatively close to the source (see 7.3.2.1)

(4) Local interference patterns are smoothed out (see 8.3.1)

3.4.4.2 Qualification Procedures. Section 10 gives procedures for qualifying indoor environments as far as requirements (1) and (2) of 3.4.4.1 are concerned.

3.4.4.3 Nearby Objects

3.4.4.3.1 Survey Method. The acoustic environment in which the measurements are made shall be taken in an "as is" condition.

3.4.4.3.2 Field Method. To the extent possible, it is usually desirable while acoustical measurements are being made to remove all objects from the test area which are not part of the source or necessary for its operation.

3.4.4.3.3 Laboratory Method. All objects which are not part of the source or necessary for its operation shall be removed from the anechoic or semi-anechoic room during the measurements, except for the microphone and its associated hardware.

4. Classification of Noise by Type

4.1 General. The spectrum of a noise is influenced by a number of factors, such as the characteristics of the source(s), environmental conditions, etc. The spectrum may contain components at one or more discrete frequencies whose amplitudes are substantially higher than those of components at adjacent frequencies.

4.2 Types of Noise. The noises usually encountered in practice are classified as steady or nonsteady noise.

4.2.1 Steady Noise. The level of a steady noise remains essentially constant (that is, fluctuations are negligibly small) during the period of observation. To the typical observer, a change in noise level of less than one decibel is not likely to be detectable while a six decibel change will be considered significant. If the average noise level is relatively constant but the spectral distribution of the sound changes during the period of observation (as determined by listening), the noise shall be classified as nonsteady.

4.2.1.1 Steady Noise Without Audible Discrete Tones. This type of noise is frequently referred to as "broad-band" noise; prominent discrete components and narrow-bands of noise are absent. The plot of pressure spectrum level versus frequency is without pronounced discontinuities. See Appendix A for procedures to identify prominent discrete tones in the presense of broad-band noise.

4.2.1.2 Steady Noise with Audible Discrete Tones. This type of noise has components at one or more discrete frequencies which have significantly greater amplitudes than those of the adjacent spectrum (see Appendix A). Clusters of such components or narrow-bands of noise may be observed. The plotted spectrum obtained with a narrow-band analyzer has very sharp peaks (prominent single-frequency components) or steep gradients (narrow bands of noise). The distinguishing feature of narrow-band noise is that its energy is concentrated in a relatively narrow portion of the spectrum.

4.2.2 Nonsteady Noise. The level of a nonsteady noise shifts significantly during the period of observation. This type of noise may or may not contain audible discrete tones. The classification of nonsteady noises depends upon the period of observation which must be defined for each measurement.

4.2.2.1 Fluctuating Noise. The sound pressure level varies over a range greater than six decibels with the "slow" meter characteristic (see 8.1) and does not equal the ambient level more than once during the period of observation. Alternatively, the noise may fluctuate between two or more steady levels six or more decibels apart when measured with the "fast" meter characteristic of a sound-level meter. Fluctuations may occur because of beats between two or more audible discrete tones having nearly the same frequency.

4.2.2.2 Intermittent Noise. The sound pressure level equals the ambient level two or more times during the period of observation. The period of time during which the level of the noise remains at an essentially constant value different from that of the ambient is of the order of one second or more.

4.2.2.3 Impulsive Noise (Bursts). Impulsive noise is characterized by brief excursions of sound pressure (acoustic impulses) which significantly exceed the ambient environmental sound pressure. The duration of a single impulse is usually less than one second. Two subcategories of impulsive noise are:

4.2.2.3.1 Isolated Bursts. One or more bursts occur during the period of observation. The envelope of the burst waveform may be that of a decaying transient or it may be of essentially constant amplitude, for example, a tone burst. The burst spacing (time interval between bursts) is such that each burst is individually distinguishable with a sound-level meter.

4.2.2.3.2 Quasi-Steady Noise. A train of two or more bursts occur during the period of observation. Individual bursts in the train may have equal or unequal amplitudes and the burst spacing (time interval between bursts) may be uniform or nonuniform. As the burst repetition rate increases, the resolution of individual bursts by a sound-level meter becomes difficult; the noise is then classified as quasi-steady.

4.3 Examples. Examples of sources of different types of noise are given in Table 3.

5. Instrumentation for Noise Measurements

5.1 Introduction. Noise measurements are often made with a sound-level meter. When one of the built-in weighting networks is used to modify the frequency response of the instrument, the reading of the meter is called the sound level and the weighting network used must be indicated. When no weighting is used, all frequency components in the range of the

Table 3
Examples of Sources of Different Types of Noise

Steady	Nonsteady
Without Audible discrete tones	Fluctuating
Distant city	Heavy traffic (nearby)
Waterfall	Pounding surf
Air-conditioning system (high velocity)	Intermittent
With audible discrete tones	Aircraft fly-over
Circular saw	Automobile passing by
Transformer	Train passing by
Turbojet engine	Impulsive
	Isolated bursts
	Drop forge hammer
	Dog barking
	Pistol shots
	Door slamming
	Electrical circuit breaker
	Quasi-steady noise
	Riveting
	Pneumatic hammer
	Machine gun

instrument are passed essentially without attenuation and the reading of the meter is the sound pressure level.

The sound level (weighted sound pressure level) is useful in many situations. It is particularly valuable when noises are to be compared which have the same general character and when the human ear does not readily recognize any important qualitative differences in the composition of the noises. When the sound-level meter indicates approximately the same sound level for two noises, but the ear distinguishes differences in the composition of the noises, a single number, such as the one a sound-level meter provides, may be misleading.

The single number provided by the sound-level meter is not sufficient for diagnostic purposes. For studies that are concerned with the causes of noise generation and methods for reducing the noise, a frequency analysis of the noise is required. To obtain this information, band-pass filters whose geometric mean frequency is either continuously or step-wise variable are used in conjunction with the sound-level meter. The sound pressure level, in frequency bands of known width, is then obtained. Eight octave-band filters (for example, those with geometric mean frequencies of 63, 125, 250, 500, 1000, 2000, 4000 and 8000 Hz) usually cover the significant portions of the audible spectrum and provide adequate information to characterize steady noise without audible discrete tones. When audible discrete tones are present in the spectrum, a spectrum analyzer having a narrow bandwidth (for example, third-octave or narrower) may be required.

5.2 General. Instrumentation for the three methods of noise measurement is described in this section.

5.2.1 Survey Method (for Ambient Noise and Source Measurements). This method uses only a sound-level meter to yield the weighted sound pressure level (sound level).

5.2.2 Field Method (for Ambient Noise and Source Measurements). This method uses octave or narrower band analyzers and provides a frequency analysis of the noise in a field environment which may or may not be changed to approximate optimal conditions.

5.2.3 Laboratory Method (Primarily for Source Measurements). This method uses precision octave or narrower band analyzers and provides a frequency analysis of the sound pressure levels produced by a source operating in a free field or a free field above a reflecting plane.

5.3 Instrumentation

5.3.1 Survey Method. For survey measurements, a sound-level meter shall be used whose performance meets or exceeds the least stringent requirements of American National Standard for Sound Level Meters, S1.4-1971 (see Section 12).

5.3.2 Field Method. For field measurements, an octave-band analyzer or a narrow-band analyzer of the constant bandwidth or constant percentage bandwidth type shall be used. The microphone shall be detachable from the instrumentation for installation at the end of a cable.

NOTE: If an analyzer with filters that meet the requirements of Z24.10-1953 (superseded) is used, reference should be made to American National Standard Specification for Octave, Half-Octave, and Third-Octave Band Filter Sets, S1.11-1966, on filters for a method to convert the sound pressure level data to the corresponding values for an analyzer that incorporates the current preferred octave-band center frequencies (see Section 12).

5.3.3 Laboratory Method. For laboratory measurements, instrumentation that meets the requirements of 5.3.2 shall be used. In addition, the microphone shall meet the stability, temperature coefficicient, and ambient-pressure coefficient requirements of American National Standard Specifications for Laboratory Standard Microphones, S1.12-1967 (see Section 12).

5.4 Precision Objectives of Basic Instrumentation Systems

5.4.1 Precision of Calibration. These systems shall be such that they are capable of being calibrated at a discrete frequency between 200 Hz and 1250 Hz with the following precisions (see 5.7):

(1) Instrumentation for survey method: ±2 dB

(2) Instrumentation for field method: ±1 dB

(3) Instrumentation for laboratory method: ±0.5 dB

A complete calibration over the entire frequency range of interest shall be performed periodically with a precision sufficient to ensure compliance with the frequency response requirements of 5.4.2. Calibrations shall be performed in accordance with the general principles of American National Standard S1.4-1971.

5.4.2 Frequency Response. The frequency response of an instrumentation system to a plane progressive sinusoidal sound wave arriving at the angle of incidence specified by the manufacturer or to sounds arriving at random incidence shall conform to the requirements of American National Standard S1.4-1971. Instrumentation for the laboratory method shall satisfy or exceed the frequency response requirements of the type of sound-level meter which has the most stringent performance specifications. For the field method, instrumentation shall satisfy or exceed the frequency response requirements of the next most stringent sound-level meter specifications and for the survey method, the least.

5.4.3 Microphone Characteristics. Microphone characteristics shall conform to the requirements of American National Standard S1.4-1971. Microphones for the laboratory method shall satisfy or exceed the appropriate requirements of the type of sound-level meter with the most stringent performance specifications and, in addition, shall satisfy the stability, temperature coefficient, and ambient-pressure coefficient requirements of American National Standard S1.4-1971. For the field method, microphones shall satisfy or exceed the next most stringent sound-level meter specifications and for the survey method, the least.

5.4.4 Filter Characteristics. The octave and third-octave band filter sets used for measurements by the field and laboratory methods shall meet the requirements of American National Standard S1.11-1966. In particular, instrumentation for the field method shall meet a Class I designation for octave-band filter sets and a Class II designation for third-octave band filter sets. Instrumentation for the laboratory method shall meet a Class II designation for octave-band filter sets and a Class III designation for third-octave band filter sets. Two other types of spectrum analyzers may be used for measurements using the field and laboratory methods. One type has a bandwidth which is a constant small fraction of the center frequency of the band. The other has a constant bandwidth.

5.5 Magnetic Tape Recorders. Instrumentation-grade magnetic tape recorders are useful for data storage and may be used to supplement the basic instruments described in 5.3.2 and 5.3.3.

5.5.1 Tape Recorder Characteristics and Operation. The electrical characteristics that are usually of critical importance in the choice of a tape recorder for noise measurements are the frequency response and the signal-to-noise ratio.

5.5.1.1 Frequency Response Characteristic. A frequency response characteristic that is uniform over the frequency range of 45 to 11 200 Hz is preferred. This response shall be checked frequently and adjusted for optimal uniformity. Corrections for the remaining irregularities shall be applied to the results of an analysis of the signal if third-octave or narrower bands are used.

5.5.1.2 Signal-to-Noise Ratio. The range in level from the internal noise level of the recorder to the level at which the distortion exceeds 2 percent shall be as wide as possible. The applied signal level must be set carefully in order to be within this range. If the applied signal is set too high, the recorded signal will be distorted, and subsequent measurements of the reproduced signal may be seriously in error. If the applied signal is set too low, the internal noise of the recorder may override the signal in the frequency ranges where the signal energy is low.

Since the signal-to-noise ratio is measured and specified in several different ways, a careful review of the significance of any particular specification shall be made for critical applications. The effect of the weighting characteristic (or preemphasis) on the signal to be recorded shall be considered.

5.5.1.3 Other Characteristics. In instrumentation recorders, the magnitude of the flutter shall be sufficiently small that measurements on the reproduced signal are not generally affected by it, unless filter bandwidths of 1 percent or narrower are used.

The phase characteristic of a system is ordinarily of little significance in acoustical measurements. In those instances where accurate reproduction of the recorded waveform is required, careful control of the phase characteristic is necessary, and the frequency-modulation process of recording is then the preferred procedure. For most noise-measurement applications either a direct-recording or a frequency modulation process may be used.

When the phase characteristic is important, the phase response of the system (including the recorder) shall ideally be an increasing linear function of frequency. Deviations from this ideal are frequently specified in terms of the delay (slope of the phase vs frequency curve) produced by the system.

The dynamic range of many systems will frequently be inadequate for the recording of nonsteady noise. For fluctuating and intermittent noise, recordings may be made at different levels on several recorder channels, or the system gain may be adjusted (either manually or automatically) during the period of observation. A method must be provided for determining the magnitude and time of occurrence of the gain changes. When recording quasi-steady noise, the signal peaks may be distorted because of the very high crest factors (for example, peak-to-rms ratios greater than 10) that are frequently encountered. A recording level must be chosen that makes a compromise between an adequate signal-to-noise ratio and excessive distortion of the signal.

5.6 Calibration and Maintenance of Instrumentation. The instruments used for the acoustical measurements shall be serviced at least once every twelve months in accordance with the manufacturer's instructions. This shall include checking the performance of all mechanical components and electrical circuits and replacing substandard items. The date of most recent servicing shall be written on tags attached to the instruments. To ensure that the calibration of the equipment has not changed during a series of measurements, the instrumentation system shall be calibrated acoustically according to the manufacturer's instructions. A comparative calibration provided by a sound-level calibrator or pistonphone of known sound pressure level is usually satisfactory for this purpose. The frequency response of the complete instrumentation system shall be checked periodically to insure that the requirements of 5.4.2 are satisfied. For the laboratory method, microphones shall be calibrated by comparison with reference standard microphones which are calibrated according to American National Standard Method for the Calibration of Microphones, S1.10-1966 (see Section 12).

5.7 Precautions To Be Taken When Selecting Instrumentation

5.7.1 Precautions (Field and Laboratory Methods)

5.7.1.1 Wind (Field Method Only). To perform sound pressure level measurements in a moving air stream, a suitably designed windscreen or nose cone shall be utilized to minimize the influence of the air stream on the output of the microphone. No such precaution is necessary if the wind noise is 10 or more decibels below the signal being measured in each frequency band of interest. Corrections for changes in microphone sensitivity for the windscreen or nose cone used during the measurements shall be applied to the observed sound pressure levels.

5.7.1.2 Humidity and Temperature. High humidity or temperature will change the sensitivity or damage many types of microphones. The microphone manufacturer's instructions shall be carefully followed to avoid such effects.

5.7.1.3 High Sound Pressure Levels. Many piezoelectric, moving-coil, and capacitor microphones may be used for the measurement of sound pressure levels up to approximately 140 dB re 20 $\mu N/m^2$. At higher levels, specially designed microphones with stiff diaphragms shall be used; these shall be calibrated at the levels to be measured and, if possible, over the entire frequency range of interest. At high sound levels, special precautions shall be taken to ensure that "microphonics" are not generated by the transmission of mechanical vibration to the microphone or instrumentation. These include:

(1) Installing the microphone and instrumentation on a soft mounting.

(2) Removing the instrumentation from the high sound levels and utilizing long cables; precautions are necessary to minimize cable noise, that is, the noise produced when the cable itself is subject to vibration or flexing.

(3) Installing the instrumentation behind suitable barriers or enclosures; a mechanically soft mounting shall be used for the low-sensitivity microphones that are utilized for the measurements of high sound levels.

(4) Determining electrical noise and possible "microphonics" problems by replacing the microphone with a highly insensitive (dummy) microphone.

5.7.1.4 Low Sound Pressure Levels. A microphone used to measure low sound pressure levels must have high sensitivity and low internal noise. When connected to suitable low-noise amplifiers, many piezoelectric, moving-coil, and capacitor microphones are suitable for measurements of sound pressure levels below 20 dB re 20 $\mu N/m^2$.

5.7.1.5 Low-Frequency Noise. Piezoelectric and some capacitor microphones are suitable for measuring sound pressures at frequencies down to fractions of a hertz. Special amplifiers are required for measurements of low-frequency noise. The low-frequency sensitivity of a microphone may vary considerably from the mid-frequency sensitivity due to the presence of a pressure-equalizing leak. Calibration shall be performed over the frequency range of interest.

5.7.1.6 High-Frequency Noise. For measurements above 20 000 Hz, miniature capacitor or piezoelectric microphones usually give the most satisfactory results.

5.7.1.7 Hum Pickup. When sound pressure levels are to be measured near electrical equipment, a moving-coil microphone shall not be used. The instrumentation shall be checked to make certain there is no hum pickup in the instruments themselves. Hum can be reduced by moving the instruments away from the source of the magnetic field or by selecting a proper orientation of the instruments with respect to the magnetic field.

5.7.1.8 Cables. When a cable is used between the microphone and the acoustical instrumentation, the system shall be calibrated according to the manufacturer's instructions with the cable in use.

5.7.2 Precautions (Survey Method). Sound-level meters with integral microphones are generally not suitable for a measurement program that requires the observance of the special precautions of 5.7.1.

5.7.3 Additional Effects on Measured Data

5.7.3.1 Effect of Observer and Meter Case on Measured Data

5.7.3.1.1 Survey Method. The sound-level meter shall be held in front of the observer. The observer shall be oriented with respect to the principal sound source so that the sound energy arrives at the microphone from the side unless some other orientation is specified by the instrument manufacturer.

5.7.3.1.2 Field and Laboratory Methods. In order to minimize the obstacle effect caused by the insertion into the sound field of the sound-level meter and the experimenter holding it, the microphone shall be connected to the sound analysis equipment by means of an appropriate cable or extension connector and mounted on a tripod or other suspension system. The observer and all acoustical instrumentation except microphone(s), associated preamplifiers and cables should be located outside the test area.

5.7.3.2 Microphone Response and Orientation

5.7.3.2.1 General. The microphone calibration applied to compute sound pressure level shall conform to the way the microphone is used in the measurement; for example, free-field calibration at the appropriate angle of incidence. It should be recognized that microphone calibrations are often furnished in terms of the pressure response, which may differ from the free-field response at high frequencies by as much as 9.5 dB for one-inch diameter microphones.

5.7.3.2.2 Survey Method. See 5.7.3.2.1.

5.7.3.2.3 Field and Laboratory Methods. The microphone shall be oriented with respect to the source so that sound strikes the diaphragm at the angle for which the microphone was calibrated to have the flattest frequency response characteristic. The variation of the response with frequency shall be taken into account in each frequency band for maximum accuracy. It should be noted that microphones are usually most sensitive for sound propagating perpendicular to the microphone diaphragm. However, the angle required to obtain the flattest response vs frequency will be a function of the microphone design. It is imperative that reliable calibration data be used to determine the angle of operation for the flattest response. It should be noted that a microphone may be extremely sensitive at high frequencies to small changes in orientation for sound waves arriving parallel to the diaphragm. Therefore, during a measurement of sound which contains significant high-frequency components, it is advisable to maintain the microphone orientation to within ±5 degrees for the survey and field methods and to within ±2 degrees for the laboratory method.

6. Installation and Operation of Source

6.1 General. The requirements of this section are applicable only to measurements of sound sources. In many cases, the sound pressure levels in the vicinity of a source depend upon the support or mounting conditions and upon the manner in which the source is operated. This section gives general recommendations concerning installation and operation of sources. Reference shall be made to individual test codes for more detailed information concerning installation and mounting conditions of specific types of sources (for example, rotating electrical machines).

6.2 Installation of Source. Whenever a typical condition of mounting exists for the source, that condition shall be used or simulated, if practicable.

6.2.1 Method of Mounting. Many small sound sources (for example, ballasts for fluorescent lamps, electric clocks, etc) although themselves poor radiators of low-frequency sound, may, as a result of the method of mounting, produce marked increases in low-frequency sound when their vibrational energy is transmitted to surfaces large enough to be efficient radiators. Resilient mounting should be interposed if possible between the device to be measured and the supporting surfaces so that the transmission of vibration to the support and the reaction on the source are both minimized. However, such resilient mounts shall not be used if the device under test is not resiliently mounted in field installations.

6.2.2 Plane Reflecting Surfaces. When a source is mounted near one or more reflecting planes, its radiation impedance may differ appreciably from that of free space. If such a mounting is typical of field installations, the reflecting plane(s) shall be considered to be a part of the source. The optimal environment for a source mounted near one reflecting plane is a semi-anechoic room (free-field above a reflecting plane). See 3.4.3.4.

6.3 Operation of Source. During the acoustical measurements, the source shall be operated in a manner typical of normal use in a field installation. The following operational conditions may be appropriate:

(1) Device under normal load
(2) Device under full load (if different from (1))
(3) Device under no-load (idling)

6.4 Test Results. The conditions under which the source is installed and operated during the acoustical testing shall be described in the test results.

7. Microphone Positions

7.1 General. Microphone positions shall be selected so that an adequate sampling is obtained of the sound field in the ambient environment or in the vicinity of a sound source. The number of microphone positions selected shall be adequate to describe the ambient environment or specify the characteristics of the source.

7.2 Ambient Noise Measurements. When the microphone position is selected, the purposes of the measurements must be carefully considered. The microphone shall be located at those positions normally occupied by the ears of the people exposed to the sound field. These people may be standing, sitting, or lying down. When it is desired to plot contours of equal sound pressure level, the required number of microphone positions will be determined by the degree of spatial irregularity in the sound pressure field and the resolution desired. The distance between microphone locations is to be specified in terms of the desired precision with which the ambient environmental levels are to be mapped.

7.2.1 Outdoors. The preferred height of the microphone above the ground for outdoor measurements is 1.5 meters. Other heights may be used if they prove to be more practicable. For example, in making measurements near an open window, the microphone shall be centered on the open window and at a horizontal distance of approximately 0.5 meter from the window.

7.2.2 Indoors. The preferred height of the microphone above the floor is 1.5 meters. Other heights may be used if they prove to be more practicable as, for example, in making measurements in a room where the occupants are normally seated (living rooms: microphone 1.1 meters above the floor) or lying down (bedrooms: microphone 0.6 meter above the floor).

7.3 Source Measurements. The distribution of sound in the vicinity of most sources is complex. Large noise-producing bodies may have surfaces which vibrate at many frequencies with many degrees of freedom. These bodies may produce sound pressure patterns that are extremely complicated. If the wavelength of the emitted sound is large compared with the dimensions of the source, the sound may be radiated uniformly in all directions. If the wavelength is short compared with the dimensions of the source, important directional effects and interference phenomena may appear. Hence, it may be necessary to determine the directivity characteristics as a function of frequency in order to completely specify the acoustical properties of the source.

The sound field of a source in the presence of one or more reflecting planes results from a superposition of the field of the actual source and that of the image source(s). The directivity pattern above a reflecting plane is generally more complex than that of the same source in a free field.

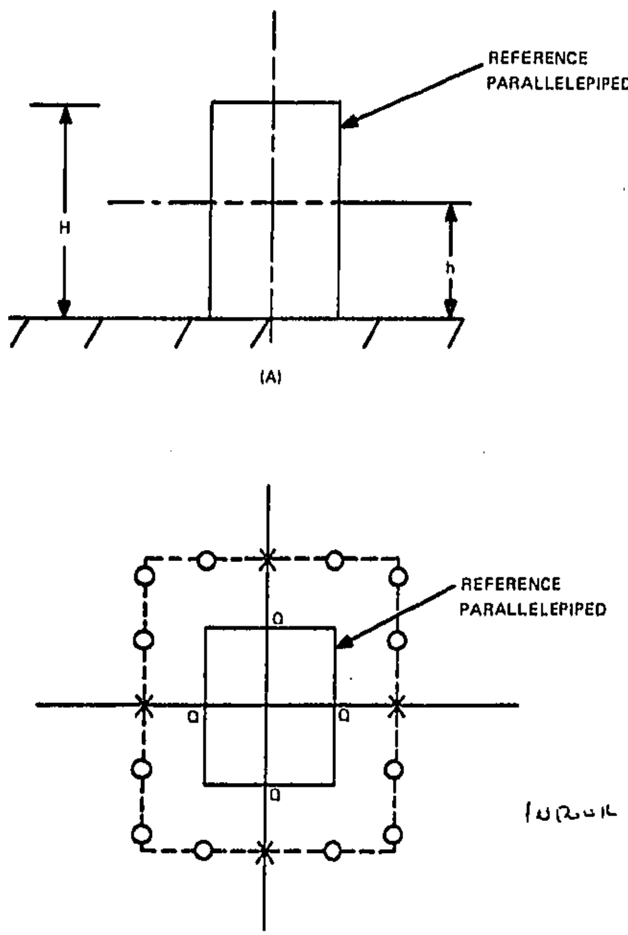
The number of microphone positions shall be sufficient to ensure that the sound pressure field in the vicinity of the source has been adequately described for the purposes of the measurements.

7.3.1 Operator Positions. If the source is attended by an operator, one microphone position shall be located at each operator position (preferably with the operator absent). If the operator stands, the microphone shall be at a specified height (for example, 1.5 meters) above the floor plane. If the operator is normally seated, the microphone shall be at a lower specified height (for example, 1.1 meters) above the floor plane.

7.3.2 Other Positions. In addition to the operator positions (if any), measurements shall be made at several locations in the vicinity of the source. When the source is not highly directional, measurements on four sides are frequently sufficient. When the source is highly directional, measurements at more than 20 different locations may be required. To locate the microphone, one of the following procedures may be used; the first procedure is suitable for both indoor and outdoor measurements; the second procedure is usually used for measurements outdoors when the microphone is a considerable distance from the source.

7.3.2.1 Rectangular Array of Microphone Positions. The smallest possible imaginary rectangular parallelepiped that will just enclose the source is utilized for reference purposes. At least one vertical side of the parallelepiped shall be parallel to one of the vertical surfaces of the source. Minor projections from the source are disregarded. The microphone positions are then specified with respect to the parallelepiped. The key measuring points are shown in Fig. 2. The microphone shall be located at each of the four key measuring points.

For small sources whose maximum linear dimension is less than 0.25 meter, the horizontal distance between the microphone positions and the parallelepiped is four times the maximum linear dimension of the source. Alternatively for small sources,



X – Key measuring points

O – Other measuring points marked off at intervals of 1 m from key points

Q – Points on the ground plane used for qualification procedure (Section 10)

Fig. 2
Location of Measuring Points with Respect to Reference Parallelepiped
(A) Vertical Section
(B) Prescribed Positions in Horizontal Plane

the location of the four key measuring points may be described with respect to the center of the parallelepiped. For most sources whose maximum linear dimension is equal to or exceeds 0.25 meter, microphone positions located one meter from the parallelepiped are suitable. For large sources (or for sources that produce higher levels at greater distances than at one meter), it may be desirable to select a larger horizontal distance (for example, two meters) between the microphone positions and the parallelepiped.

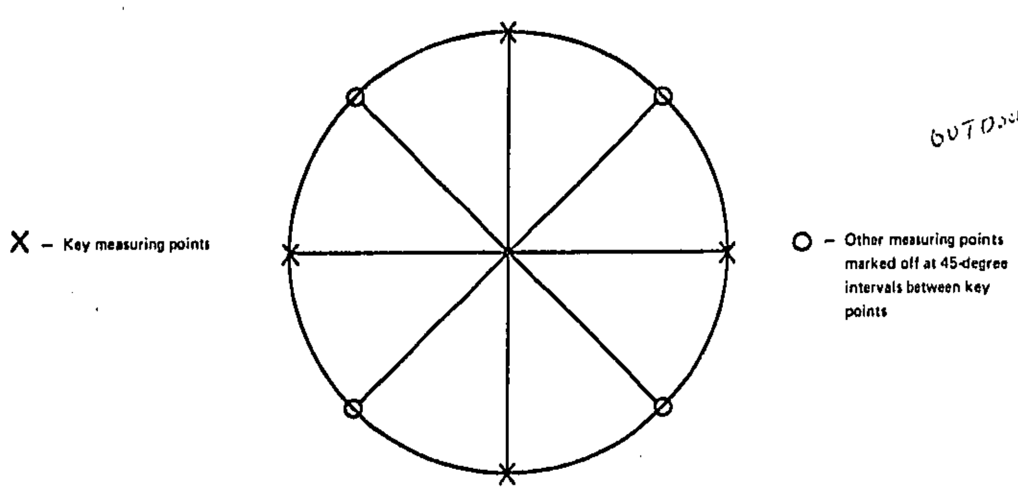
For large or highly directional sources, additional measuring points marked off at a suitable uniform interval (for example, one meter) from the key measuring points may be used as supplementary microphone positions. If this spacing results in two sets of microphone positions near the corners of the dotted rectangle of Fig. 2, it may be desirable to eliminate one of the two sets. The preferred height, h, of the microphone above the ground plane is 1.5 meters. For special applications, it may be more appropriate to select $h = H/2$, but not less than 0.25 meter.

7.3.2.2 Circular Array of Microphone Positions. The microphone positions are located on the circumference of a circle with the source at the center of the circle as shown in Fig. 3. The height of the microphone above the ground plane is determined in the same manner as for the rectangular array of microphone positions (see 7.3.2.1). As a minimum requirement, measurements on the periphery of the circle at angular displacements of 0, 90, 180, and 270 degrees in a horizontal plane shall be obtained. Measurements may also be made at intermediate points to adequately describe the sound field in the vicinity of the source. The radius of the circle shall preferably be more than five times the major source dimension, but never less than two times the major source dimension. Measurements at microphone positions around the complete circumference of the circle of Fig. 3 may not be required for sound fields known to exhibit spatial symmetries. When measurements at varying distances from the source are to be obtained, the distance of the microphone from the source shall be marked off at suitable uniform intervals on either a logarithmic scale (preferred) or a linear scale.

7.3.3 Microphone Positions for Sound Power Determinations. If a determination of sound power is desired, microphone positions shall be selected according to American National Standard S1.2-1962.

7.3.4 Microphone Positions for Moving Sources.

Fig. 3
Location of Measuring Points in Alternate Prescribed Pattern



The microphone positions used shall be those of 7.2 and 7.3. For moving sources, the microphone may be oriented so that the highest sound pressure is incident on the diaphragm from the direction for which the microphone was calibrated. Alternatively, the orientation may be such that the sound pressure from the moving source impinges on the microphone diaphragm at the same angle of incidence throughout the period of observation. The relative position of the source with respect to the microphone, particularly the distance of closest approach, shall be specified.

7.3.5 Microphone Positions for Sources That Contain Audible Discrete Tones. When audible discrete tones are present (see Appendix A), the microphone shall be moved in order to reduce the effects of localized interferences (see 8.3).

8. Measurement of Steady and Nonsteady Noise

8.1 General. The purpose of this section is to provide quantitative guidelines for determining the type of noise (that is, steady or nonsteady) being measured, and to prescribe methods for reading the meter of a noise-measuring instrument. Variations in the output of noise sources combined with short-term environmental changes affecting sound propagation result in fluctuations of the sound level. The meter does not respond instantaneously when a signal is presented to it; the reading at any instant depends upon the amplitude of the signal a short time before, the amount of damping that has been applied to the meter movement, and the rate at which the level is changing. Two ballistic characteristics are normally provided for a sound-level meter: "fast" and "slow." The "fast" meter characteristic has a response time of approximately 0.1 second, and the response time of the "slow" meter characteristic, obtained by increasing the meter damping, is approximately 1 second. The meter characteristics are specified more precisely in American National Standard S1.4-1971. When the fluctuations of the meter with the "fast" characteristic are greater than ±3 dB, the "slow" position shall be used. Exceptions to this rule are discussed in 8.4.

8.2 Procedures for Measuring Steady Noise Without Audible Discrete Tones

8.2.1 Measurement Procedure. When measurements of steady noise are made in a frequency band that does not contain an audible discrete tone, the level corresponding to the rms sound pressure during the period of observation is of greatest interest. When the fluctuations of the indicating pointer on the sound-level meter are less than ±3 dB using the "slow" meter characteristic, the noise is considered to be steady, and the level is taken to be the average of the maximum and minimum levels during the period of observation. A situation may arise when the use of the "fast" meter characteristic indicates that the level fluctuates between two or more well-defined steady levels less than 6 dB apart. In this case, the procedures of 8.4.2.4 may be used.

8.2.2 Data To Be Obtained. For steady noise in frequency bands that do not contain an audible discrete tone, the following data shall be obtained.

8.2.2.1 Survey Method. At each microphone position (see Section 7), the sound level (with A or other appropriate weighting) shall be obtained. No effort is required to control or change the acoustic environment.

8.2.2.2 Field Method. At each microphone position (see Section 7), an octave-band or third-octave band analysis shall be obtained. Exceptions to this requirement are discussed in 11.2. No weighting shall be used for these analyses. If desired, the sound level (with A or other appropriate weighting) may be recorded. For outdoor measurements of sources, environmental conditions shall approximate as closely as possible those described in 3.4.2. For indoor measurements of sources, environmental conditions shall approximate as closely as possible those described in 3.4.3 unless it is desirable or necessary to work under the conditions of 3.4.4, in which case environmental conditions shall be fully described.

8.2.2.3 Laboratory Method. At each microphone position (see Section 7), an octave-band or third-octave band analysis shall be obtained. Exceptions to this requirement are discussed in 11.2. No weighting shall be used for these analyses. If desired, the sound level (with A or other appropriate weighting) may be recorded. The measurements shall be performed in an anechoic (or semi-anechoic) room that meets the requirements of 3.4.3.

8.3 Procedures for Measuring Steady Noise with Audible Discrete Tones

8.3.1 Measurement Procedure. Standing waves or large spatial variations in sound pressure are frequently produced by sound sources that radiate audible discrete tones (see Appendix A). In a free field, standing waves may be created by interferences between sound waves generated at two or more separated areas on the surface of a large source. In a free field above a reflecting plane, destructive interferences will also occur at those locations where the difference between the length of the direct path and the path reflected from the plane is an odd multiple of a half wavelength. Indoors, standing wave interferences may be particularly pronounced unless the room is extremely large or optimized as described in 3.4.3.

At a particular point in such an interference field, the sound pressure level in a frequency band containing the discrete tone is rarely relevant except when evaluating the effect of noise from a fixed source on an observer whose position with respect to the source and all reflecting surfaces is clearly defined. Even then it must be borne in mind that the interference field will shift in space with slight changes of temperature (speed of sound) or frequency (machine speed). Usually it is more relevant to measure either the maximum or the rms sound level (or rms sound pressure level) during the period of observation for a suitable choice of microphone positions.

To reduce the influence of localized interferences, the microphone may be moved along circular arcs in a vertical plane with arc lengths of at least $\lambda/2$ and preferably greater than λ where λ is the wavelength of the sound at the audible discrete frequency of interest. The microphone shall be moved at a rate of at least one traverse per second, but with a velocity less than two meters per second to avoid the effects of wind noise. The motion of the microphone shall not generate noise or vibration that affects the sound pressure level readings. The center point of each arc shall pass through the measuring points of Section 7 and the arc radius shall be at least one meter. The microphone shall continue in motion about each measuring point for a sufficient period of time to permit an average reading to be obtained with the "slow" response setting of the meter. Alternatively, the true rms pressure along the path may be determined by direct computation using analog or digital techniques.

To evaluate regions of maximum sound level, the microphone shall be moved slowly along a path connecting the measuring points shown in Fig. 2 or Fig. 3 while simultaneously reducing the influences of localized interferences as described above.

8.3.2 Data To Be Obtained. When audible discrete tones are present, a narrow-band analysis shall be performed. In frequency bands that contain an audible discrete tone, the maximum and average sound level or sound pressure level observed during each traverse of the microphone shall be obtained. If the sound pressure level fluctuates due to beats between noise sources, the "slow" setting of the meter movement shall be used; the maximum (and minimum) sound pressure level produced by spatial and temporal fluctuations shall be reported. These data are obtained in addition to the data described in 8.2.2 for frequency bands that do not contain an audible discrete tone.

8.4 Procedures for Measuring Nonsteady Noise

8.4.1 General. Noises that are nonsteady are classified in 4.2.2 as fluctuating noise, intermittent noise, isolated bursts, or quasi-steady noise.

Two kinds of temporal fluctuations shall be distinguished. For the first kind, the noise fluctuates between two or more well-defined steady levels as, for example, could occur during the cyclic operation of a machine. The length of time the noise remains steady at each of the well-defined levels is sufficient to obtain an estimate of the average value for each level using the "fast" meter characteristic. For the second kind, the level fluctuates continuously over a wide range. For example, noise levels near a busy highway may fluctuate over a range of 30 dB or more, and the level does not remain at a steady level for an appreciable length of time during the period of observation.

An intermittent noise is usually "on" for a time long enough to determine an average level using the "fast" meter characteristic. The "on" periods may occur at regular or irregular intervals during the period of observation, and the noise level may be steady or may fluctuate during the "on" period.

There are two distinctly different approaches to the measurement of intermittent noise. The conventional approach utilizes standard instrumentation, and is described in this section. Alternatively, the intermittent noise may be treated as a burst or series of bursts, and the methods of Appendix B may be used.

Quasi-steady noise is a series of impulses whose repetition rate is sufficiently high that the noise can be considered as steady (see 8.2).

It is often difficult to distinguish between isolated bursts and quasi-steady noise. When 10 or more impulses occur each second, the noise is nearly always quasi-steady, and may be conveniently measured with the equipment used for steady noise described in Section 5. When one impulse per second or less occurs, the noise nearly always consists of isolated bursts, and may be measured using the techniques described in Appendix B.

In the range 1-10 impulses per second, the distinction is much less clear. An estimate of the average level, the magnitude of the fluctuations in sound pressure level, and an oscilloscope photograph of the envelope of at least 10 bursts are useful, and provide a description of the noise. A calibration of the vertical scale of the oscilloscope in terms of sound pressure or sound pressure level shall be made.

8.4.2 Measurement Procedures. Because the characteristics of nonsteady noise are difficult to define quantitatively, the procedure to be followed in reading the sound-level meter will vary with the ultimate use of the measured data. The type of data desired usually falls into one of five categories.

(1) An estimate of the level corresponding to the true rms value of the sound pressure (rms level) for a specified period of observation. (See 8.4.2.1.)

(2) An estimate of central tendency (for example, the average level) during the specified period of observation. (See 8.4.2.2.)

(3) An estimate of the maximum and minimum levels (using the "fast" or "slow" meter characteristic) during the specified period of observation. (See 8.4.2.3.)

(4) An estimate of the level during the "on" time of an intermittent noise, or an estimate of the levels that occur when a noise fluctuates between two or more well defined values. (See 8.4.2.4.)

(5) An estimate of the variations in level with time. (See 8.4.2.5.)

Data are obtained by observing the fluctuations of the pointer on the meter of the noise-measuring instrument. The observed readings are not independent because a finite time is required for the pointer to assume a new value. When using the "fast" meter characteristic, at least one-half second shall be allowed between observations; when using the "slow" meter characteristic, the interval between observations shall be at least two seconds.

8.4.2.1 Estimates of the Level Corresponding to True rms Sound Pressure. If the fluctuations of the pointer on the indicating meter are between ±3 dB and ±5 dB ("slow" meter characteristic), the level corresponding to the rms sound pressure is approximately 3 dB below the maximum level; when successive excursions are observed to have different maximum levels, the level is approximately 3 dB below the mean of the maximum levels for several excursions. If the range of the fluctuations is greater than ±5 dB, the estimate of the level is less certain; it may deviate from the true value by several decibels. An estimate may be obtained by reading the sound level meter 10 or more times during the period of observation. The level is estimated from the following equation:

$$L = 10 \log \frac{1}{N} \sum_{i=1}^{N} 10^{\frac{L_i}{10}} \qquad \text{(Eq 1)}$$

where

N = the total number of observations

L_i = the level at each observation

If the time scale of the fluctuations is such as to make this procedure impractical, other techniques such as direct computation of the rms pressure by analog or digital means are required.

NOTE: A useful rule-of-thumb is that the number of observations shall equal the range of the fluctuations in decibels.

8.4.2.2 Estimates of Central Tendency. The average indication of the meter may be estimated by following the procedure of 8.4.2.1 and using the following equation:

$$L = \frac{1}{N} \sum_{i=1}^{N} L_i \qquad \text{(Eq 2)}$$

to estimate the average level. A better estimate of the average level may be obtained if the average is taken only over the middle 50 percent of the readings.

The method of averaging shall be reported with the test results. If the time scale of the fluctuations is such as to make this procedure impractical, and the fluctuations are less than ±5 dB, the average of the maximum and minimum readings approximates the average level.

8.4.2.3 Estimates of Maximum and Minimum Level. The maximum and minimum level during the period of observation can be determined by observing the meter using the "fast" or "slow" characteristic. When the time required for a variation from minimum to maximum is five seconds or more, the "slow" meter characteristic may be used. For more rapid variations, the "fast" meter reading is more relevant.

8.4.2.4 Variations in Steady Level. For intermittent noise that varies between two or more well-defined steady values when observed using the "fast" or "slow" meter characteristic, the rms level for each steady value is usually of interest, and can be obtained using the "slow" meter characteristic when the level is steady for five seconds or more. For levels that are steady for one to five seconds, the "fast" meter characteristic shall be used. For shorter bursts, the maximum value of the "fast" meter reading shall be recorded, or the noise shall be treated as impulsive or quasi-steady.

8.4.2.5 Determination of the Variations in Level with Time. The survey method is not useful if the history of level variations is to be determined because a recording device is required. The electrical and mechanical characteristics of the device shall be such that the history of the fluctuations of the indicating meter can be determined.

8.4.3 Data To Be Obtained

8.4.3.1 Survey Method. If the noise is fluctuating between two or more well defined values, the value at each level shall be recorded. If the level fluctuates constantly over a range greater than ±3 dB using the "slow" meter characteristic, the maximum and minimum values and the rms or average level shall be recorded.

If the noise is intermittent, the level during the "on" period is usually of greatest interest. The average or rms level during the "on" period shall be recorded.

If the noise is quasi-steady, it may be treated as steady noise with the exception that the system gain shall be adjusted so that the level is measured at the lowest possible position on the indicating meter scale. The meter may read on scale if the system gain is increased by 10 dB. However, many instruments will produce an inaccurate reading because of the high crest factor usually encountered in quasi-steady noise.

8.4.3.2 Field and Laboratory Methods. A magnetic tape recording may be obtained of the non-steady noise. To perform the frequency analysis, the tape recording shall be played back through the instrumentation system containing a spectrum analyzer, and a separate playback shall be made each time the selected frequency of the analyzer is changed. Alternatively, an endless loop of tape may be used for the analysis, or a parallel set of analyzers having the desired bandwidth characteristics may be used.

A description of the filter outputs as a function of time depends upon the nature of the signal. For fluctuating noise having two or more well-defined steady levels, the rms levels can be estimated for each frequency band of interest.

For noise levels that fluctuate continuously over a wide range, the maximum and minimum levels shall be determined, and the rms or average level shall be estimated.

For intermittent noise, the average or rms level during the "on" time shall be estimated in each frequency band of interest.

For quasi-steady noise, the methods of 8.4.1 shall be used. The peak levels should, however, be monitored with an oscilloscope to ensure that no clipping occurs in the amplifying or recording systems.

9. Corrections for Ambient Noise During Source Measurements

9.1 General. The ambient sound pressure level with the source not operating shall, if possible, be determined at typical microphone locations in all frequency bands. If the increase in the sound pressure level in any given band, with the source operating, compared to the ambient sound pressure level alone is 15 decibels or more, the sound pressure level due to both the source and ambient sound is essentially the sound pressure level due to the source alone. This is the preferred condition, but is frequently unattainable in the field.

If the increase in sound pressure level in any given band, with the sound source operating, compared to the ambient sound pressure level is 3 decibels or less, the sound pressure level due to the sound source is equal to or less than the ambient sound pressure level, and the two contributions cannot be properly separated with the measuring techniques described in this standard.

9.2 Survey and Field Methods. If the increase in sound pressure level in any given band, with the sound source operating, compared to the ambient sound pressure level, is between 4 and 15 decibels, the sound pressure level due to the sound source may be approximated by applying the corrections listed in Table 4. These corrections are based on the assumption that the indicating meter gives a close approximation of the value of the rms sound pressure level. It is also assumed that the ambient sound pressure and the sound pressure due to the sound source are incoherent and can therefore be added on a pressure-squared basis. When the contributions from source and ambient sound are partially coherent, phase relations are important and corrections in general terms cannot be stated.

9.3 Laboratory Method. Since precision measurements are carried out under controlled environmental conditions, the combined level of the ambient noise and the instrument noise shall be at least 10 decibels and preferably 15 or more decibels below the sound pressure levels generated by the source in each band within the frequency range of interest.

10. Qualification Procedures for Indoor Environments

10.1 Procedure When Source Can Be Moved. One useful qualification procedure for checking items (1) and (2) in 3.4.4.1 is to remove the source under evaluation, and to place a reference sound source at selected points whose locations are defined with respect to the rectangular parallelepiped (see 7.3.2.1 and Fig. 2). The reference source shall have dimen-

Table 4
Corrections for Ambient Sound Pressure Levels

Difference (in Decibels) Between Sound Pressure Level Measured with Sound Source Operating and Ambient Sound Pressure Level Alone	Correction (in Decibels) To Be Subtracted From Sound Pressure Level Measured with Sound Source Operating To Obtain Sound Pressure Level Due to Sound Source Alone
4	2.2
5	1.7
6	1.3
7	1.0
8	0.8
9	0.6
10	0.4
11	0.3
12	0.3
13	0.2
14	0.2
15	0.1

NOTE: For the survey and field methods, corrections of less than 0.5 dB are seldom necessary. For the laboratory method, a measurement shall not be considered valid if the correction exceeds 0.5 dB. Exceptions to the latter requirement are discussed in 11.2.2.

sions that are small compared with the wavelength of sound at the lowest frequency of interest, shall radiate broad-band sound energy having no audible discrete tones, and shall be relatively omnidirectional. The sound pressure level produced by the reference source shall be at least 10 dB above the ambient level in the frequency bands of interest.

The reference sound source shall be operated on the floor at each of the points Q on the parallelepiped shown in Fig. 2. The sound pressure levels at the key measuring points shall be compared with the sound pressure levels measured at convenient intervals (for example, 0.25 meter) along a line passing through each key measuring point and perpendicular to the surface of the parallelepiped. The closest point of measurement shall be 1 meter from each key measuring point (for example, 2 meters from the parallelepiped). If at one or more points along the line the level is at least 6 dB below the level at the key measuring point, the direct sound energy will usually be sufficiently greater than the reflected sound energy that the environment approximates a free field over a reflecting plane for survey and field measurements. If the difference is less than 6 dB, the room can often be modified to meet this objective by covering the walls and other large surfaces near the measuring points with sound absorptive materials.

10.2 Procedure When Source Cannot Be Moved. If the source being evaluated cannot be removed from the test site, or if the sound pressure level produced by the reference sound source is not 10 dB above the ambient levels produced by the source undergoing evaluation, the measurement procedure of 10.1 may be followed using the actual source instead of the reference source.

NOTES:

(1) The second procedure (10.2) will be difficult to use if the source radiates audible discrete tones. The space averaging procedure of 8.3.1 shall be used to ensure that a minimum in the interference pattern is not taken as representative of the sound field at the key or other measuring points.

(2) If the environment is not or cannot be qualified according to one of the above procedures, this information shall be reported with the test results.

11. Reporting Sound Pressure Level Data

11.1 General. The following information, when applicable, shall be compiled and reported for measurements that are made according to the requirements of this standard.

11.1.1 Sound Source Under Test (Source Measurements Only)

(1) Description of the sound source under test

(2) Operating conditions

(3) Mounting conditions

11.1.2 Acoustic Environment (Indoors)

(1) Location of sound source(s) (if any)

(2) Dimensions of test room; description of the physical treatment of the walls, ceiling, and floor; sketch showing the location of source(s) and room contents

(3) Qualifications of test room (see Sections 3.4.4 and 10)

(4) Air temperature in degrees Celsius, relative humidity in percent, and barometric pressure in

millimeters of mercury (field and laboratory methods only)

11.1.3 Acoustic Environment (Outdoors). (Survey and field methods only.)

(1) Location of sound source(s) (if any)

(2) Dimensioned sketch and photograph(s) of the test area showing buildings, trees, structures, and other reflecting objects

(3) Physical and topographical description of the ground surface

(4) Meteorological conditions at a specified height above the ground: air temperature in degrees Celsius, relative humidity in percent, barometric pressure in millimeters of mercury, wind direction in degrees of azimuth, and average wind speed in meters per second

11.1.4 Instrumentation

(1) The equipment used for the measurements, including name, type, serial number, and manufacturer

(2) Bandwidth of frequency analyzer (field and laboratory measurements only)

(3) Frequency response of instrumentation system including weighting used (if any)

(4) The time response of the measuring system; that is, "slow," or "fast" response, or alternate appropriate description

(5) For the field and laboratory methods, the method used to calibrate the microphone and the date and place of calibration

11.1.5 Acoustical Data

(1) The locations and orientation angles of the microphone (a sketch shall be included if necessary).

(2) The sound pressure levels obtained, for all frequency bands or weightings, or both, used, in decibels with reference 20 $\mu N/m^2$. When appropriate, the maximum, minimum, and estimated average or rms sound pressure levels shall be reported as required by 8.4.3.

(3) The corrections in decibels, if any, applied in each frequency band to account for the frequency response of the microphone, frequency response of the filters, ambient noise, etc.

(4) The corrected sound pressure levels shall be tabulated or plotted to the nearest decibel for survey and field measurements and to the nearest half decibel for laboratory measurements. For plotting the results of measurements obtained with the field and laboratory methods, suggested formats are given in Fig. 4 for octave- and third-octave band analyses and in Fig. 5 for narrow-band analyses. The scale length on the ordinate of Figs. 4 and 5, corresponding to a 10:1 frequency ratio on the abscissa, is equal to 10, 25, or 50 dB.

(5) The duration of the period of observation.

(6) For source measurements, the sound pressure levels in decibels of the ambient environmental noise with the source not in operation shall be given re 20 $\mu N/m^2$.

(7) The date and time when the measurements were performed.

11.2 Comparison of Data. When the data obtained from measurements made according to the requirements of this standard are to be compared with other acoustical data, great care shall be exercised to ensure the validity of the comparison.

11.2.1 Comparison with Other Measured Values. In order for a valid comparison to be made, it is imperative that the conditions under which the two sets of data were obtained be as nearly identical as is practicable. Section 11.1 lists the information to be compiled and reported as part of a series of sound pressure level measurements. It is particularly important that the environmental conditions as well as the operating and mounting conditions for the source (if any) be nearly identical.

11.2.2 Comparison with Prescribed Values. Frequently, sound pressure level measurements are made to determine how the measured data compare with a prescribed value or set of values. Four different techniques, based on sound pressure level data obtained at a given microphone position, are commonly used to obtain the values to be compared. In some cases, field or laboratory measurement of the sound level may be all that is required for comparison with prescribed values. In this case, octave- or third-octave band data are not required. If no interference effects are present, the ambient noise requirements of Section 9 may be relaxed. However, the measured level will not be that of the source alone, and in the presence of interference effects the level measured with the source operating may be lower than the ambient level.

11.2.2.1 Octave- or Third-Octave Band Levels. The sound pressure levels prescribed for comparative purposes may be specified in either octave bands or third-octave bands over the frequency range of interest. Lower and upper cut-off frequencies of 45 and 11 200 Hz are usually adequate. However, special circumstances may require the use of higher or lower cut-off frequencies for the filter set. The levels prescribed for comparative purposes may be given on an octave-band or third-octave basis. Only the field and laboratory methods yield octave- or third-octave band data that may be used for comparative purposes.

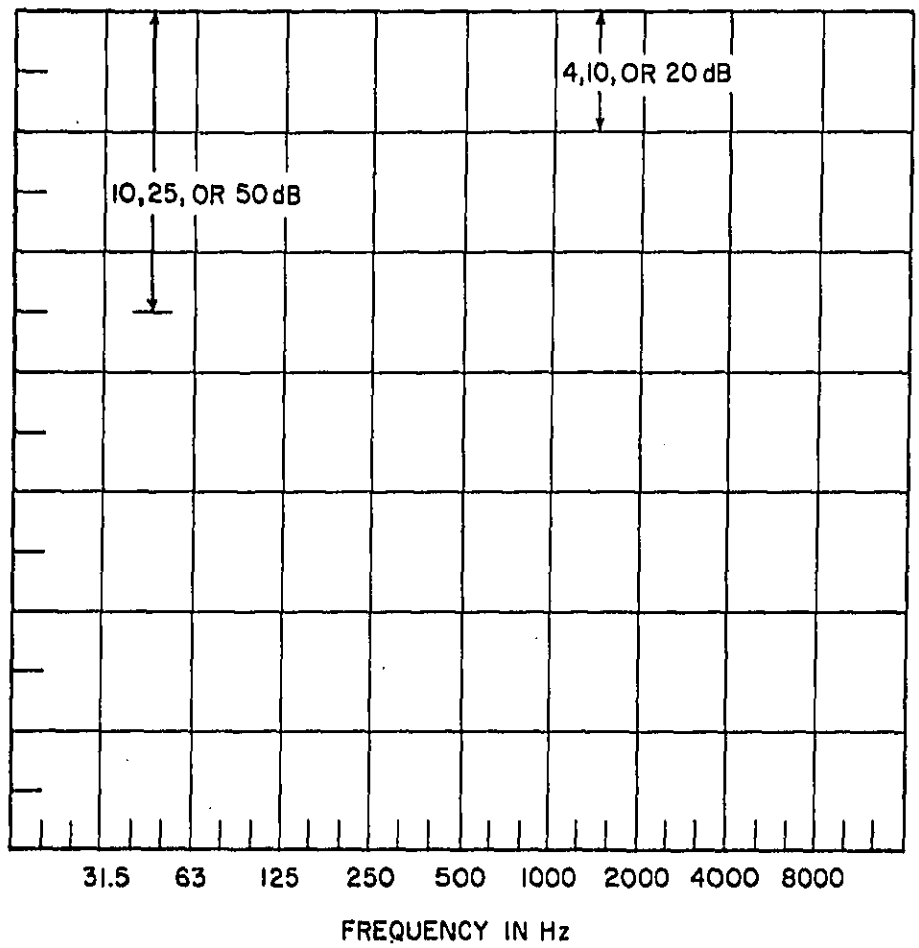


Fig. 4
Preferred Format for Reporting Octave- and Third-Octave Band Measurements of Sound Pressure Level

11.2.2.2 Sound Levels. The sound-level value prescribed for comparative purposes may be, for example, sound level A. The measured value may be obtained by using either the survey, field, or laboratory methods. Alternatively, an approximation to the measured value may be obtained with the field or laboratory methods by applying corrections to each octave- or third-octave band level. The resultant mean-square pressures in each band are then added and converted to a logarithmic quantity such as sound level A. Shapes of standard weighting curves are given in American National Standard S1.4-1971. It is not recommended that the calculation procedure be used when audible discrete tones are present in the spectrum of the noise.

11.2.2.3 Band Selection. The value prescribed for comparative purposes may be based on a band selection method. Measured octave band sound pressure levels are converted to new values by means of an equation, a set of tables, or a family of curves.

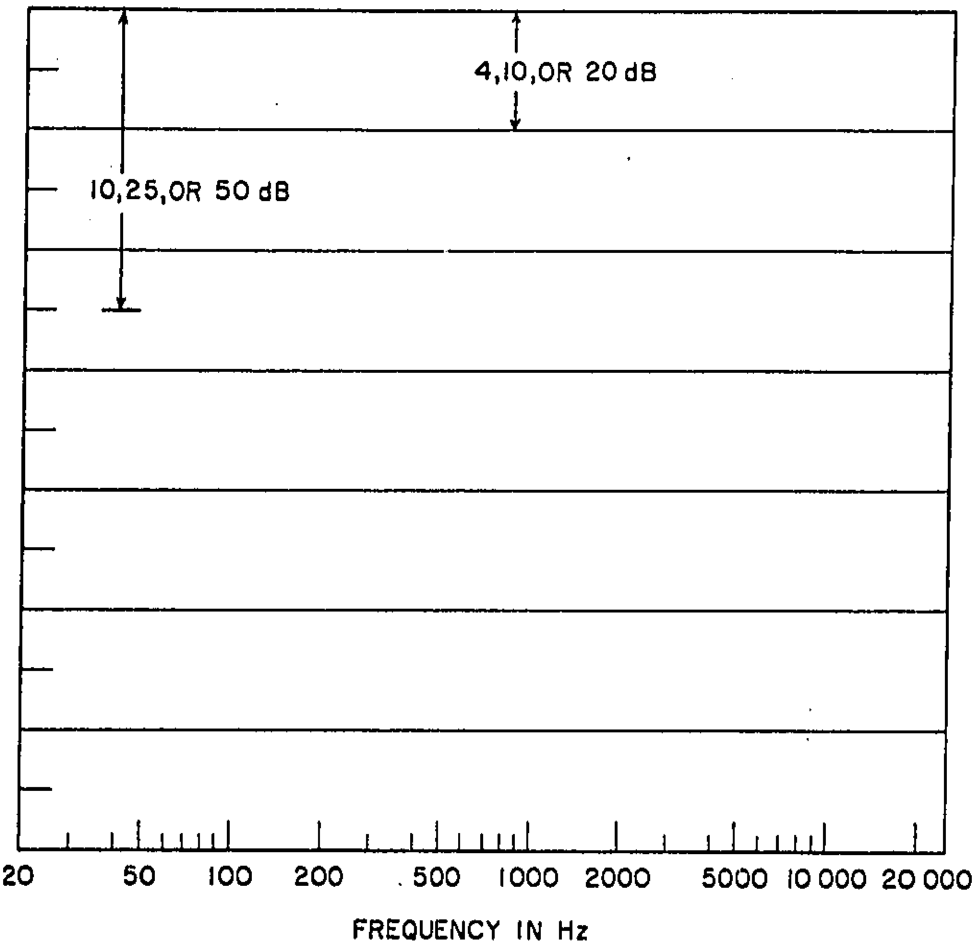


Fig. 5
Preferred Format for Reporting Narrow-Band Measurements of Sound Pressure Level

The highest number calculated by this procedure is usually selected as the single-number value. Data that are converted by this technique must be obtained using either the field or laboratory methods. A correction is often applied if audible discrete tones are present in the spectrum.

11.2.2.4 Band Summation. The value prescribed for comparative purposes may be based on a band summation method. Measured octave- or third-octave band sound pressure levels are converted to new numerical values. These numbers are then added with suitable weighting. It is common practice to use a weighting of 1.0 for the highest number, and smaller weightings for the remaining numbers. The resulting sum may be converted to a logarithmic unit. For example, the band pressure levels may be converted to loudness index, weighted and summed to yield a loudness in sones, and then converted to a calculated loudness level in phons.

(Reference: American National Standard Procedure for the Computation of Loudness of Noise, S3.4-1971 [see Section 12].) Data that are converted by this technique must be obtained by either the field or laboratory methods. A correction is often applied if audible discrete tones are present in the spectrum.

11.2.2.5 Band Averaging. The value prescribed for comparative purposes may be based on a band averaging method. Measured octave band sound pressure levels covering a restricted frequency range are arithmetically averaged to obtain a single-number value. This value is then compared with the prescribed value. Data that are converted by this technique must be obtained using either the field or laboratory methods.

11.2.3 Choice of Methods for Comparing Data. Data obtained by the survey method may be compared by use of the procedures prescribed in 11.2.2.2 only. Data obtained using the field or laboratory methods may be compared using any of the techniques described in 11.2.2. For diagnostic analyses which are undertaken to establish a basis for engineering action when noise control is desired, the techniques described in 11.2.2.1 and 11.2.2.3 have proven useful. For relating measured sound pressure level data to the subjective effects of noise, the techniques described in 11.2.2.4 and 11.2.2.5 have proven useful.

12. Revision of American National Standards Referred to in This Document

When the following American National Standards referred to in this document are superseded by a revision approved by the American National Standards Institute, the revision shall apply:

American National Standard Acoustical Terminology, S1.1-1960

American National Standard Method for the Physical Measurement of Sound, S1.2-1962 (R1971)

NOTE: American National Standard S1.13-1971 represents a revision of Section 2 of American National Standard S1.2-1962.

American National Standard for Sound Level Meters, S1.4-1971

American National Standard Preferred Frequencies and Band Numbers for Acoustical Measurements, S1.6-1967

American National Standard Preferred Reference Quantities for Acoustical Levels, S1.8-1969

American National Standard Method for the Calibration of Microphones, S1.10-1966

American National Standard Specification for Octave, Half-Octave and Third-Octave Band Filter Sets, S1.11-1966

American National Standard Specifications for Laboratory Standard Microphones, S1.12-1967

American National Standard Procedure for the Computation of Loudness of Noise, S3.4-1971

Appendixes (These Appendixes are not a part of American National Standard Methods for the Measurement of Sound Pressure Levels, S1.13-1971, but are included to facilitate its use).

Appendix A
Identification of Prominent Discrete Tones

A1. Prominent Discrete Tones

A discrete tone will be audible in the presence of wide-band noise if its sound pressure level exceeds the sound pressure level of the noise in a Fletcher critical band centered at that frequency. In general, the tone is just audible (at its masked threshold) when its level equals that of the noise in the Fletcher critical band centered at the frequency of the tone (Reference 1). This is the relationship used to define the width of the Fletcher critical band, and it is valid for masking noises having continuous spectra without excessive slopes. Noise spectra obtained using constant percentage bandwidth filters having slopes greater than approximately 10 dB per octave (particularly negative slopes and high levels) may produce remote masking for which the Fletcher critical band concept is not valid. A prominent discrete tone may be defined as a tone whose level is a specified number of decibels (X) or more above the level at which the discrete tone would be just audible in the presence of wide-band continuous noise. In many practical situations, a discrete tone would be classified as "prominent" by a panel of listeners if the specified number of decibels (X) is between 5 and 15. The value of X must be selected by the user of this procedure.

To determine if a discrete tone is prominent, the filter of the narrow-band analyzer used for the measurements should have a bandwidth that is approximately equal to or less than the width of the Fletcher critical band, f_c (see Table A1). A prominent discrete tone is present if the sound pressure level of the tone measured with a filter of bandwidth Δf is at least $[X - 10 \log_{10} (\Delta f / f_c)]$ dB above the arithmetic average of the band pressure levels measured on each side of the discrete tone. The term $10 \log_{10} (\Delta f / f_c)$ relates the band pressure level measured with a band Δf in width to the width of the Fletcher critical band f_c. The value of X is the specified number of decibels in the definition of a prominent discrete tone.

The curve of Fig. A1 may be used to identify a prominent discrete tone with a constant percentage bandwidth analyzer (approximately 7 percent) when X is specified as being 10 dB. The response of the narrow-band analyzer is down 3 dB at ±3.5 percent of the selected frequency.

As it is not always obvious at what frequency the sound pressure levels should be chosen in order to obtain the arithmetic average of the band pressure levels on each side of the discrete tone, the measurement procedure requires clarification. In the ideal case of a discrete tone superposed on wide-band continuous noise, the selectivity curve characteristic of the filter in the narrow-band analyzer will be traced with its center at the frequency of the discrete tone. If the observed band pressure level versus frequency curve deviates from the selectivity characteristic of the narrow-band analyzer at the frequency of the discrete tone, this is an indication that multiple discrete tones or narrow bands of noise are present. The procedure of Section A2 should be followed.

Table A1
Fletcher Critical Bandwidths (f_c) as a Function of Frequency

Frequency (Hz)	f_c (Hz)
100	87
200	52
315	50
400	50
630	53
800	58
1000	63
1250	71
1400	76
1600	83
1800	91
2000	98
2500	123
3150	150
3550	173
4000	204
6300	404
8000	589
10 000	832

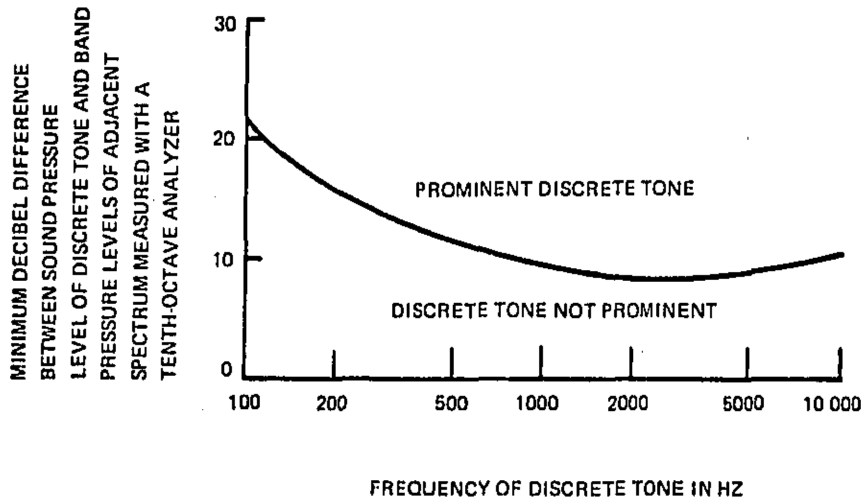


Fig. A1
Criterion for the Prominence of a Discrete Tone Based on Tenth-Octave Bandwidth

A2. Narrow Bands of Noise

From a practical standpoint, no distinction need be made between multiple discrete tones clustered together and narrow bands of noise. However, a narrow band of noise may be distinguished from a single discrete tone if the width of the narrow band as plotted can be distinguished from the bandwidth of the analyzer. Considerable judgment must be exercised in selecting the frequencies on either side of the narrow band of noise at which the arithmetic average is to be calculated. It is usually appropriate to select points that are between ±2 and ±4 bandwidths from the selected frequency (for example, if a 7 percent analyzer is set to 1000 Hz, the points at which the average is taken should be 140 to 280 Hz above and below 1000 Hz).

A3. Alternate Procedure

Another procedure for identifying prominent discrete tones in the presence of broadband noise is described in Reference 2.

References to Appendix A

(1) FLETCHER, H. *Speech and Hearing in Communication.* New York: D. Van Nostrand Co, Inc, 1953, p 101.

(2) Section B36.3, Federal Aviation Regulations. Published in the Federal Register, vol 34, no. 221, Nov 18, 1969.

Appendix B
Measurement of Impulsive Noise (Bursts)

B1. Introduction

In practice, sources that produce an impulsive sound are frequently encountered. If the duration of the impulse is sufficiently long, the noise may be analyzed by the methods described in Section 8. However, the duration of an impulse is usually less than one second, and is frequently less than 0.5 second. The methods described in Section 8 are therefore not applicable. When a standard sound-level meter is used to measure a short impulse, the meter will show a momentary rise and decay, but the maximum reading obtained is commonly 15 to 30 dB below the peak pressure level of the sound wave.

In Section 8, the characteristic of the noise of primary interest is usually the value of the effective (rms) pressure of the sound wave. In dealing with impulses of short duration, other characteristics are also of interest. For airborne impulsive noise, the envelope of the pressure versus time pattern is generally of greatest interest. Fig. B1 shows a typical impulsive noise burst.

To define methods for assessing the effects of impulsive-type noise, a considerable amount of experimental data must be accumulated. The collection of these data has been hampered by the lack of well-defined parameters to specify the characteristics of a burst as well as a simple technique for measuring these parameters. The peak pressure level and the burst duration are of major importance. For certain applications, measurements of the values of other parameters may also be of value, and are described elsewhere. (See Reference 1.)

B2. Categories of Impulsive Noise

Impulsive noise is readily identified by an observer when only a single burst occurs during the period of observation (see 4.2.2.3.1 of the standard) or the time interval between acoustic impulses is long. The human ear is less valuable as a guide when a distinction is to be made between quasi-steady noise with a high burst repetition rate (see 4.2.2.3.2 of the standard) and steady noise. The distinction in this case should be made in terms of specified values of the parameters that characterize the impulsive noise.

B2.1 Example of Classification of Impulsive Noise. To be classified as impulsive noise, an individual burst must have a duration of less than 0.25 second measured between the instants at which the instantaneous sound pressures have a value equal to one-half the peak value. If the noise is repetitive, the repetition rate of the bursts must be less than 5 per second and the arithmetic average of the peak sound pressure levels (determined using an A-weighting network) of 10 consecutive bursts in the train, must be more than 15 decibels above the A-weighted sound pressure level in the presence of the impulses.

B3. Instrumentation (Field and Laboratory Methods)

For the reasons given in Section B1, instrumentation appropriate for the survey method should not be used. A typical instrumentation system that is appropriate for burst measurements is shown in Fig. B2. This system consists of a microphone, a wide-band amplifier, a spectrum analyzer or weighting networks, an oscilloscope (with camera) and a peak-reading circuit. The microphone and wide-band amplifier should be of laboratory quality; their combined frequency response should be uniform over a frequency range whose lower limit is less than half the lowest frequency of interest and whose upper limit is more than twice the highest frequency of interest. The peak value of the sound level or sound pressure level may be determined with the aid of a peak-reading circuit. The rise time of the peak detector should be less than 200 μs and of such a value that a single pulse of 200 μs duration produces a meter deflection no more than 4 dB below the deflection produced by a reference pulse having a duration of 10 μs and equal peak amplitude. The amplitude of the 10 μs reference pulse should be such as to produce a full-scale (+0, −1 dB) meter deflection. The peak value can also be obtained with the oscilloscope. The oscilloscope is included in the system to facilitate the measurement of the values of other parameters that may be of interest. It is useful if the oscilloscope is equipped with a memory or storage feature, a single sweep capability and a camera to obtain a permanent record for later analysis. The oscilloscope sweep may be synchronized to a timing signal derived either from an electrical signal related to the burst or to an acoustical signal.

In this section, the only instrumentation described is that for burst display. Photographs of such displays may be used to obtain the values of the burst parameters of interest. Alternatively, hybrid methods (a combination of analog and digital techniques) may be used to measure and store burst parameters. Or, digital processing may be utilized to analyze the characteristics of a burst after it has been converted from analog to digital form. However, these methods lie outside the scope of this document.

B4. Microphone Positions

The same considerations as discussed in Section 7 are applicable. However, burst measurements in the near-field of an impulsive-noise source are frequently of interest. For this reason, it may be desirable to make measurements at positions closer to the source than those described in Section 7.

B5. Types of Measurement (Field and Laboratory Methods)

Wide-band waveforms with the spectrum analyzer of Fig. B2 removed from the measuring system are usually of greatest interest; however, the burst may also be observed at the output of the analyzer, for example, with an A-weighting network in the analyzer. A single burst (pressure-time pattern) incident on the microphone will produce an envelope that is highly dependent on the bandwidth and center frequency of the analyzer since the rise time and decay time of the filters are defined by these parameters. It is not clear that the observed peak pressure level in a particular band has real significance by itself, since this peak is not one that actually occurs in a typical sound wave. Nevertheless, the peak pressure level in a band may give a useful indication of the frequency distribution of the sound energy. (See Reference 2.)

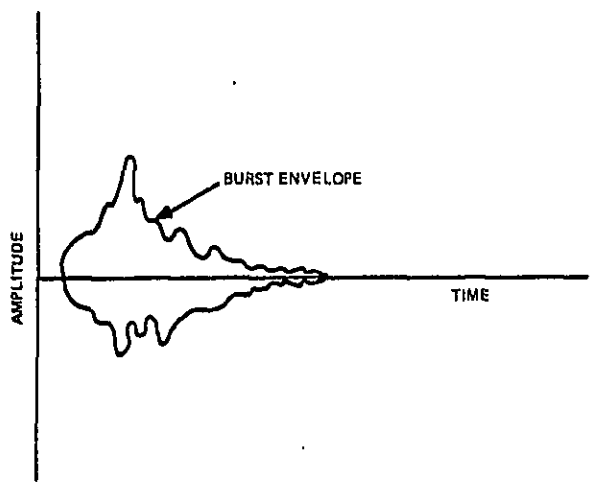
The characteristics of a burst that are usually of greatest interest include the burst duration and the magnitude of the burst (either peak, average, or rms). Other parameters of interest and methods of measurement are given in Reference 1.

References to Appendix B

(1) Institute of Electrical and Electronics Engineers. Recommended practices for burst measurements in the time domain. IEEE No. 257, May 1964.

(2) PETERSON, A.P.G. The measurement of impact noise. *General Radio Experimenter*, vol 30, no. 9, 1956.

Fig. B1
Typical Burst of Sound Pressure



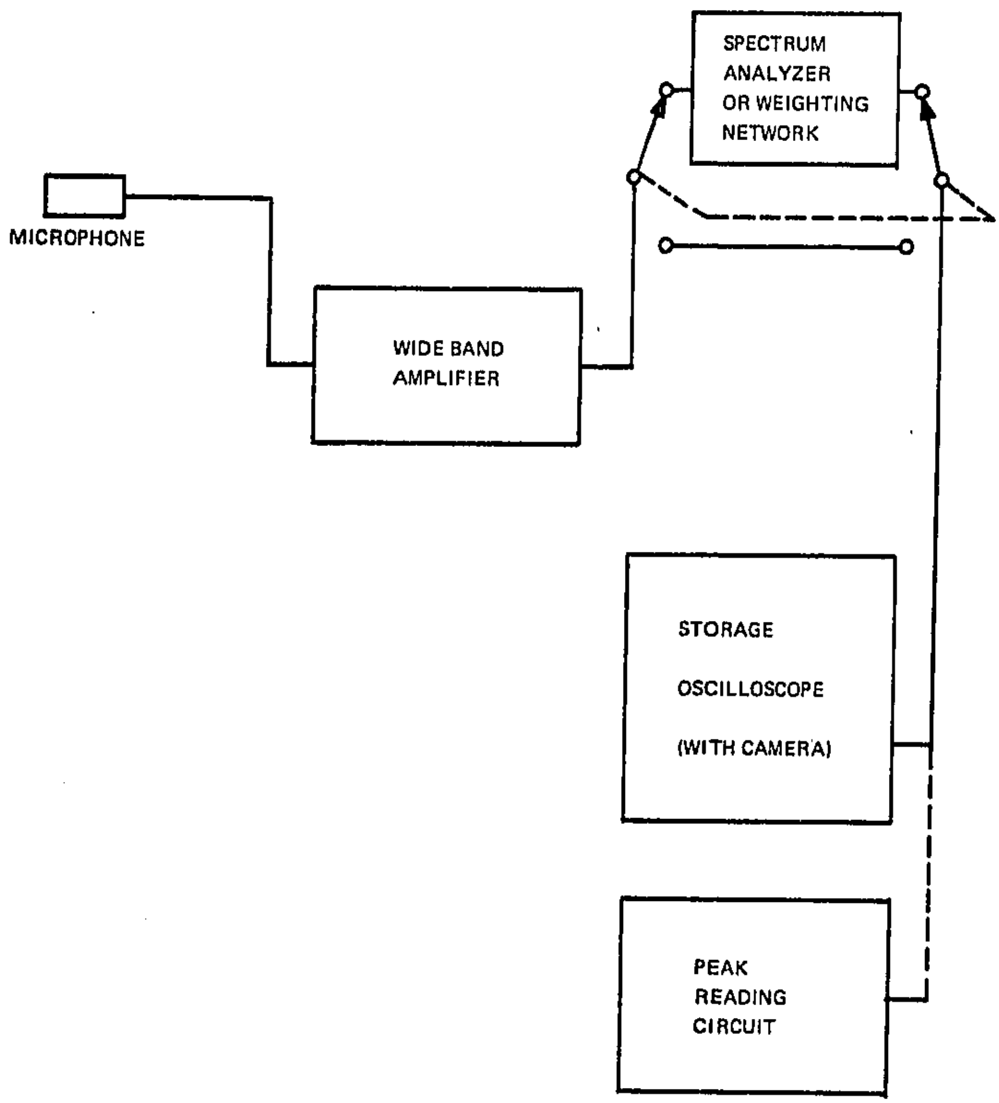


Fig. B2
Instrumentation for Burst Measurements

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American National Standard

specification for sound level meters

S1.4-1971

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ANSI
S1.4-1971
Revision of
S1.4-1961

American National Standard Specification for Sound Level Meters

Secretariat
Acoustical Society of America

Approved April 27, 1971
American National Standards Institute, Inc

American National Standard

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Foreword

(This Foreword is not a part of American National Standard Specification for Sound Level Meters, S1.4-1971.)

This standard is a revision of American National Standard Specification for General Purpose Sound Level Meters. It specifies four (4) types of sound level meters; precision, general purpose, survey, and special purpose. These four types are intended to satisfy the existing diverse requirements for precision and accuracy for the various applications of a sound level meter.

Suggestions for improvement gained in the use of this standard will be welcome. They should be sent to the American National Standards Institute, 1430 Broadway, New York, N.Y. 10018.

The S1 Standards Committee on Acoustics, which processed and approved this standard, had the following personnel at the time of approval:

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Avril Brenig, *Secretary*

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Writing Group S1-W-45 on Sound Level Meters and their Calibration, which prepared this standard, had the following personnel:

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Arnold P. G. Peterson
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Robert W. Young

Contents

American National Standard Specification for Sound Level Meters

Introduction

A sound level meter satisfying this specification will consist, in general, of the following elements: a microphone to pick up sound, an amplifier to raise the microphone output to a useful level, a calibrated attenuator to adjust the amplification to a value appropriate to the sound level being measured, an indicating instrument exhibiting the measured sound level, weightings to adjust the frequency characteristic of the response, and an output connection to accommodate additional measuring equipment.

The chief use of the sound level meter is making noise measurements in air; but it should be recognized that this standard provides for other uses, such as measuring the sound pressure level of many kinds of sound-generating devices in various media. Among the variety of uses for sound level meters are: the precision measurement of the output of noise sources and of noise environments; routine measurement of office building ventilation systems; typewriter, machinery, and other noises. In general, the more precise measurements often require more detailed analysis than can be made with the auxiliary equipment which is the subject of other American National Standards.

Because of the diverse nature of requirements for precision and absolute accuracy for the various applications, four (4) types of sound level meters are specified in this standard. These are:

Type 1 — Precision
Type 2 — General Purpose
Type 3 — Survey
Type S — Special Purpose

The precision instrument has tighter tolerances than have been heretofore specified for sound level meters; an instrument satisfying this standard will essentially satisfy the tolerances of *Precision Sound Level Meters*, IEC Publication 179, published by the International Electrotechnical Commission, Geneva, Switzerland, 1965. The general purpose instrument has tolerances which are essentially identical to those required in American National Standard Specification for General-Purpose Sound Level Meters, S1.4-1961, and which are generally more stringent than the tolerances given in *Recommendations for Sound Level Meters*, IEC Publication 123, published by the International Electrotechnical Commission, Geneva, Switzerland, 1961. The choice of instrument type by the user generally should be guided by the degree of precision required for the intended application.

It must be recognized that all practical microphones exhibit certain directional characteristics, particularly at higher frequencies, and that care must be taken to minimize errors resulting from these characteristics. Since the calibration of the sound level meter with its microphone is referred to random-incidence response, measurements of directional sounds should usually be made at a number of angles of orientation and the results averaged. Alternatively, measurements may be made at an angle at which the response of the microphone approximates its response to random-incidence sounds.

It should also be recognized that the ballistics and other characteristics of the indicating instrument are adapted mainly for measuring ordinary machinery noises and other sounds of a reasonably constant character. For intermittent sounds, and more particularly for repetitious sounds involving high peak-to-average ratios in sound pressure, and for impact noises, other specialized equipment will be required in place of the ordinary indicating instrument.

1. Purpose and Scope

1.1 Purpose. The purpose of this American National Standard for Sound Level Meters and their calibration is to ensure maximum practical accuracy in any particular sound level meter, and to reduce to the lowest practical minimum any difference in corresponding readings with various makes and models of meters that meet the standard.

1.2 Design Goal. The sound level meter is intended to be equally sensitive to sounds arriving at various angles, and to provide an accurate measurement of sound level with certain weightings for sounds within stated ranges and with an indicating instrument that has standardized characteristics. The basic calibration of the sound level meter is given in terms of a random-incidence acoustic field of known properties.

1.3 Scope. It is recognized that various degrees of precision and accuracy are required in the practical measurement of sounds of various kinds for different purposes. Hence, this standard provides the minimum requirements for three basic types of sound level meters: Types 1, 2, and 3, with performance requirements that become progressively less stringent, proceeding from Type 1 to Type 3. Further, it is recognized that sound level meters may be desired for special purposes that do not require the complexity of any of the three basic types. Therefore, provision is made for a special purpose sound level meter, Type S. The Type S meter can be qualified to the performance of any of the basic types (1, 2, and 3), but is not required to have all three weighting networks.

1.4 Limitations. If a sound level meter that meets this standard is modified, it must be demonstrated that the modified sound level meter meets this standard, if its readings are to be stated as sound level and purported to be measured in accordance with this standard.

2. Definitions

sound pressure level. 20 times the logarithm to the base of 10 of the ratio of the pressure of a sound to the reference pressure. For the purpose of this standard, the reference pressure is 20 micronewtons per square meter (2×10^{-4} microbar). Unit: decibel (dB).

sound level (noise level). Weighted sound pressure level measured by the use of a metering characteristic and weighting A, B, or C, as specified in this standard. The weighting employed must be indicated, otherwise the A weighting is understood. The reference pressure is 20 micronewtons per square meter (2×10^{-4} microbar). Unit: decibel (dB).

relative response level. Amount in decibels by which the sound level exceeds the sound pressure level. The relative response level is often negative.

indicating instrument. A device in which a pointer moves over a scale in response to an electrical signal applied to its terminals. In a sound level meter, special characteristics are required. (See Section 5.)

weightings. A prescribed frequency response provided in a sound level meter.

3. Weighting and Amplifier Characteristics and Tolerances

3.1 Weighting. The frequency characteristics for the A, B, and C weightings required for Types 1, 2, and 3 sound level meters are given in Table 1. The response for all three weightings is the same at 1000 Hz. The Type S sound level meter may incorporate one or more of these weightings, rather than the three required for the basic types (1, 2, and 3). In this event, the Type S meter must be clearly labeled as to its capabilities, such as: "Sound Level Meter Type S2A," designating a special purpose sound level meter meeting the general Type 2 requirements, but with the A weighting only. An optional wider range, "flat," characteristic may also be provided.

3.1.1 The C weighting is obtained by a network that is designed to have its lower frequency 1/2 power, or 3 decibels down point, with respect to the 1000 Hz response, at $10^{1.5}$ (or 31.62) Hz, and to approach a roll-off of 12 decibels per octave below 10 Hz. It is designed to have its high frequency 1/2 power point at $10^{3.9}$ (or 7943) Hz, and to approach a roll-off of at least 12 decibels per octave above 20 000 Hz. However, in no case shall the roll-off above 20 000 Hz and below 10 Hz be less than 6 decibels per octave.

3.1.2 The B weighting is obtained by adding a network with a response that has the performance characteristics equivalent to a simple resistor-capacitor network; it is cascaded with and isolated from the C network. The 1/2 power point for the added network is at $10^{2.2}$ (or 158.49) Hz.

3.1.3 The A weighting is obtained by adding a network with a response that has the performance characteristics equivalent to two simple cascaded identical nonisolated resistor-capacitor networks; these are cascaded with and isolated from the C network. The 1/2 power point for each of the identical added networks is at $10^{2.45}$ (or 281.84) Hz.

3.1.4 The optional flat characteristic shall have the frequency range as stated by the manufacturer.

3.2 Tolerances

3.2.1 The tolerances for Types 1, 2, and 3 sound level meters are given in Tables 2, 3, and 4 and are shown graphically in Figs. 1, 2, and 3 for illustrative purposes only. These tolerances apply for sound at random incidence and include all tolerances in the entire instrument.

The tolerances for the Type S meter shall be consistent with the performance of the basic type of sound level meter to which it is qualified. (See 3.1.)

The optional flat characteristic shall have the tolerance limits as stated by the manufacturer.

3.2.2 All settings of the sensitivity range attenuator, if provided, shall be accurate for pure tones

Table 1
Sound Level Meter Random-Incidence Relative Response Level
As a Function of Frequency for Various Weightings

Frequency Hz	A Weighting Relative Response dB	B Weighting Relative Response dB	C Weighting Relative Response dB
10	-70.4	-38.2	-14.3
12.5	-63.4	-33.2	-11.2
16	-56.7	-28.5	- 8.5
20	-50.5	-24.2	- 6.2
25	-44.7	-20.4	- 4.4
31.5	-39.4	-17.1	- 3.0
40	-34.6	-14.2	- 2.0
50	-30.2	-11.6	- 1.3
63	-26.2	- 9.3	- 0.8
80	-22.5	- 7.4	- 0.5
100	-19.1	- 5.6	- 0.3
125	-16.1	- 4.2	- 0.2
160	-13.4	- 3.0	- 0.1
200	-10.9	- 2.0	0
250	- 8.6	- 1.3	0
315	- 6.6	- 0.8	0
400	- 4.8	- 0.5	0
500	- 3.2	- 0.3	0
630	- 1.9	- 0.1	0
800	- 0.8	0	0
1000	0	0	0
1250	+ 0.6	0	0
1600	+ 1.0	0	- 0.1
2000	+ 1.2	- 0.1	- 0.2
2500	+ 1.3	- 0.2	- 0.3
3150	+ 1.2	- 0.4	- 0.5
4000	+ 1.0	- 0.7	- 0.8
5000	+ 0.5	- 1.2	- 1.3
6300	- 0.1	- 1.9	- 2.0
8000	- 1.1	- 2.9	- 3.0
10 000	- 2.5	- 4.3	- 4.4
12 500	- 4.3	- 6.1	- 6.2
16 000	- 6.6	- 8.4	- 8.5
20 000	- 9.3	-11.1	-11.2

within the following tolerance limits with respect to the setting for 80 decibels. (If no 80 decibel setting is provided, the tolerance limits shall apply with respect to a reference setting stated by the manufacturer.)

Type 1

within ± 0.5 dB   22.4 to 11 200 Hz

Type 2

within ± 0.5 dB   63 to 2000 Hz
within ± 1.0 dB   22.4 to 11 200 Hz

Type 3

within ± 1.0 dB   63 to 4000 Hz
within ± 2.0 dB   31.5 to 8000 Hz

If more than one sensitivity range is provided, it is recommended that the attenuator steps be at 10 decibel intervals.

3.3 Internal Noise and Distortion (Dynamic Range)

3.3.1 In an environment in which the sound level meter is free of observable extraneous influences, the internal noise of the sound level meter shall be specified by bands no wider than octave bands and stated in equivalent sound level for all attenuator settings. It is intended that this measurement be made at the amplifier output with an acoustically shielded microphone in place. In addition, for Type 1 and Type 2 instruments, the internal noise equivalent sound level for all attenuator settings 30 decibels or more above the maximum sensitivity setting shall be at least 40 decibels below the maximum scale reading when measured in octave bands.

3.3.2 When the microphone is replaced by an equivalent electrical impedance, the background noise level presented to the indicating instrument shall be at least 5 decibels below the lowest sound

Table 2
Total Tolerance Limits for Sound at Random Incidence
for Type 1 Sound Level Meter

Frequency Hz	A Weighting dB	B Weighting dB	C Weighting dB
10	±4	±3	±2.5
12.5	±3.5	±2.5	±2
16	±3	±2	±2
20	±2.5	±2	±2
25	±2	±2	±1.5
31.5	±1.5	±1.5	±1.5
40	±1.5	±1.5	±1
50	±1	±1	±1
63	±1	±1	±1
80	±1	±1	±1
100	±1	±1	±1
125	±1	±1	±1
160	±1	±1	±1
200	±1	±1	±1
250	±1	±1	±1
315	±1	±1	±1
400	±1	±1	±1
500	±1	±1	±1
630	±1	±1	±1
800	±1	±1	±1
1000	±1	±1	±1
1250	±1	±1	±1
1600	±1	±1	±1
2000	±1	±1	±1
2500	±1	±1	±1
3150	±1	±1	±1
4000	±1	±1	±1
5000	+1.5, -2	+1.5, -2	+1.5, -2
6300	+1.5, -2	+1.5, -2	+1.5, -2
8000	+1.5, -3	+1.5, -3	+1.5, -3
10 000	+2, -4	+2, -4	+2, -4
12 500	+3, -6	+3, -6	+3, -6
16 000	+3, -∞	+3, -∞	+3, -∞
20 000	+3, -∞	+3, -∞	+3, -∞

level that the sound level meter is intended to measure. The rated lowest level may be different for each weighting.

3.3.3 With the indicating instrument replaced by an equivalent impedance, the response to electrical sine waves in the frequency range 22.4 to 11 200 Hz shall be linear within 1.0 decibel up to 10 decibels above the voltage equivalent to the maximum scale reading for Type 1 and Type 2 instruments. The response of the Type 3 instruments in the frequency range 63 to 8000 Hz shall be linear within 1.0 decibel up to 8 decibels above the voltage equivalent to the maximum scale reading.

3.3.4 The maximum sound level for which linearity exists within 1.0 decibel shall be stated as a function of frequency for each weighting network provided, or suitable overload indicator(s) shall be provided.

4. Omnidirectional Response and Tolerances

4.1 Omnidirectional Response. Response to sound of random incidence is used as the measure of omnidirectional response. It may be measured in a diffuse sound field or calculated from free-field responses to sound arriving in different directions. The free-field calibration should be accomplished by comparison, under the general principles set forth in 7.2.1 of American National Standard Method for the Calibration of Microphones, S1.10-1966, except that sound level is to be measured instead of microphone free-field response level. One of the various methods of measurement and calculation is given in Appendix A.

Table 3
Total Tolerance Limits for Sound at Random Incidence
for Type 2 Sound Level Meter

Frequency Hz	A Weighting dB	B Weighting dB	C Weighting dB
20	+5.0, -∞	+4.0, -∞	+3.0, -∞
25	+4.0, -4.5	+3.0, -3.5	+2.0, -2.5
31.5	+3.5, -4.0	+2.5, -3.0	+1.5, -2.0
40	+3.0, -3.5	+2.0, -2.5	+1.0, -1.5
50	±3.0	±2.0	±1.0
63	±3.0	±2.0	±1.0
80	±3.0	±2.0	±1.0
100	±2.5	±2.0	±1.0
125	±2.5	±2.0	±1.0
160	±2.5	±1.5	±1.0
200	±2.5	±1.5	±1.0
250	±2.5	±1.5	±1.0
315	±2.0	±1.5	±1.0
400	±2.0	±1.5	±1.0
500	±2.0	±1.5	±1.0
630	±2.0	±1.5	±1.0
800	±1.5	±1.5	±1.0
1000	±2.0	±2.0	±1.5
1250	±2.0	±2.0	±1.5
1600	±2.5	±2.5	±2.0
2000	±3.0	±3.0	±2.5
2500	+4.0, -3.5	+4.0, -3.5	+3.5, -3.0
3150	+5.0, -4.0	+5.0, -4.0	+4.5, -3.5
4000	+5.5, -4.5	+5.5, -4.5	+5.0, -4.0
5000	+6.0, -5.0	+6.0, -5.0	+5.5, -4.5
6300	+6.5, -5.5	+6.5, -5.5	+6.0, -5.0
8000	+6.5, -6.5	+6.5, -6.5	+6.0, -6.0
10 000	+6.5, -∞	+6.5, -∞	+6.0, -∞

Table 4
Total Tolerance Limits for Sound at Random Incidence
for Type 3 Sound Level Meter

Frequency Hz	A Weighting dB	B Weighting dB	C Weighting dB
20	+6.0, -∞	+5.0, -∞	+4.0, -∞
25	+5.0, -6.0	+4.0, -5.5	+3.0, -4.5
31.5	+4.5, -5.0	+3.5, -4.0	+2.5, -3.0
40	+4.0, -4.5	+3.0, -3.5	+2.0, -2.5
50	±4.0	±3.0	±2.0
63	±4.0	±3.0	±2.0
80	±3.5	±3.0	±2.0
100	±3.5	±3.0	±2.0
125	±3.0	±2.5	±2.0
160	±3.0	±2.5	±2.0
200	±3.0	±2.5	±2.0
250	±3.0	±2.5	±2.0
315	±3.0	±2.5	±2.0
400	±3.0	±2.5	±2.0
500	±3.0	±2.5	±2.0
630	±3.0	±2.5	±2.0
800	±3.0	±3.0	±2.5
1000	±3.0	±3.0	±2.5
1250	±3.0	±3.0	±2.5
1600	±3.5	±3.5	±3.0
2000	±4.0	±4.0	±3.5
2500	±4.5	±4.5	±4.0
3150	±5.0	±5.0	±4.5
4000	±5.5	±5.5	±5.0
5000	±6.5	±6.5	±6.0
6300	±7.0	±7.5	±7.0
8000	±7.5	±7.5	±7.0
10 000	+7.5, -∞	+7.5, -∞	+7.0, -∞

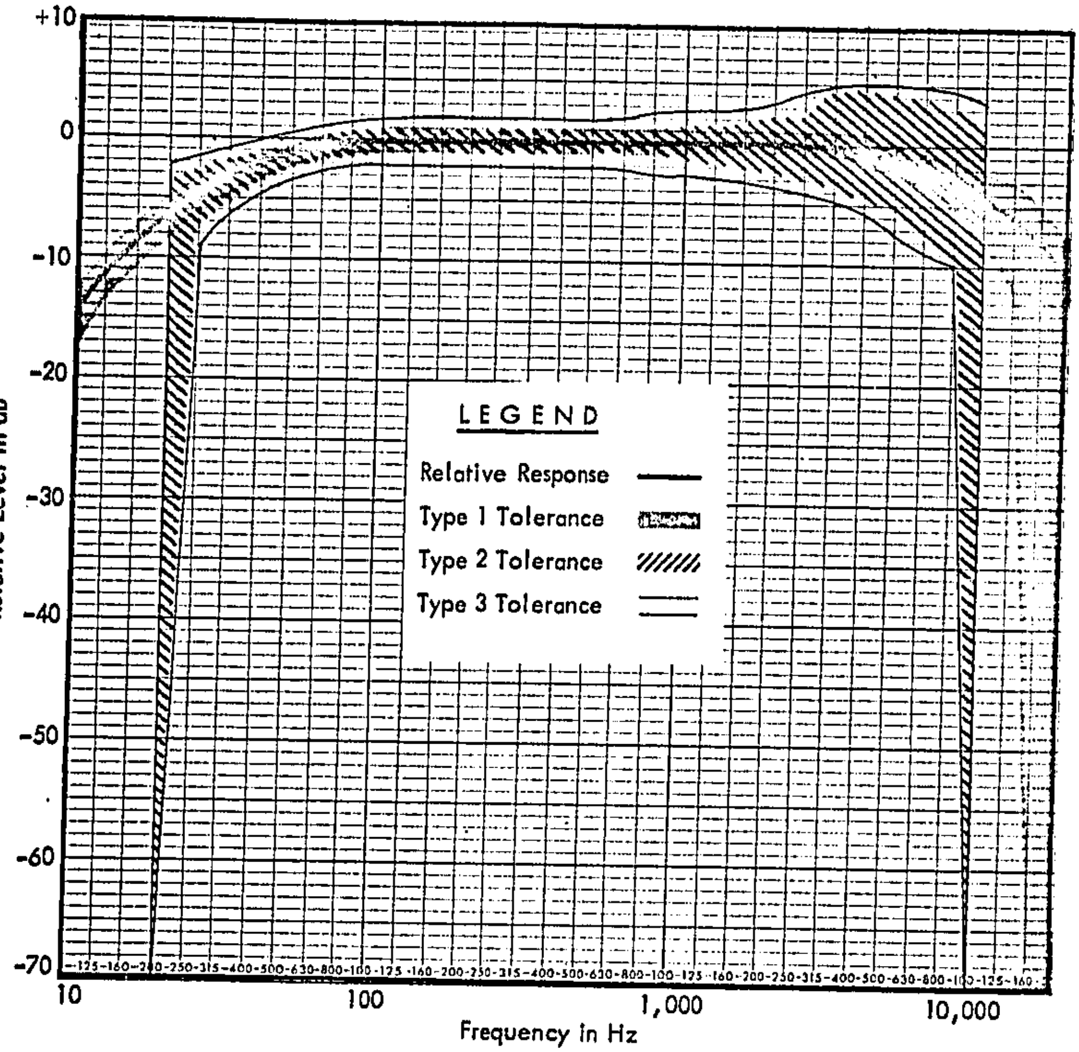

Fig. 1
Illustration of C Weighting and Tolerances for Sound at Random Incidence for Three Types of Sound Level Meters

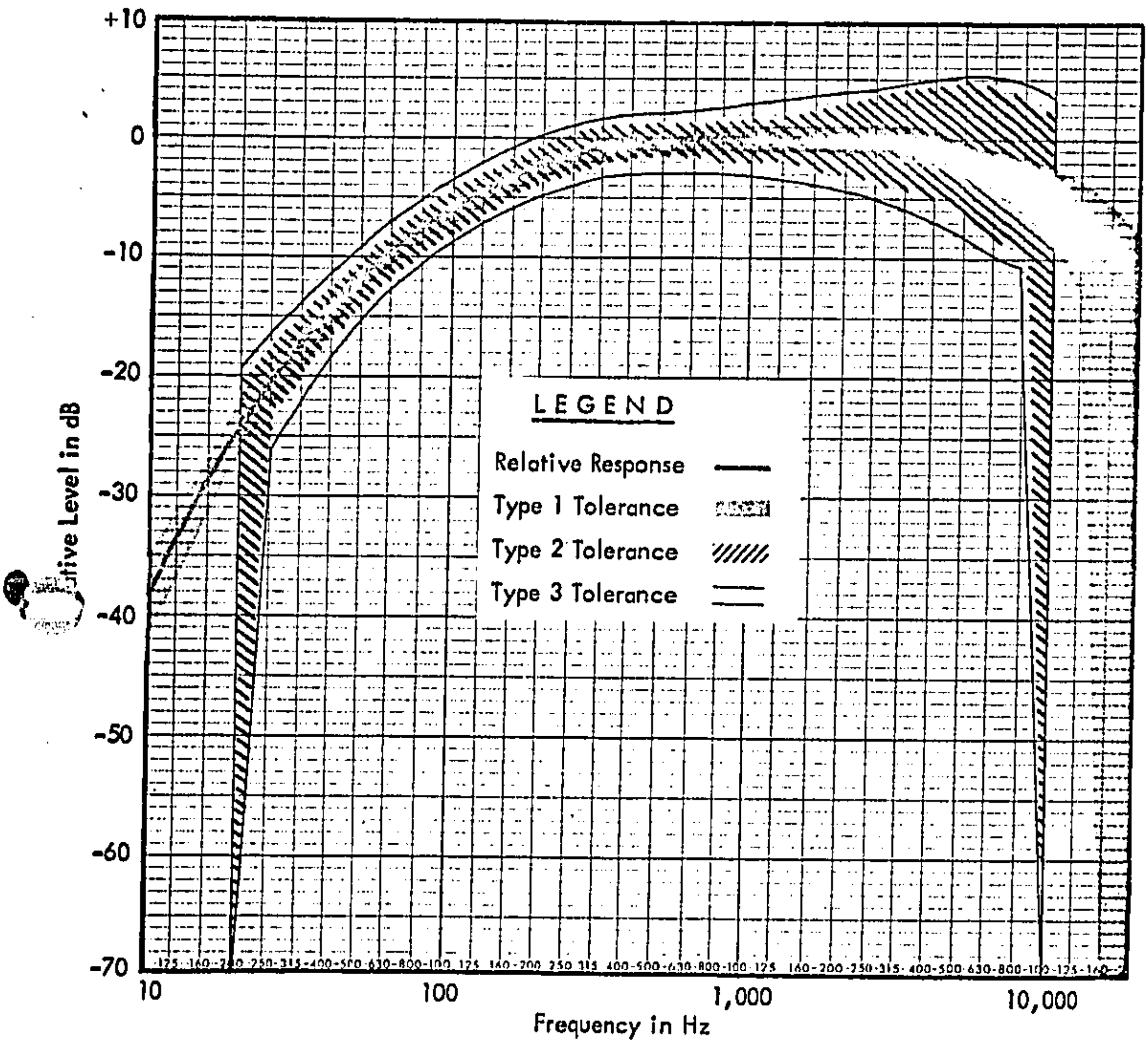

Fig. 2
Illustration of B Weighting and Tolerances
for Sound at Random Incidence
for Three Types of Sound Level Meters

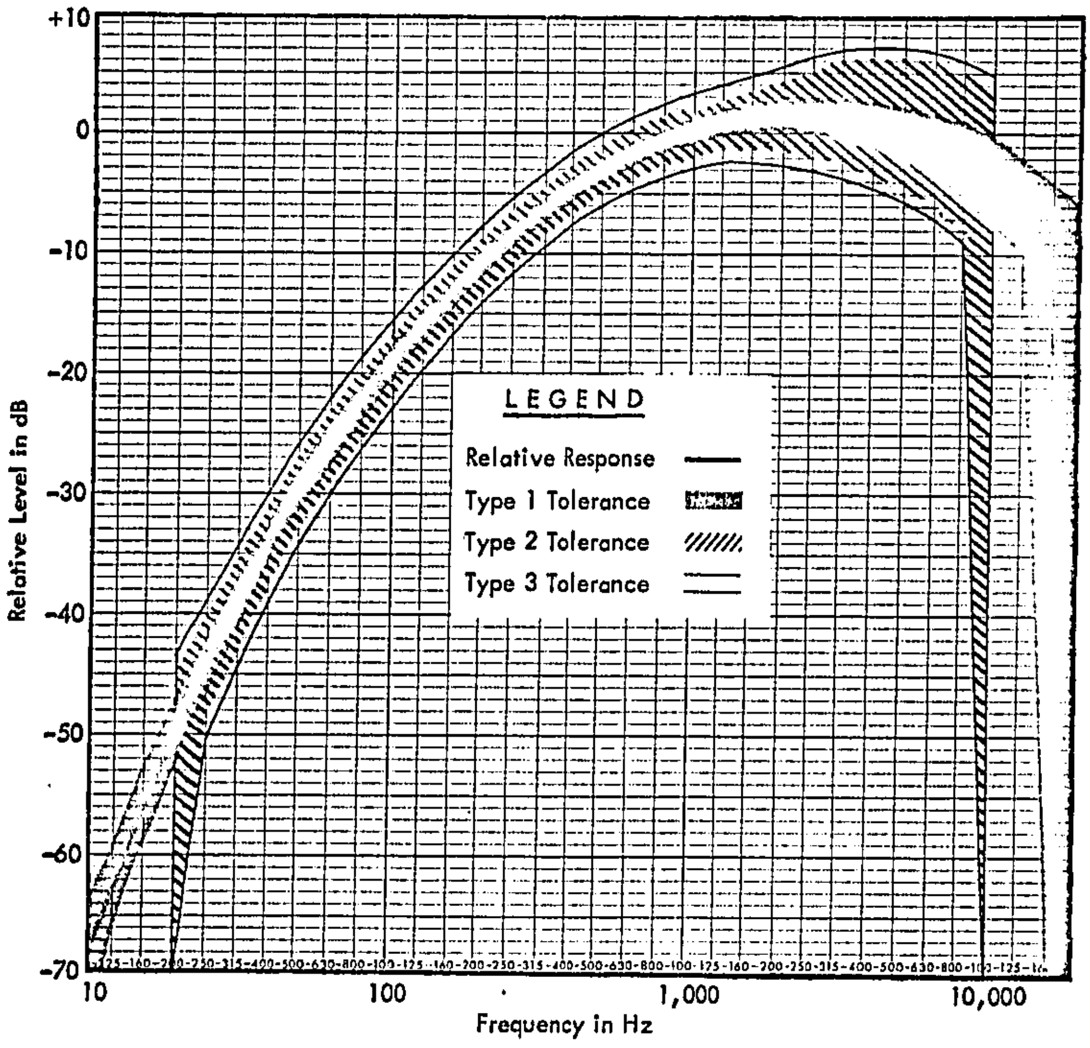

Fig. 3
Illustration of A Weighting and Tolerances for Sound at Random Incidence for Three Types of Sound Level Meters

Table 5
Maximum Allowable Deviation of Free-Field Relative Response Level with Respect to Random-Incidence Relative Response Level When the Angle of Incidence Is Varied from 45° to 90° from the Axis About Which the Response Is Most Nearly Cylindrically Symmetrical

These allowances are added arithmetically to the respective tolerance limits in Tables 2, 3, and 4.

Frequency Hz	Type 1 dB	Type 2 dB	Type 3 dB
31.5 to 2000	+1 , -1	±2	±4
2000 to 4000	+1.5, -1	±2.5	±5
4000 to 5000	+2 , -1.5	±3	±6
5000 to 6300	+2.5, -2	±3.5	±7
6300 to 8000	+3 , -2.5	±4.5	±9
8000 to 10 000	+3.5, -3.5		
10 000 to 12 500	+4 , -6.5		

Table 6
Maximum Allowable Deviation of Free-Field Relative Response Level for Sounds Arriving at Any Angle of Incidence with Respect to Random-Incidence Relative Response Level for Any Angle of Incidence

These allowances are added arithmetically to the respective tolerance limits in Tables 2, 3, and 4.

Frequency Hz	Type 1 dB	Type 2 dB	Type 3 dB
31.5 to 2000	+1.5, -1	±3	±5
2000 to 4000	+2.5, -2	+3, -4	±8
4000 to 5000	+3.5, -3	+4, -6	±9
5000 to 6300	+4 , -4	+5, -8	±12
6300 to 8000	+5.5, -5.5	+7, -9	±15
8000 to 10 000	+6.5, -8		
10 000 to 12 500	+7.5, -11		

4.2 Random Incidence Response and Tolerance

4.2.1 The free-field relative response level shall be determined with sufficient accuracy and number of frequencies to establish that the random-incidence response level of the sound level meter meets the frequency response characteristics and tolerance limits given in Tables 1 and 2, 3, or 4.

4.2.2 The maximum deviation of the free-field relative response level as a function of angle of incidence with respect to the random-incidence relative response level shall not exceed the values given in Tables 5 and 6. The specification applies for sound incident on the complete instrument and with the observer in a position specified by the manufacturer for use of the sound level meter. If the microphone can be detached and used at the distant end of an extension cable, this mode of operation may be specified.

4.3 Instrument Diffraction Effects. It is recognized that achievement of the tolerances may not be possible for all types of sound level meters unless the microphone is detached from the meter, or the observer is remote from the meter. Such limitations shall be stated clearly in the instruction book to reduce the possibility of unknowing misuse.

5. Indicating Instrument Characteristics

5.1 Scale of the Indicating Instrument

5.1.1 The scale of the indicating instrument shall be graduated in decibels in steps of 1 decibel, over a range of at least 15 decibels.

5.1.2 It is recommended that the scale be graduated from +10 decibels to the lower limit.

5.1.3 The scale of the indicating instrument shall be accurate with ±(0.2 decibel + 2 percent of the number of decibels down from full-scale indication) for a Type 1 instrument, ±(0.2 decibel +3 percent of the number of decibels down from full-scale indication) for Type 2 instruments, and ±(0.4 decibel +6 percent of the number of decibels down from full-scale indication) for Type 3 instruments.

5.2 Rule of Combination for Complex Sounds. The indicating instrument shall be of the square law type as verified by the Rule of Combination Measurement Procedure described in Appendix B. The rule of combination shall be satisfied within 0.5 decibel for the Type 1 and Type 2 meters and within 1.1 decibels for the Type 3 meter.

5.3 Fast Dynamic Characteristic. The sound level meter shall possess the following dynamic characteristics which may be identified as "FAST":

5.3.1 If a pulse of sinusoidal signal having a frequency of 1000 Hz and duration of 0.2 second is applied, the maximum reading for a Type 1 instrument shall be 0 to 2 decibels less than the reading for a steady signal of the same frequency and amplitude. For Type 2 and Type 3 instruments, the maximum reading shall be 0 to 4 decibels less.

5.3.2 If a sinusoidal signal at any frequency between 125 and 8000 Hz is suddenly applied and thereafter held constant, the maximum reading shall exceed the final steady reading by 0 to 1.1 decibels.

5.3.3 The above requirements hold for a steady reading 4 decibels less than the full-scale reading.

5.3.4 It is recommended that the decay time be essentially the same as the rise time.

5.4 Slow Dynamic Characteristic. The sound level meter may also be provided with the following dynamic characteristics which may be identified as "SLOW":

5.4.1 If a pulse of sinusoidal signal having a frequency of 1000 Hz and duration of 0.5 second is applied, the maximum reading for a Type 1 instrument shall be 3 to 5 decibels less than the reading for a steady signal of the same frequency and amplitude. For Type 2 and Type 3 instruments, the maximum reading shall be 2 to 6 decibels less.

5.4.2 If a sinusoidal signal at any frequency between 63 and 8000 Hz is suddenly applied and thereafter held constant, the maximum reading shall exceed the final steady reading by 0 to 1.6 decibels.

5.4.3 The above requirements hold for a steady reading of 4 decibels less than the full-scale reading.

5.4.4 The steady reading for any sinusoidal signal of any frequency between 31.5 and 8000 Hz shall not differ from the corresponding "FAST" reading by more than 0.1 decibel for Types 1 and 2, and 0.3 decibel for Type 3.

5.4.5 It is recommended that the decay time be essentially the same as the rise time.

5.5 Battery Indicator. If the sound level meter is battery operated, means shall be provided to indicate whether battery voltage is adequate to maintain the performance specified for the sound level meter.

6. Sensitivity Stability and Checks

6.1 Stability Precautions. The manufacturer shall state the precautions necessary to ensure that the sensitivity of the sound level meter is maintained within the limits prescribed in 3.2.

6.2 Sensitivity Checks

6.2.1 A Type 1 instrument shall include a means to check and maintain sensitivity without resort to additional equipment. For this purpose, the instrument shall contain either an acoustic coupler to check the sensitivity of the entire sound level meter or means to check the electrical sensitivity of only the amplifier and indicating instrument. If the latter approach is used, it must be possible to check the sensitivity of the entire sound level meter with an acoustic calibrator of the coupler type.

6.2.2 It is recommended that the Type 2 instrument be in accordance with 6.2.1. However, if the instrument does not contain means for checking its sensitivity, it shall be designed so that it is possible to check the sensitivity of the entire sound level meter with an acoustic calibrator of the coupler type.

6.2.3 A Type 3 instrument shall be designed so that it is possible to check the sensitivity of the entire sound level meter with an acoustic calibrator of the coupler type, or so that it is possible to check its electrical sensitivity by the insert voltage method. (See 2.1 of American National Standard S1.10-1966.)

6.2.4 For a Type 1 or 2 instrument, the internal or external electrical sensitivity check signal shall be sinusoidal, having a frequency within the range of 200 to 1250 Hz, and be stated by the manufacturer. For a Type 3 instrument, any frequency stated by the manufacturer may be used. The sound level meter shall be in either the C weighting or "flat" operation during calibration. However, if the instrument is a Type S and has no C or "flat" weighting network, it shall be calibrated at a frequency in the range of 200 to 1250 Hz, selected such that the relative response level gradient is less than 1.5 decibels per one-third octave.

6.2.5 For a Type 1 or 2 instrument, the acoustic sensitivity check signal shall be a pure tone having a frequency within the range 200 to 1250 Hz, and be stated by the manufacturer. The sound level meter shall be in either the C weighting or "flat" operation during calibration. However, if the instrument is a Type S and has no C or "flat" weighting network, it shall be calibrated at a frequency in the range of 200 to 1250 Hz, selected such that the relative response level gradient is less than 1.5 decibels per one-third octave.

6.2.6 For a Type 3 instrument, the acoustical or electrical sensitivity check signal and method for checking shall be specified by the manufacturer.

7. Sensitivity Under Various Conditions

7.1 Temperature. The temperature range over which the sensitivity of the sound level meter varies less than 0.5 decibel at any frequency shall be stated by the manufacturer. If this range does not include the extremes of −10° to 50° C, the manufacturer shall supply temperature correction values over that range. If provision for internal calibration is made in the sound level meter, the manufacturer shall state the effect, if any, of temperature upon the calibration system, and thence upon the self-calibrated sound level meter over the temperature range of −10° to 50° C. The manufacturer shall state the temperature limits beyond which permanent damage to the sound level meter may occur.

7.2 Humidity. The manufacturer shall state the range of relative humidity over which the sound level meter is intended to operate continuously. The effect of changes in relative humidity on the sensitivity of a Type 1 instrument shall be less than 0.5 decibel at any frequency between 20 and 20,000 Hz in the range of 5 to 90 percent relative humidity.

7.3 Vibration. The sound level meter shall be designed and constructed so as to reduce the effects of vibration resulting from mechanical excitation. The manufacturer shall state the precautions that should be taken by the user to ensure that readings are within specification.

For a Type 1 instrument, the manufacturer shall state the readings obtained with each weighting network when the sound level meter, with a vibration-insensitive equivalent electrical impedance substituted for the microphone, is vibrated sinusoidally along each of three mutually orthogonal axes at an acceleration of $0.1g_n$ over the frequency range 63 - 4000 Hz. The manufacturer shall also state the readings obtained under the same excitation with the microphone mounted in its normal position on the sound level meter, noting where the indicated sound pressure level exceeds that radiated directly from the vibration exciter, as determined by a nearby microphone not being vibrated. During the above tests, precaution should be exercised to reduce the acoustic radiation of the shaker.

It is recommended that the manufacturer of Type 2 and Type 3 instruments provide similar data.

7.4 Airborne Noise. The sound level meter shall be designed and constructed so as to minimize effects of vibration resulting from airborne noise. The manufacturer shall state the precautions that should be taken by the user to ensure that readings are not erroneous.

When the sound level meter with microphone, Type 1 or Type 2, is exposed to pure tone sound at any frequency or octave band noise at any center frequency in the range 63 - 8000 Hz, the reading shall be at least 20 decibels greater than a reading taken under the same conditions with the microphone replaced by an equivalent electrical impedance. This requirement shall be met, with each weighting provided and for all attenuator settings 30 decibels or more above the maximum sensitivity setting, at all sound levels that the instrument can indicate up to 130 decibels. It is recommended that the test also be made at higher levels, even if over a more limited frequency range, and that the manufacturer state the frequency range and levels over which compliance with the requirements has been verified.

If an electrical extension must be used to remove the amplifier from the sound field in order to meet this requirement, the sound level meter shall be marked to indicate the maximum sound level at which the extension is not necessary.

7.5 Magnetic and Electrostatic Fields. The effects of magnetic and electrostatic fields shall be reduced to a minimum. The sensitivity to magnetic fields, including those on the microphone, shall be indicated by the manufacturer of the sound level meter in terms of the number of oersteds required to produce a zero reading at each attenuator setting, up to a limit of 1 oersted, in a magnetic field of 50 or 60 Hz in a direction which gives maximum indication for each response curve provided.

8. Provision For Use With Auxiliary Apparatus

8.1 Analysis. A sound level meter is frequently used as a precision amplifier preceding auxiliary apparatus for data acquisition and analysis, including data storage devices, frequency filters, and indicating equipment. When the sound level meter is used as a precision amplifier for auxiliary apparatus, it is recommended that the meter be set for the C weighting, or optional "flat" weighting if it is provided, unless specific circumstances indicate that one of the other weightings should be used to obtain the information that is required. The selection of the appropriate weighting should be based on consideration of both the auxiliary apparatus utilized and the phenomenon being measured to obtain an appropriate signal-to-noise level and to reduce the magnitude of any adjustments to the data made necessary by the frequency response characteristics of various components of the entire measuring system.

8.2 Output Connections. When the sound level meter is provided with an output connection for use with auxiliary apparatus, the manufacturer shall state the nominal output voltage, the output impedance, and the recommended range of load impedances that may be connected to the sound level meter without affecting the indicating instrument reading by more than 0.5 decibel in the frequency range from 22.4 to 11 200 Hz. If a resistive load impedance of 10 000 ohms at the output connection affects the sound level meter indicating instrument reading by more than 0.5 decibel in the specified frequency range, or if the indicating instrument circuitry introduces significant distortion to the electrical output when connected to a resistive load impedance of 10 000 ohms or greater, the sound level meter indicating instrument circuitry must be automatically disconnected from the electrical output of the sound level meter, when the load is connected.

9. General

9.1 Name Plate Data. An instrument that complies with this specification shall be marked "Sound Level Meter Type 1 (2 or 3)" or "Sound Level Meter Type S 1 (2 or 3) A (B or C)," as applicable. The descriptive terms, "Precision," "General Purpose," "Survey," and "Special Purpose," may be included, as applicable. It also shall be marked with the name of the manufacturer, the model or type, and the serial number.

9.2 Instruction Manual Data. It is recommended that items of information specified for Type 1 instruments be provided for Types 2 and 3, if applicable. Each sound level meter shall be accompanied by an instruction manual that provides at least the following information, in addition to that given on the name plate:

(1) Reference sound pressure specified in 2.1.

(2) Weightings specified in 3.1 and 3.2.

(3) Calibration procedure necessary to maintain the accuracy specified in 3.2, including an explanation of the principles of operation of the calibration systems or devices and their limitations.

(4) Relative positions of observer, sound level meter, and sound source for normal use, including use of a microphone extension cable, if necessary, to satisfy the requirements of Section 4.

(5) Square law characteristic specified in 5.2.

(6) Dynamic characteristics (fast-slow) specified in 5.3 and 5.4.

(7) Procedure and frequency for acoustic and electrical sensitivity check as specified in 6.2.

(8) Range of temperature over which the sensitivity variation of the entire instrument is within 0.5 decibel (including corrections if this range does not include −10° to 50° C). (See 7.1.)

(9) Effect of temperature upon the battery life and internal calibration system (if any), including the effect upon the entire internally-calibrated instrument. (See 7.1.)

(10) Limits of temperature and relative humidity beyond which permanent damage to the instrument may occur. (See 7.1 and 7.2.)

(11) Range of relative humidity over which the sound level meter is intended to operate continuously. (See 7.2.)

(12) Influence of vibration, high level sound fields, and magnetic and electrostatic fields on the indications of the complete apparatus, including a statement of the conditions under which tests were made as well as precautions to minimize or determine the effects upon readings of these influences. (See 7.3, 7.4, and 7.5.)

(13) Procedure to ensure optimum operating conditions when the sound level meter is used with filters

or analyzers, if applicable. (See 8.1.)

(14) Electrical impedance that may be connected to the output jack (if provided) without producing a change in the meter reading greater than 0.5 decibel. (See 8.2.)

(15) For a Type 1 instrument, pressure or free-field calibration and equivalent electrical impedance in the frequency range of 20 - 20 000 Hz of the microphone furnished with the instrument.

(16) For a Type 1 instrument, the relative response of the microphone, the entire sound level meter, or both, at typical angles of incidence and random incidence.

(17) Type of microphone (electrostatic, moving coil, etc.) and model(s).

(18) Any corrections necessary when a microphone extension cable is used.

(19) Directional response characteristics and recommended angular orientation for use with plane wave sound.

(20) Upper limit of sound pressure level that the instrument can measure within the tolerances given in this standard.

10. Revision of American National Standards Referred to in This Document

When the following standards referred to in this document are superseded by a revision approved by the American National Standards Institute, the revision shall apply:

American National Standard Method for the Calibration of Microphones, S1.10-1966

Appendixes

(These Appendixes are not a part of American National Standard Specification for Sound Level Meters, S1.4-1971, but are included for information purposes only.)

Appendix A — Approximation of the Random-Incidence Relative Response Level

This appendix reviews the concept of the random incidence calibration required in Section 4, and suggests a method for determination of the random-incidence relative response level. (See Section 8 of American National Standard S1.10-1966.)

The square of the random incidence sensitivity ($S_d(f)$) is the space average mean of the squares of the sensitivities for all directions, given by:

$$S_d^2(f) = \frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi} S_o^2(\Theta, \phi, f)\sin\Theta\, d\Theta\, d\phi \qquad \text{(Eq A1)}$$

where $S_o(\Theta, \phi, f)$ = the free-field sensitivity to sound incident at the angles Θ and ϕ (where Θ is measured from the axis of the microphone and ϕ is from an arbitrary reference in the plane perpendicular to the axis), and at frequency f, both S_d and S_o are expressed in the same units, for example, volts meter²/newton.

For the purpose of basic calibration of a sound level meter as a function of both angle of incidence and frequency, it is necessary to determine the relative response level for random incidence sound as a function of frequency. The relative response level for random incidence may be calculated in a manner similar to the aforementioned from Equation A2:

$$R_{rf} = 10\log_{10}\left[\frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi}\text{antilog}\left(\frac{R(\Theta,\phi,f)}{10}\right)\sin\Theta d\Theta\, d\phi\right] \qquad \text{(Eq A2)}$$

where R_{rf} is the relative response level for random incidence sound at frequency f and $R(\Theta, \phi, f)$ is the relative response level for plane wave sound at angles Θ and ϕ, and at frequency f.

For the purpose of satisfying the specification of Section 4, the relative response level for random incidence may be computed from relative response levels obtained at a finite number of frequencies and angular orientations. The contribution (ΔK) to the random-incidence relative response from each orientation (Θ, ϕ) is given by:

$$\Delta K(\Theta_r, \phi_s, f) = \frac{1}{4\pi}\int_{\phi_s-\frac{\Delta\phi}{2}}^{\phi_s+\frac{\Delta\phi}{2}}\int_{\Theta_r-\frac{\Delta\Theta}{2}}^{\Theta_r+\frac{\Delta\Theta}{2}}\text{antilog}\left(\frac{R(\Theta,\phi,f)}{10}\right)\sin\Theta\, d\Theta\, d\phi$$

$$\cong \frac{1}{4\pi}\text{antilog}\left(\frac{R(\Theta_r,\phi_s,f)}{10}\right)\left[\cos\left(\Theta_r-\frac{\Delta\Theta}{2}\right)-\cos\left(\Theta_r+\frac{\Delta\Theta}{2}\right)\right]\Delta\phi \qquad \text{(Eq A3)}$$

where the orientation Θ_r and ϕ_s give the position of an elemental area on a unit sphere; the extent of the area is defined by the elements $\Delta\phi$ and $\Delta\Theta$; and r and s are integers representing the various elements.

Then, the random-incidence relative response level for random incidence is given by:

$$R_{rf} \cong 10\log_{10}\sum_n \Delta K(\Theta_r, \phi_s, f) \qquad \text{(Eq A4)}$$

where n is the number of elemental areas.

For this purpose, the sphere is divided into non-overlapping areas that cover the sphere completely. In no case shall n be less than 7. The angular orientation can be chosen such that the elemental areas are equal or have approximately equal contribution to the random-incidence relative response.

In general, for equal areas and cylindrical symmetry, the angles are selected by setting:

$$\cos\Theta = \pm\frac{2k}{n}, k = 0, 1, 2 \ldots\ldots \frac{n-1}{2} (n, \text{odd})$$

$$\cos\Theta = \pm\frac{2k+1}{n}, k = 0, 1, 2 \ldots\left(\frac{n}{2} - 1\right)(n, \text{even})$$

When n is chosen as 7, the values of Θ which give equal area contributions are:

31°0′, 55°9′, 73°24′, 90°0′, 106°36′, 124°51′, 149°0′

and

$$\Delta K(\Theta, f) = \frac{1}{7}\text{antilog}\frac{R(\Theta, f)}{10} \qquad \text{(Eq A5)}$$

Appendix B Method of Checking the Rule of Combination of the Indicating System for Noise

Arrange a circuit wherein a series of sine waves and one-third octave or octave bands of noise may be applied alternately to a resistor. The resistor current is measured by a thermocouple meter operating in the range in which its reading is proportional to the square of the current. The voltage developed across the resistor is applied as an electrical input to the sound level meter through a suitable network replacing the microphone, or in series with the microphone, if the acoustic pickup can be made negligible. The resistor should have a resistance no greater than one percent of the absolute value of the input impedance of the sound level meter.

Apply a sine wave voltage at a frequency of 1000 Hz and adjust the thermocouple current and sound level meter gain controls to values that yield an indicating instrument deflection of 1.0 decibel below full scale deflection. Now, instead of the sine wave, substitute a one-third octave or octave band of noise centered at 1000 Hz and adjust to obtain the same thermocouple current as before. Note the resulting average reading of the indicating instrument. The specification given in 5.2 may be considered satisfied if this reading is within the appropriate tolerances required, as compared with the reading for the 1000 Hz tone.

Repeat the operation given in the preceding paragraph for a deflection of the indicating instrument 10 decibels below full scale deflection. The average reading for the noise should be the same within the required tolerances.

Repeat the above two tests for a tone and a one-third octave or octave band of noise at frequencies of 6300 Hz and 63 Hz. Do both pairs of tests with the sound level meter set for C weighting or FLAT weighting if they are provided. For the test at 63 Hz, use the SLOW meter characteristic and determine the average deflection in the following manner: After the noise signal has been applied for at least ten seconds, note the instantaneous deflection of the indicating instrument. After a wait of at least two seconds, again note the instantaneous deflection. Continue in this manner until at least 50 values have been recorded. The average of these values is the desired average deflection.

The one-third octave or octave bands of noise should be derived from a gaussian noise source that is "pink" over the range from at least 20 Hz to 20 000 Hz, within ± 1 decibel, by means of one-third octave band filters that meet the requirements of American National Standard Specification for Octave, Half-Octave, and Third-Octave Band Filter Sets, S1.11-1966, Type 2 or 3. Here "pink" is used to mean a spectrum-level downward slope of 10 decibels/10:1 frequency span. The spectrum level of the noise source beyond 20 000 Hz should continue to decrease at a rate of at least as great as 10 decibels/10:1 frequency span.

If neither C nor FLAT weighting is provided, the signals may be inserted in the linear electronic section of the sound level meter between the weighting networks and the detection system of the sound level meter.

If A or B weighting must be used for the tests, the test at 63 Hz should be modified as follows: Determine the cutoff frequencies of the one-third octave or octave band filters used. For the purpose of this test, these frequencies may be selected as the frequencies at which the response of the filter is 4 decibels less than the maximum response of the filter. For one-third octave band filters and A weighting, set the pure tone at a frequency of 1.01 times the geometric mean of the two cutoff frequencies to account for the shift of the effective center of the band by the weighting. For one-third octave band filters and B weighting, set the pure tone at a frequency of 1.007 times the geometric mean. For an octave band of noise, the corresponsing ratios are 1.07 for A weighting and 1.03 for B weighting.

American National Standards

The standard in this booklet is one of nearly 4,000 standards approved to date by the American National Standards Institute, formerly the USA Standards Institute.

The Standards Institute provides the machinery for creating voluntary standards. It serves to eliminate duplication of standards activities and to weld conflicting standards into single, nationally accepted standards under the designation "American National Standards."

Each standard represents general agreement among maker, seller, and user groups as to the best current practice with regard to some specific problem. Thus the completed standards cut across the whole fabric of production, distribution, and consumption of goods and services. American National Standards, by reason of Institute procedures, reflect a national consensus of manufacturers, consumers, and scientific, technical, and professional organizations, and governmental agencies. The completed standards are used widely by industry and commerce and often by municipal, state, and federal governments.

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For a free list of all American National Standards, write:

American National Standards Institute, Inc

1430 Broadway **New York, N. Y. 10018**

ANSI S1.21-1972

American National Standard

methods for the determination of sound power levels of small sources in reverberation rooms

S1.21-1972

ANSI
S1.21-1972
Partial Revision of
S1.2-1962 (R1971)

American National Standard Methods for the Determination of Sound Power Levels of Small Sources in Reverberation Rooms

Secretariat

Acoustical Society of America

Approved July 11, 1972

American National Standards Institute, Inc

American National Standard

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Foreword

(This Foreword is not a part of American National Standard Methods for the Determination of Sound Power Levels of Small Sources in Reverberation Rooms, S1.21-1972.)

This standard comprises a part of a group of definitions, standards, and specifications for use in acoustical work. It has been developed under the Standards Committee Method of Standards Institute procedure. The Acoustical Society of America is the secretariat.

American National Standards Committee S1, under whose jurisdiction this standard was developed, has the following scope:

Standards, specifications, methods of measurement and test, and terminology in the fields of physical acoustics, including architectural acoustics, electroacoustics, sonics and ultrasonics, and underwater sound, but excluding those aspects which pertain to safety, tolerance, and comfort.

Various working groups have been organized to take care of the committee's program, and this standard was developed by Working Group S1-50.

This standard is a revision of Section 3.5, Determination of Sound Power in a Diffuse Field, of American National Standard Method for the Physical Measurement of Sound, S1.2-1962 (R1971).

Suggestions for improvement of this standard will be welcome. They should be sent to the American National Standards Institute, Inc, 1430 Broadway, New York, N.Y. 10018.

American National Standards Committee on Acoustics, S1, had the following personnel at the time it approved this standard:

W. W. Lang, Chairman
E. E. Gross, Jr, Vice-Chairman
Avril Brenig, Secretary

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American National Standard Methods for the Determination of Sound Power Levels of Small Sources in Reverberation Rooms

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Directional characteristics of the source

Applicability

Type of Source:	Device, machine, component, subassembly
Volume of Source:	Preferably less than 1% of test room volume
Noise of Source:	Steady, broad-band sound, with or without discrete-frequency and narrow-band components
Test Environment:	Prescribed reverberation room

Laboratory Methods

Direct
Comparison

Introduction

(The material in this Introduction is intended for purposes of background and orientation.)

This standard describes in detail two laboratory methods for determining the sound power radiated by a device, machine, component, or subassembly as a function of frequency using a reverberant test room having prescribed acoustical characteristics. While other methods could be used to measure the noise emitted by machinery and equipment, the methods described in this standard are particularly advantageous for rating the sound output of sources which produce steady noise and for which directivity information is not required. If the source emits nonsteady noise or if directivity information is desired, the methods specified in the following standards and recommendations should be selected:

American National Standard Method for the Physical Measurement of Sound, S1.2-1962 (R1971)

American National Standard Methods for the Measurement of Sound Pressure Levels, S1.13-1971

ISO Recommendation R 495-1966, General Requirements for the Preparation of Test Codes for Measuring the Noise Emitted by Machines[1]

ISO/TC 43 Draft ISO Recommendation No. 2204, Guide to the Measurement of Acoustical Noise and Evaluation of Its Effects on Man[1]

The measurement described here yields physical data that may be used for:

(1) Rating apparatus according to its sound power output.

(2) Establishing sound control measures.

(3) Predicting sound pressure levels produced by a device or machine in a given enclosure or environment.

However, the detailed methods for utilizing the data for these purposes are not included in this standard.

In this standard, the computation of sound power levels from sound pressure level measurements made in a reverberant sound field is based on the premise that the mean-square sound pressure averaged in space and time is: 1) directly proportional to the sound power output of the source, 2) inversely proportional to the total absorption in the room, and 3) otherwise depends only on the physical constants of air density and velocity of sound.

The relationship between the space/time average sound pressure generated in the reverberation room by an unknown source of sound and the sound power output of that source can be established by either one of two methods: the direct method or the comparison method. The direct method uses measurements of the reverberation time (decay rate) in the room, and the comparison method uses a calibrated reference sound

[1]Publications of the International Organization for Standardization are available from the American National Standards Institute, 1430 Broadway, New York, N.Y. 10018.

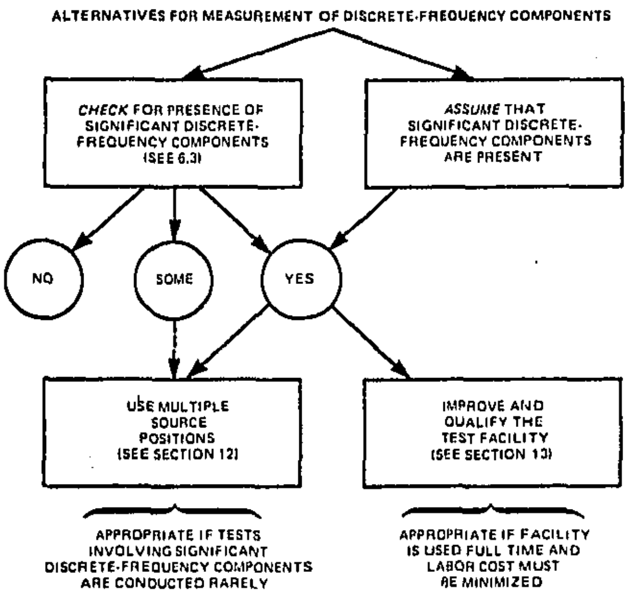

Fig. 1
Alternatives for Measurement of Discrete-Frequency Components

source. While the comparison method is almost exclusively used in industrial test programs, the direct method is frequently used in research. It is expected that some industrial sound test codes for specific types of equipment will specify only one of these methods.

As far as the direct method is concerned, it should be noted that Eq 3 contains a correction term which was not used in the corresponding equation in American National Standard S1.2-1962 (R1971). This term, $10 \log_{10} (1 + S\lambda/8V)$, accounts for the fact that a space-averaging procedure which, for practical reasons, excludes the region near the walls, tends to yield results which are consistently somewhat lower than the true space average taken over the entire room volume (see [4][2]). While this difference is no larger than the expected random errors (Table 1), it was felt that the correction should be included to eliminate the systematic differences often observed in comparing data obtained by the direct method against data obtained from free-field measurements (see [3]). This correction is not necessary when using the comparison method because the comparison method is based on relative rather than absolute values of the space-averaged sound pressure level.

It is recognized that precision measurements in reverberation rooms become more complicated when the spectrum of the sound to be measured is not distributed smoothly but contains significant discrete-frequency or narrow-band components. One might, therefore, be tempted to limit the standard to broad-band sound as was done in the case of the corresponding section of American National Standard S1.2-1962 (R1971). This limitation is particularly tempting because the sound generated by most well-designed equipment, in fact, does not contain significant discrete-frequency components. On the other hand, there is obviously no guarantee that such components are not radiated by the equipment under test. Moreover, there is no longer a serious problem in measuring the sound power output of discrete-frequency sources, provided the wavelength is short compared to the size of the test room [1, 2].

Ideally, the reverberation room should be big enough (or equipped with rotating diffusers or low-frequency absorbers, or both), and extensive sampling of the sound field should be carried out to provide the desired accuracy regardless of the shape of the spectrum emitted by the source. The cost of such an ideal facil-

[2]Numbers in brackets refer to corresponding numbers in Section 14.2, References to the Text.

Table 1
Uncertainty in Determining Sound Power Levels of Sound Sources in Reverberation Rooms

Octave Band Center Frequencies (Hz)	One-Third Octave Band Center Frequencies (Hz)	Standard Deviation (dB)
125	100 to 160	3.0
250	200 to 315	2.0
500	400 to 630	1.5
1000	800 to 1250	1.5
2000	1600 to 2500	1.5
4000	3150 to 5000	1.5
8000	6300 to 10 000	3.0

ity, however, is high and can be justified only if the usage factor is sufficiently great. If a facility is used only occasionally for sound power determinations of sounds containing discrete-frequency components, the extra cost is not likely to be justifiable. This standard, therefore, allows an alternative procedure in which the source is tested in a number of positions, the number of positions depending upon the prominence of the discrete-frequency component, its frequency, and the properties of the reverberation room. The test for the presence and significance of discrete-frequency components is described in 6.3, and the computation of the number of source positions required is described in Section 12.

It is, of course, possible to bypass the tests of 6.3 if one is willing to use either the maximum number of source positions called for in Section 12 or if the test facility is qualified for discrete-frequency sound in accordance with Section 13. A flowchart for these various alternative approaches is shown in Fig. 1.

1. General

1.1 Scope and Purpose. This standard describes a direct method and a comparison method for determining the sound power level produced by a source. This standard contains test room requirements, source location and operating conditions, instrumentation, and techniques for obtaining an estimate of the mean-square sound pressure from which the sound power level of the source in octave or one-third octave bands is calculated. It is intended to provide techniques for acoustical measurements that can be used in test codes for particular types of equipment.

1.2 Applicability. This standard applies primarily to the measurement of sound that is uniformly distributed in frequency over the frequency range of interest and is relatively steady for at least 30 seconds. The spectrum of the sound may also include prominent discrete-frequency components or narrow bands.

When a source emits narrow-band or discrete-frequency sound, a determination of its sound power level in a reverberation room requires the use of a greater number of source locations and microphone positions (or a greater path length of a moving microphone). The required numbers of locations and positions depend upon the desired accuracy, the spectrum of the radiated noise, and the properties of the test room. These numbers can usually be reduced if one or more rotating diffusers are operated in the test room during the measurements. Guidelines for the design of suitable rotating diffusers are given in Appendix B. The use of rotating diffusers reduces the effort required to make measurements on sources that emit discrete-frequency components. If the source emits primarily discrete-frequency sound below 200 Hz, this standard may not be suitable, and a free-field measurement should be considered.

1.2.1 Size of Source. This standard applies only to small sound sources; that is, sources with volumes which are preferably less than 1% of the volume of the reverberation room used for the test.

1.3 Measurement Uncertainty. Measurements made in conformance with this standard tend to result in standard deviations which are equal to or less than those given in Table 1. The standard deviations of Table 1 reflect the cumulative effects of all causes of uncertainty. (See [1, 2].)

2. Definitions

In this standard the following definitions shall apply:

comparison method. Calculation of sound power level by comparison of measured sound pressure levels produced by the source in a reverberation room with the mean-square sound pressure levels produced in the same room by a reference sound source (RSS) of known sound power output.

direct method. Calculation of sound power level from the measured sound pressure levels produced by the source in a reverberation room and from the reverberation time and volume of the reverberation room.

discrete-frequency component of the sound emitted. A component having an instantaneous sound pressure which varies essentially as a simple sinusoidal function of time.

frequency range of interest. For general purposes, the octave bands of interest are those with center frequencies between 125 and 8000 Hz. The one-third octave bands of interest are those with center frequencies between 100 Hz and 10 000 Hz. For special purposes, the frequency range of interest may be extended by one octave (or three one-third octaves) at either end, provided the test room is satisfactory for use over the extended frequency range. For sources which radiate predominantly high (or low) frequency sound, the frequency range of interest may be limited in order to optimize the test facility and procedure. For this purpose, any band in which the level is 40 dB or more below the highest band pressure level may be excluded from consideration.

mean-square sound pressure. The sound pressure averaged in space and time on a mean-square basis using the time-averaging procedure specified in 4.2 and the space-averaging procedure specified in 6.2.

The finite averaging time and finite microphone path length (or finite number of fixed microphone positions) as well as deviations from the ideally reverberant sound field are responsible for the uncertainties given in Table 1.

reverberant sound field. That portion of the sound field in the test room over which the influence of sound received directly from the source is negligible.

reverberation room. A test room characterized by a small amount of sound absorption and satisfying the criteria of Section 3.

sound power level, L_W. Ten times the logarithm to the base 10 of the ratio of a given sound power to the reference sound power. The reference sound power is 1 pW (1 pW = 10^{-12} W). Unit: decibel (dB).

sound pressure level, L_p. Ten times the logarithm to the base 10 of the ratio of the mean-square pressure of a sound to the square of the reference pressure. The reference pressure is 20 μN/m^2. Unit: decibel (dB).

NOTE: The width of the frequency band should be indicated by a qualifying modifier; for example, octave band sound pressure level, one-third octave band sound pressure level, etc.

wavelength, λ. The speed of sound in air (approximately 345 meters per second) divided by the frequency in hertz.

3. Test Room Requirements

3.1 General. The test room shall be large enough and have low enough total sound absorption to provide an adequate reverberant sound field for all frequency bands within the frequency range of interest. (See Appendix A.) The test room shall be adequately isolated from extraneous noise.

3.1.1 Criterion for Room Adequacy. The adequacy of the test room for measurements according to this standard, including benefits resulting from stationary and moving sound diffusers, shall be established by the procedure of Section 11.

3.1.2 Criterion for Adequate Isolation. The background noise level shall be at least 6 dB and preferably more than 12 dB below the sound pressure level to be measured in each frequency band within the frequency range of interest.

3.2 Room Volume. The room volume should be at least 180 m^3 and preferably 200 m^3 for measurements including the 125-Hz octave band, and 70 m^3 for measurements covering only the 250-Hz and higher octave bands (see Appendix A).

3.3 Room Absorption. The absorption of the test room affects the minimum distance to be maintained between the source and the microphone positions. It may also influence the sound radiation of the source. For these reasons the absorption should be neither too large nor extremely small (see Appendix A).

3.3.1 Surface Treatment. The floor of the test room shall be reflective with an absorption coefficient below 0.06. None of the other surfaces should have absorptive properties significantly deviating from each other. For each one-third octave band within the frequency range of interest, the mean value of the absorption coefficient of each wall and of the ceiling should be within 0.5 and 1.5 times the mean value of the absorption coefficient of all walls and ceiling.

3.4 Criteria for Temperature and Humidity. The air absorption in the reverberation room varies with the temperature and humidity particularly at frequencies above 1000 Hz. The temperature t (in degrees Celsius) and the relative humidity rh (in percent) shall be controlled during the sound pressure level measurements. The product rh (t + 5°C) shall not differ by more than

± 10% from the value of the product which prevailed during the measurements of the reverberation time (for the direct method) or reference sound source (for the comparison method).

4. Instrumentation

4.1 General. The characteristics of the instrumentation shall be consistent with the procedure selected for averaging the sound pressure, on a mean-square basis, in space and in time. Several alternative procedures for space averaging are listed in 6.2. Those involving automatic sampling of the sound field by either a moving microphone or a scanned array combine the space-averaging and time-averaging operations and thus require indicating devices with correspondingly long integration (averaging) time constants.

4.2 Indicating Device. There are two alternative approaches to time-averaging the output voltage of the octave (or one-third octave) band filters, $e_o(t)$:

(1) Integration of the squared voltage over a fixed time interval, τ_D, by analog or digital means. This is the preferred method.

(2) Continuous analog averaging of the squared voltage using an RC network with a time constant, τ_A. This provides only an approximation of the true time average, and it places restrictions on the "settling" time and observation time (see 6.4.1).

4.2.1 Integration over a Fixed Time Interval. If this method is used, the standard deviation of estimates of the level of the mean-square voltage shall be less than 0.25 dB for a steady sine wave input over the frequency range of interest, and the average value of a series of 10 estimates of the level of the mean-square value of $e_o(t)$ shall not differ from the value obtained by continuous integration by more than ± 0.25 dB. The integration time, τ_D, shall be identical to the observation period used (for minimum values of observation periods, see 6.4; for the relationship between integration time and microphone traversing or scanning period, if applicable, see 6.2.1).

4.2.2 Continuous Averaging. The time constant, τ_A, shall be at least 1 second, and long enough to meet the criterion of 6.2.1.

4.3 The Microphone and Its Associated Cable. The microphone shall have a flat frequency response for randomly incident sound over the frequency range of interest. The microphone shall meet the requirements for use in a Type 1 precision sound level meter according to American National Standard Specification for Sound Level Meters, S1.4-1971. The microphone (and its associated cable) shall be chosen so that its sensitivity does not change by more than 0.5 dB in the temperature range encountered in the measurement. If a moving microphone is used, care shall be exercised to avoid introducing acoustical or electrical noise (for example, from gears, flexing cables, or sliding contacts) that could interfere with the measurements.

Table 2
Relative Tolerances for the Instrumentation System

Frequency (Hz)	Tolerance Limits (dB)
50 to 80	± 1.5
100 to 4000	± 1
5 000	+ 1.5, −2
6 300	+ 1.5, −2
8 000	+ 1.5, −3
10 000	+ 2, −4
12 500	+ 3, −6

4.4 Frequency Response of the Instrumentation System. The frequency response of the instrumentation calibrated for randomly incident sound shall be determined according to the procedures of American National Standard Method for the Calibration of Microphones, S1.10-1966 (R1971). The random-incidence response shall be within the tolerances given in Table 2.

4.5 Frequency Analyzer. An octave band or one-third octave band filter set meeting at least the requirements for Class II filters of American National Standard Specification for Octave, Half-Octave, and Third-Octave Band Filter Sets, S1.11-1966 (R1971), shall be used.

4.6 Calibration. At least before each series of measurements, an acoustical calibrator with an accuracy of ± 0.5 dB or better shall be applied to the microphone for calibration of the entire measuring system at a single frequency (or preferably at several frequencies). The calibrator shall be checked at least annually to verify that its output has not changed.

In addition, an electrical calibration of the complete instrumentation system over the entire frequency range of interest shall be performed at least annually and preferably prior to each series of measurements. An acoustical calibration over the entire frequency range of interest should be performed at least annually.

5. Installation and Operation of Source

5.1 General. When the source is mounted near one or more reflecting planes, the radiation impedance may differ appreciably from that in free space, and the sound power radiated by the source may depend strongly upon its position and orientation. It may be of interest to determine the radiated sound power either for a particular position and orientation of the source or as the average value for several positions and orientations.

5.2 Source Location. The source to be tested shall be placed in the reverberation room in one or more positions that are typical of normal usage.

NOTE: If possible, the source should be located at least 1.5 m from any wall of the room.

5.3 Source Mounting. In many cases the sound power emitted will depend on the support or mounting conditions of the source, which shall be carefully described in the test report. Whenever a typical condition of mounting or use exists for the apparatus under test, that condition should be used or simulated for the test, if practicable. No major surfaces of the source should be oriented parallel to a nearby surface of the reverberation room unless the source is so oriented in its typical mounting condition.

NOTES:

(1) A source normally mounted through a window, wall, or ceiling shall be mounted through the wall or ceiling of the reverberation room and located at least 1.5 m from any other surface, except that sources normally mounted near a corner shall be located at the normal distance from such a corner.

(2) Equipment normally installed on a table or stand shall be so mounted during the test.

5.4 Auxiliary Equipment. Care should be taken to assure that any electrical conduits, piping, or air ducts connected to the equipment do not radiate a significant amount of sound energy into the test room. If possible, all auxiliary equipment necessary for the operation of the device under test shall be located outside the reverberation room.

5.5 Operation of Source During Tests. During the acoustical measurements, the source shall be operated in a specified manner typical of normal use. The following operational conditions may be appropriate:

(1) Device under normal load

(2) Device under full load (if different from (1))

(3) Device under no-load (idling)

(4) Device under operating conditions corresponding to maximum sound generation

The sound power levels of sources may be determined for any desired set of operating conditions (that is, temperature, humidity, device speed, etc). These test conditions shall be selected beforehand and shall be held constant during the test. The source should be warmed up and in a stable condition before any sound measurements are made.

6. Determination of Mean-Square Pressure and Number of Source Positions

6.1 General. The major cause of uncertainty in determining sound power in a reverberation room is the spatial irregularity of the sound field. The extent of this irregularity and, hence, the effort required to determine the mean-square pressure accurately is greater for discrete-frequency sound than for broad-band sound.

The procedure of 6.3 shall be used to determine if significant discrete-frequency components or narrow bands of noise are present in the sound emitted by the source. If so, the provisions of Section 12 or Section 13 shall be applied in addition to those of this section.

6.2 Microphone Positions. Space averaging of the sound field shall be accomplished by one of the following two procedures:

(1) Traversing a microphone at constant speed over a path *at least* 3 m in length while the signal is being averaged on a mean-square basis. The path may be a line, an arc as obtained by swinging the microphone, a circle, or some other geometric figure.

(2) Using an array of *at least* three fixed microphones (or microphone positions) spaced at least $\lambda/2$ from each other, where λ is the wavelength of sound corresponding to the lowest frequency in the frequency range of interest. The outputs of the microphones shall be either scanned automatically and averaged on a mean-square basis by the indicating device, or the average shall be computed from the mean-square outputs of each individual microphone position.

NOTE: A path length of 3 m for the traverse and three positions for the array are minimum requirements. It may be necessary to use a more extensive microphone traverse or array, or use moving or stationary sound diffusers, or both, in order to meet the requirements of 11.5.

6.2.1 Repetition Rate. The repetition rate of the microphone traverse (or the scanning rate for an array of fixed microphones) shall meet the following criteria

(1) There shall be a whole number of microphone traverses or array scans during the observation period (see 6.4.1).

(2) If integration over a fixed time interval, τ_D, is used (see 4.2.1), there shall be a whole number of microphone traverse or array scans during the integrating time of the indicating device.

(3) If continuous averaging is used (see 4.2.2), the traverse or scanning period shall be less than 2 times the time constant of the indicating device.

6.2.2 Location of Microphone Traverse or Array. The microphone traverse or array shall be within that part of the test room where the reverberant sound field dominates and where the contribution of the direct field to the measured mean-square pressure is negligible. To ensure that the chosen microphone traverse or array is within the reverberant field, the following criteria shall be met:

(1) The minimum distance between the sound source and the nearest microphone position shall not be less than

$$d_{min} = 0.08 \sqrt{V/T}$$

where

V = volume of test room in cubic meters

T = reverberation time in seconds

(2) The requirements given in 11.5 shall be met, using the chosen traverse or array.

The microphone traverse or array shall not lie in any plane within 10 degrees of a room surface. No point on the traverse or array shall be closer than $\lambda/2$ to any room surface of the reverberation room, where λ is the wavelength of sound corresponding to the lowest frequency in the frequency range of interest.

The microphone traverse or array shall avoid areas of air discharge (if any) or sound beaming from the equipment being tested.

6.3 Determination of the Significance of Discrete-Frequency Components and Narrow Bands of Noise. If the source spectrum contains significant discrete-frequency components or narrow bands of noise, additional microphone positions and more than one source location are usually required (see Section 12) to meet the accuracy objectives of Table 1. First, however, determination may be made concerning the presence and significance of discrete-frequency components or narrow bands of noise in the spectrum of the sound emitted by the source.

Alternatively, it may be assumed that the spectrum of the sound emitted by the machine or equipment under test does contain significant discrete-frequency components. In this case, either the additional source positions described in Section 12 shall be used, or the test setup shall be qualified as described in Section 13.

If the room qualifies according to the requirements of Section 13, additional source locations are not required. Qualification of the test setup according to Section 13 is usually possible only when a rotating diffuser and additional microphone positions are used in the room.

6.3.1 Presence of Discrete-Frequency Components. When a discrete-frequency component is present in the spectrum of a source, the spatial distribution of the sound pressure level usually exhibits maxima separated by minima having an average spacing of approximately 0.8λ where λ is the wavelength corresponding to the frequency of the sound. An example of the spatial variation in pressure level for discrete-frequency sound is shown in Fig. 2.

6.3.2 Qualitative Procedure. The presence of a significant discrete-frequency component can often be detected by a simple listening test. If such a component is audible (or detectable by narrow-band analysis), the measurements described in 6.3.3 may be omitted. In this case, either the provisions of the bottom row of Table 6 shall be applied or the test setup shall be qualified as described in Section 13.

Discrete-frequency components may be present in the spectrum even when these components are not audible. A conclusion that no significant discrete-frequency components are present can only be reached by performing the test described in 6.3.3.

6.3.3 Estimate of Standard Deviation. An estimate of the standard deviation of the sound pressure levels in the room is obtained as follows:

(1) Select an array of six fixed microphones (or microphone positions) spaced at least $\lambda/2$ apart where λ is the wavelength of the sound corresponding to the lowest frequency of the frequency band of interest. Locate the source at a single position in the test room. Obtain the time-averaged sound pressure level L_i at each microphone position. Instead of a fixed array, a single microphone may be positioned at six points equally spaced along a path at least three wavelengths long. The time-averaged sound pressure level is determined at each point.

(2) For each one-third octave or octave band within the frequency range of interest, calculate the standard deviation from the following equation:

$$s = (n-1)^{-1/2} \left[\sum_{i=1}^{n} (L_i - L_m)^2 \right]^{1/2} \qquad \text{(Eq 1)}$$

where

s = standard deviation in decibels

L_i = sound pressure levels measured at the individual microphone positions in decibels

L_m = arithmetic mean of sound pressure levels, L_i, in decibels

n = number of measurements (six)

(3) The standard deviation, s, is used in 12.2 to determine the microphone path length and the number of source locations required. The magnitude of s depends upon the properties of the sound field in the test room. These properties are influenced by the characteristics of the room as well as the characteristics of the source (that is, directivity and spectrum of emitted sound). In theory, a standard deviation of 5.56 dB corresponds to a spectral component of infinitesimal bandwidth, that is, a discrete tone (see [5]).

6.4 Sound Pressure Level Readings. Determinations of the sound pressure level along the microphone traverse

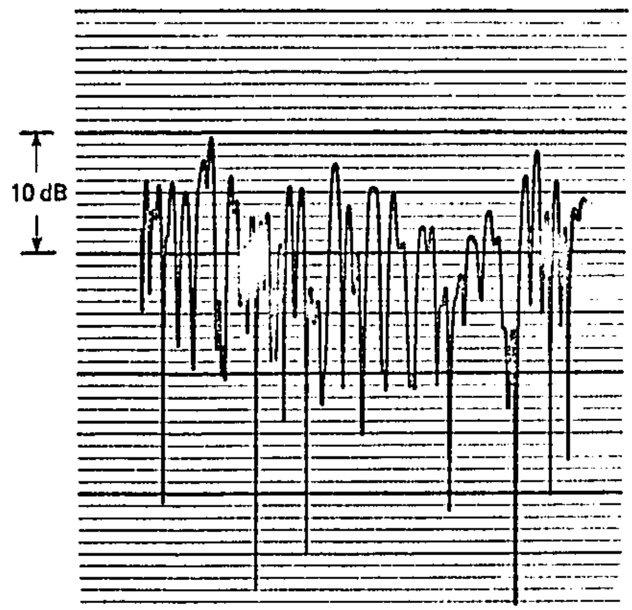

Fig. 2
Spatial Variation in Sound Pressure Level for a Discrete-Frequency Source
(f = 1000 Hz; scan speed = 15 cm per second)

(or at individual microphone positions) shall include the following values for each frequency band within the frequency range of interest:

(1) The space/time averaged band pressure levels produced by background noise, including noise from the support equipment, the motion of the microphone and diffuser (if any), and internal electrical noise in the measuring instrumentation.

(2) The space/time averaged band pressure levels during operation of the source being tested.

(3) If applicable, the space/time averaged band pressure levels during operation of the reference sound source (see 7.3.2).

The microphone traverse or array shall be the same for each set of readings and shall meet the requirements of 6.2. The sound diffuser(s) (if any) shall be operated identically for each set of readings. No observers or operators shall be in the test room during the measurements unless necessary for operating the device under test.

6.4.1 Period of Observation. The readings shall be averaged over the following periods of observation:

(1) For frequency bands centered on or below 160 Hz, the period of observation shall be at least 30 seconds.

(2) For frequency bands centered on or above 200 Hz, the period of observation shall be at least 15 seconds.

NOTE: If the instrumentation uses continuous time averaging (RC smoothing), no observation shall be started after switching the averager to a new microphone or filter until a "settling" time of five times the time constant of the instrumentation has elapsed. The observation time shall be at least as long as the "settling" time.

6.4.2 Correction for Background Sound Pressure Level. The measured band pressure levels shall be corrected, if necessary, for the background noise according to Fig. 3. When the background noise level is less than 6 dB below the sound pressure level with either the reference sound source or the equipment operating, the accuracy of the measurements will be reduced, and no data shall be reported.

6.4.3 Calculation of Mean Band Pressure Levels. If a continuous path or automatic microphone scanning is used, the measured levels (corrected according to 6.4.2) in each frequency band of interest constitute the desired estimate of the space/time averaged sound pressure level, L_p. If individual microphone positions are used, the levels (corrected according to 6.4.2) for each

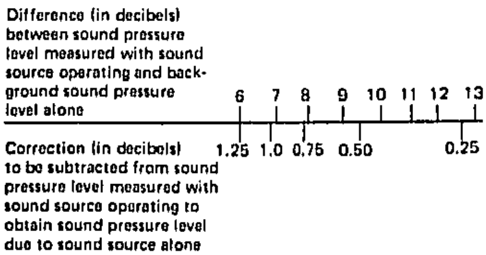

Fig. 3
Corrections for Background Sound Pressure Levels

frequency band of interest shall be averaged by using the following equation:

$$L_p = 10 \log_{10} \left[\frac{1}{n} \sum_{i=1}^{n} \text{antilog}_{10} \left(\frac{L_i}{10} \right) \right] \qquad \text{(Eq 2)}$$

where

L_p = mean band pressure level in decibels. Reference: 20 μN/m^2

L_i = band pressure level resulting from ith measurement in decibels. Reference: 20 μN/m^2

n = total number of measurements in the band

7. Calculation of Sound Power Level

7.1 General. In this standard two methods are described for determining the sound power level of a source. Both methods are based on the space/time averaged sound pressure level, in octave or one-third octave bands, determined according to Section 6.

7.2 Direct Method. In addition to the data required by 6.4.1, the direct method requires that the reverberation time of the room, T, be determined in each octave band or one-third octave band within the frequency range of interest by means of the procedures described in American National Standard Method of Test for Sound Absorption of Acoustical Materials in Reverberation Rooms, S1.7-1970 (ASTM C 423-66), using at least the microphone positions specified in 6.2.

NOTE: The loudspeaker system used for the measurement of the reverberation time should be considered a part of the test room, and should remain in the room during the measurements of 6.4.

7.2.1 Calculation Procedure. The sound power level produced by the source in each octave band within the frequency range of interest shall be calculated from the following equation:

$$L_W = L_p - 10 \log_{10} (T/T_o) + 10 \log_{10} (V/V_o) + 10 \log_{10} (1 + S\lambda/8V) + 10 \log_{10} (B/1000) - 14 \qquad \text{(Eq 3)}$$

where

L_W = sound power level of the source under test in decibels. Reference: 1 pW (1 pW = 10^{-12} W)

L_p = mean band pressure level (corrected for background noise) determined according to 6.4 in decibels. Reference: 20 μN/m^2

T = reverberation time of the room in seconds

T_o = 1 second

V = volume of the room in cubic meters

V_o = 1 m^3

λ = wavelength in meters at the center frequency of the octave or one-third octave band

S = total surface area of room in square meters

B = barometric pressure in millibars

NOTE: The term involving λ accounts approximately for the effect of the interference pattern formed near the room surfaces. (See [2, 3, 4].)

7.3 Comparison Method. The comparison method requires the use of a reference sound source whose sound power output is known (see Section 10). This method has the advantage that it is not necessary to measure the reverberation time of the test room. In this section, requirements for determining sound power by the comparison method are presented.

7.3.1 Location of the Reference Sound Source. The reference sound source shall be mounted on the floor of the reverberation room at least 1.5 m away from any other sound reflecting surface such as a wall or the source being evaluated. The distance from the microphone path or array shall be such that the microphone(s) is in the reverberant field as required by 6.2.2.

7.3.2 Required Additional Data. The sound pressure level, L_{pr}, corresponding to p^2_{av} during operation of the reference sound shall be determined following the procedures of 6.4.

7.3.3 Calculation Procedure. The sound power level produced by the source in each octave or one-third octave band within the frequency range of interest shall be calculated as follows:

$$L_W = L_p + L_{Wr} - L_{pr} \qquad \text{(Eq 4)}$$

where

L_W = band power level of source under test in decibels. Reference: 1 pW (1 pW = 10^{-12} W)

L_p = mean band pressure level of source under test in decibels. Reference: 20 μN/m^2 (20 μN/m^2 = 2 X 10^{-5} N/m^2)

L_{Wr} = band power level of reference sound source in decibels. Reference: 1 pW

L_{pr} = mean band pressure level of reference sound source in decibels. Reference: 20 μN/m^2

8. Information To Be Recorded

8.1 The following information shall be compiled and recorded for measurements that are made according to the requirements of this standard.

8.1.1 Sound Source under Test

(1) Description of the sound source under test, including its mounting conditions

(2) Operating conditions

(3) Location of sound source in test room

8.1.2 Acoustic Environment

(1) Dimensions of test room; description of the physical treatment of the walls, ceiling, and floor; sketch showing the location of source and room contents

(2) Qualification of reverberation room (Section 11)

(3) Air temperature in degrees Celsius, relative humidity in percent, and barometric pressure in millibars

8.1.3 Instrumentation

(1) Equipment used for the measurements, including name, type, serial number, and manufacturer

(2) Bandwidth of frequency analyzer

(3) Frequency response of instrumentation system

(4) Method used to calibrate the microphone, and the date and place of calibration

(5) Calibration of reference sound source (for the comparison method only)

8.1.4 Acoustical Data

(1) Locations and orientation of the microphone path or array (a sketch should be included if necessary)

(2) Corrections in decibels, if any, applied in each frequency band for the frequency response of the microphone, frequency response of the filter in the passband, background noise, etc

(3) Corrected sound power levels tabulated or plotted to the nearest half-decibel (The preferred format for plotting sound power level data is shown in Fig. 4 [one octave equals 15 mm, 10 dB equals 20 mm].)

(4) Date and time when the measurements were performed

9. Information To Be Reported

The following information shall be reported:

(1) The sound power levels for all frequency bands of interest and all operating conditions of the source.

(2) The location of the sound source under test with respect to the wall, floor, and ceiling of the reverberation room.

(3) Those items in Section 8 which are required for the proper application of the sound power data.

(4) The statement that the sound power levels have been obtained in full conformance with the direct method or the comparison method of this standard. The sound power levels shall be in decibels. Reference: 10^{-12} W.

10. Characteristics and Calibration of Reference Sound Source

10.1 Characteristics of Reference Sound Source. The reference sound source shall have the following characteristics over the frequency range of interest:

(1) The sound radiated shall be broad band in character without discrete-frequency components; that is, the sound pressure level in every one-tenth octave band shall be at least 5 dB below the corresponding octave band level.

(2) The reference sound source shall be suitably mounted to prevent transmission of vibration to the structure on which it rests.

(3) The highest sound pressure level, in any direction in any one-third octave band, shall not exceed 3 dB relative to the level of the mean-square sound pressure for hemispherical radiation.

(4) The reference sound source shall be physically small (maximum dimension preferably less than 0.5 m).

(5) The band power level in each frequency band shall remain constant within the tolerances of Table 3.

10.2 Calibration of Reference Sound Source. The sound power produced by the reference sound source shall be determined in octave and one-third octave bands with an accuracy as specified in Table 3. During

Table 3
Calibration Accuracy for Reference Sound Source

One-Third Octave Band Center Frequencies (Hz)	Tolerance (dB)
100	± 1.0
125	± 1.0
160	± 1.0
200 to 4000	± 0.5
5 000	± 1.0
6 300	± 1.0
8 000	± 1.0
10 000	± 1.0

NOTE: The accuracy required by Table 3 can only be obtained by more elaborate measurement procedures than those described in this standard.

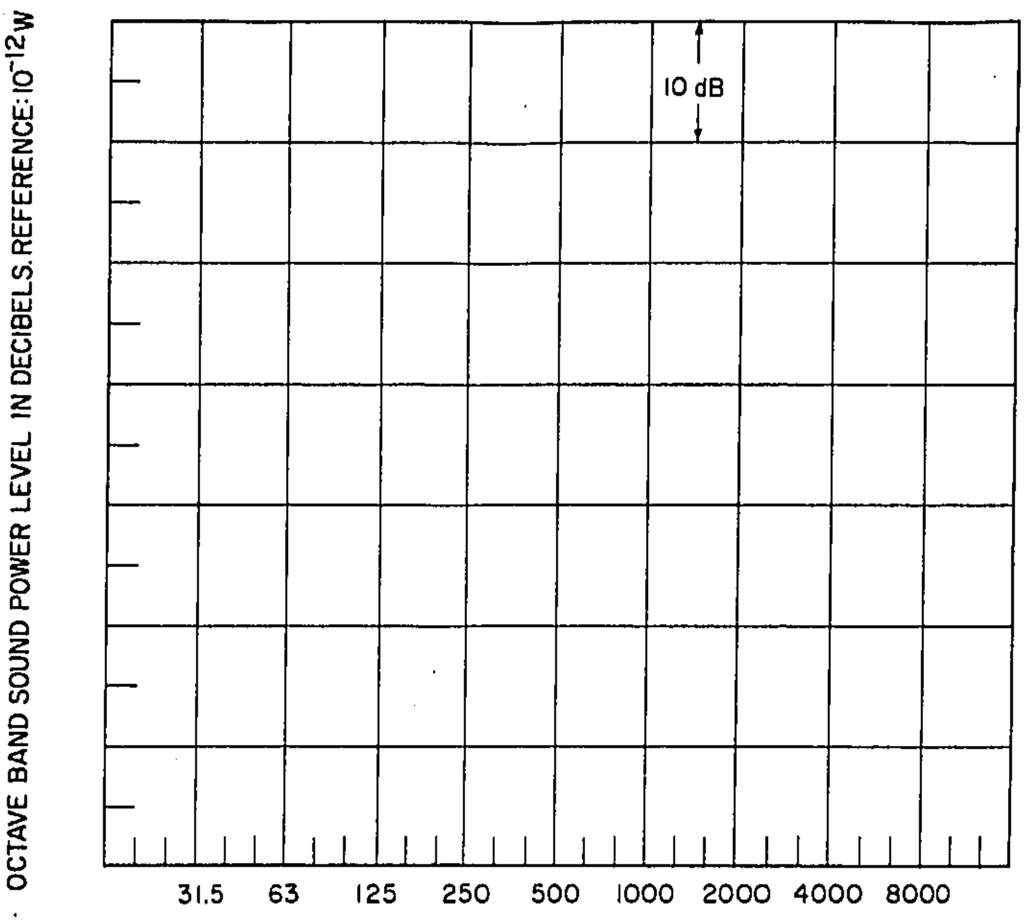

Fig. 4
Preferred Format for Reporting Octave and One-Third Octave Band Sound Power Levels

calibration, the source shall be placed on the floor in the same manner as during the intended use.

11. Room Qualification Procedure for the Measurement of Broad-Band Sound

11.1 Introduction. The procedure described in this section shall be used to determine the accuracy with which broad-band sounds can be measured with a given test facility and instrumentation. It provides a measure of the uncertainties in the coupling between the sound source and the reverberant field as well as uncertainties in the space/time averaging procedure. The accuracy of the broad-band sound measurements for each one-third octave band is expressed in terms of the standard deviation of the measurements.

11.2 Instrumentation and Equipment. The instrumentation and microphone path or array shall be the same as intended for use during the actual testing of a source. The test procedure given in this section requires the use of a reference sound source having the characteristics specified in 10.1.

(1) The instrumentation shall conform to the requirements given in Section 4.

(2) The microphone path or array shall conform to the requirements given in 6.2.

11.3 Test Procedure. Eight or more reverberant field measurements shall be taken of the one-third octave or octave band sound pressure levels in the room, each with the reference sound source placed at a different location within the room, under the following conditions:

(1) The source location shall be selected within a floor area not closer than 1.5 m to a wall and not closer to the microphone than permitted by 6.2. The distance between any two source locations shall be greater than $\lambda/4$ where λ is the wavelength of the lowest frequency for which the room is to be qualified. No source location shall fall near a room center line. The source positions shall be in the general vicinity of the location intended for the equipment being evaluated.

(2) With the reference sound source at each of the above locations, measurements of the one-third octave or octave band sound pressure levels shall be recorded at least to the nearest half decibel.

(3) The microphone path or array, sound diffusers (if any), instrumentation, and observation time shall be identical to those used for conducting actual tests with equipment in the source area being qualified. If a graphic level recorder or plotter is used as the indicating device, each set of measurements shall be plotted on a separate chart.

11.4 Computational Procedure. For each frequency band in which the test room is to be qualified, the standard deviation shall be computed using the equation:

$$s = (n-1)^{-1/2}\left[\sum_{i=1}^{n} (L_i - L_m)^2\right]^{1/2} \qquad \text{(Eq 5)}$$

where

s = standard deviation in decibels

L_i = sound pressure levels measured according to the space-averaging technique described in Section 6, in decibels

L_m = arithmetic mean of sound pressure levels, L_i, in decibels

n = number of measurements

11.5 Qualification. For each particular frequency band, the test room qualifies for the measurement of broadband sound if the computed standard deviation does not exceed the limits given in Table 4.

Table 4
Maximum Allowable Standard Deviations of L_i

Octave Band Center Frequencies (Hz)	One-Third Octave Band Center Frequencies (Hz)	Maximum Allowable Value of Standard Deviation (dB)
125	100 to 160	1.5
250	200 to 315	1.0
500	400 to 630	1.0
1000	800 to 1250	0.5
2000	1600 to 2500	0.5
4000	3150 to 5000	1.0
8000	6300 to 10 000	1.0

12. Determination of the Number of Microphone and Source Positions for Sources Containing Discrete-Frequency Components

12.1 Introduction. The total error (apart from that due to calibration and decay rate measurement) is attributed to: 1) limited sampling (space averaging) of the sound pressure in the reverberant field, and 2) a limited number of room modes excited by the source.

It is assumed that these errors are statistically independent so that the variances (squares of the standard deviations) add. This is the reason that Eq 7 contains the sum of two terms. The term $1/N_m$ expresses the variance due to incomplete space averaging using N_m microphone positions. Equation 6 expresses an equivalence between averaging at a number of discrete microphone positions and continuous averaging (or integration) over a microphone traverse. Experimental proof of Eq 6 is furnished in [1]. It should be noted that, for a microphone traverse of given length, this term is inversely proportional to frequency.

The other term in Eq 7 is based on Lyon's theory for the variance in the sound power output of a monopole source in a reverberant field as a function of modal overlap [6]. It should be noted that this term diminishes with the square of the frequency and, thus, tends to govern only at low frequencies. For a given room volume, this term also depends on reverberation time. For this reason, it is recommended that low frequency damping be provided in the room (see Appendix A). Maling [1] gives experimental evidence of the trends predicted by Lyon's theory. Equation 7 also shows that the use of multiple source positions reduces *both* types of error. The error due to a limited number of room modes is reduced because the extent to which a given mode is excited depends on source positions (see [7]). The error due to incomplete space averaging is reduced because the total number of samples of the sound field is the product of the number of microphone positions used for each source position times the number of the source positions.

The constant K in Eq 7 is an empirical one (see Table 5) based on the fact that the accuracy of all acoustical measurements falls off at very low frequencies so that a relaxation of the objectives (see Table 1) is justified at low frequencies.

Table 5
Number of Microphone Positions Required and Values of Constant K for Determining Number of Source Locations

Octave Band (and One-Third Octave Band) Center Frequencies	Number of Microphone Positions (N_m) If $1.5 < s \leq 3$ dB	Number of Microphone Positions (N_m) If $s > 3$ dB	Constant K for Determining Number of Source Locations
125 (100, 125, 160)	3	6	5
250 (200, 250, 315)	6	12	10
500 (400, 500, 630)	12	24	20
1000 (800, 1000, 1250) and up	15	30	25

Table 6
Procedure to be Followed in the Measurement of Discrete-Frequency Components or Narrow Bands of Noise

Standard Deviation s (dB)	Procedure	Number of Microphone Positions (or Microphone Path Length)	Number of Source Locations
$s \leq 1.5$	Broad-band procedure adequate	$N_m = 3$ or l computed from Eq 6 for a continuous path	$N_s = 1$
$1.5 < s \leq 3$	Assume that a narrow band of noise is present	N_m determined from Table 5 or l computed from Eq 6 for a continuous path	Use half the number of source locations computed from Eq 7
$s > 3$	Assume that a discrete-frequency component is present	N_m determined from Table 5 or l computed from Eq 6 for a continuous path	Compute N_s from Eq 7

12.2 General. Because Eq 1 (see 6.3.3) gives only an estimate of the true standard deviation, three broad ranges of values for s are used to determine the number of microphone positions (or path length) and the number of source locations required to achieve the accuracy objectives when discrete-frequency components are present in the spectrum. Detailed knowledge of the spectrum of the source is not necessary for carrying out the measurements. Irregularities in the sound field are taken into account insofar as they influence the estimate of the standard deviation, s.

12.3 Computational Procedures. The value of s calculated according to Eq 1 is used with Tables 5 and 6 to determine the recommended microphone path length and the number of source locations.

The number of microphone positions, N_m, is determined from Table 5. If a continuous microphone traverse is used, the length of the traverse should be at least

$$l = N_m \; (\lambda/2) \qquad \text{(Eq 6)}$$

where λ is defined as 6.3.3 (1), and N_m is the number of microphone positions. The required number of source locations depends on the reverberation time and volume of the room, and on the frequency. For discrete-frequency tones, the recommended number of source locations, N_s, shall be computed from the following equation and rounded to the nearest higher integer:

$$N_s \geq K \left\{ 0.78 \left(\frac{T}{V}\right) \left(\frac{1000}{f}\right)^2 + \frac{1}{N_m} \right\} \qquad \text{(Eq 7)}$$

where

T = reverberation time of the room for the one-third octave band containing the discrete-frequency component, in seconds
V = room volume in cubic meters
f = frequency of the discrete component in hertz
K = value of a constant given in Table 5
N_m = number of microphone positions for the narrow-band noise or discrete-frequency component (see Table 6)

After the minimum number of microphone positions (or appropriate microphone path length) and the recommended number of source locations have been selected, the procedures of 6.4 shall be followed to ob-

Table 7
Test Frequencies (or Periods) for Qualification of Facility for Measuring Sounds Containing Significant Discrete-Frequency Components

	Center Frequencies of One-Third Octave Bands (Hz)														
	100	125*	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500
	Period of Test Frequency (ms)								Test Frequency (Hz)						
			7.08			3.54	2.76								
			7.02	5.60	4.48	3.51	2.74					1130	1410		2260
	11.10	8.88	6.96	5.55	4.44	3.48	2.72	2.22	564	712		1140	1425		2280
	11.00	8.80	6.90	5.50	4.40	3.45	2.70	2.20	570	720	900	1150	1440	1800	2300
	10.90	8.72	6.84	5.45	4.36	3.42	2.68	2.18	576	728	910	1160	1455	1820	2320
	10.80	8.64	6.78	5.40	4.32	3.39	2.66	2.16	582	736	920	1170	1470	1840	2340
	10.70	8.56	6.72	5.35	4.28	3.36	2.64	2.14	588	744	930	1180	1485	1860	2360
	10.60	8.48	6.66	5.30	4.24	3.33	2.62	2.12	594	752	940	1190	1500	1880	2380
	10.50	8.40	6.60	5.25	4.20	3.30	2.60	2.10	600	760	950	1200	1515	1900	2400
	10.40	8.32	6.54	5.20	4.16	3.27	2.58	2.08	606	768	960	1210	1530	1920	2420
	10.30	8.24	6.48	5.15	4.12	3.24	2.56	2.06	612	776	970	1220	1545	1940	2440
	10.20	8.16	6.42	5.10	4.08	3.21	2.54	2.04	618	784	980	1230	1560	1960	2460
	10.10	8.08	6.36	5.05	4.04	3.18	2.52	2.02	624	792	990	1240	1575	1980	2480
	10.00	8.00	6.30	5.00	4.00	3.15	2.50	2.00	630	800	1000	1250	1590	2000	2500
	9.90	7.92	6.24	4.95	3.96	3.12	2.48	1.98	636	808	1010	1260	1605	2020	2520
	9.80	7.84	6.18	4.90	3.92	3.09	2.46	1.96	642	816	1020	1270	1620	2040	2540
	9.70	7.76	6.12	4.85	3.88	3.06	2.44	1.94	648	824	1030	1280	1635	2060	2560
	9.60	7.68	6.06	4.80	3.84	3.03	2.42	1.92	654	832	1040	1290	1650	2080	2580
	9.50	7.60	6.00	4.75	3.80	3.00	2.40	1.90	660	840	1050	1300	1665	2100	2600
	9.40	7.52	5.94	4.70	3.76	2.97	2.38	1.88	666	848	1060	1310	1680	2120	2620
	9.30	7.44	5.88	4.65	3.72	2.94	2.36	1.86	672	856	1070	1320	1695	2140	2640
	9.20	7.36	5.82	4.60	3.68	2.91	2.34	1.84	678	864	1080	1330	1710	2160	2660
	9.10	7.28	5.76	4.55	3.64	2.88	2.32	1.82	684	872	1090	1340	1725	2180	2680
	9.00	7.20	5.70	4.50	3.60	2.85	2.30	1.80	690	880	1100	1350	1740	2200	2700
		7.12	5.64		3.56	2.82	2.28		696	888	1110	1360	1755	2220	2720
									702			1370	1770		2740
									708			1380	1785		2760
												1390			2780
Increment	0.10	0.08	0.06	0.05	0.04	0.03	0.02	0.02	6	8	10	10	15	20	20
Tolerance of Increment	± 0.03	± 0.03	± 0.02	± 0.02	± 0.01	± 0.01	± 0.005	± 0.005	± 2	± 3	± 3	± 3	± 5	± 5	± 5
n	22	23	25	23	24	25	25	22	25	23	22	27	26	22	27

tain values of L_p, the mean band pressure levels in the one-third octave bands of interest. The sound power emitted by the source is then calculated using the pro-

13. Alternative Qualification Procedure for the Measurement of Discrete-Frequency Components

13.1 Introduction. The accuracy objectives for this alternative procedure (see Table 8) are empirical. The procedure uses frequency rather than source position as the independent variable in order to include the effects of the modal frequency distribution of the particular room being qualified.

It should be pointed out that the loudspeaker test (see 13.4) uses a near-field measurement to qualify the frequency response of the loudspeaker. This is based on the fact that the near-field sound pressure level of a small monopole-type source is proportional to the sound power level in a manner which is essentially independent of frequency, because the real part of the acoustic admittance seen by such a source is essentially independent of frequency (see [8]). The test frequency in the left-hand part of Table 7 is specified indirectly (that is, in terms of the period) because it is tedious to set up an oscillator at low frequencies using the counter in the frequency mode. Much time can be saved by using the counter in the period mode.

The qualification procedure given in this section provides data on the total uncertainty due to both a limited number of modes excited by a discrete-frequency source and to a limited sampling and averaging of the resulting sound field. The former is not a problem at high frequencies. At high frequencies, therefore, the limiting factor is the number of microphone posi-

Table 8
Maximum Allowable Standard Deviations of L_i

Octave Band Center Frequencies (Hz)	One-Third Octave Band Center Frequencies (Hz)	Maximum Allowable Value of Standard Deviation (dB)
125	100 to 160	3.0
250	200 to 315	2.0
500	400 to 630	1.5
1000	800 to 1250	1.0
2000	1600 to 2500	1.0
4000	3150 to 5000	2.0
8000	6300 to 10 000	2.0

NOTE: If a continuous microphone traverse of length l is used, the qualification test needs to be carried out only at frequencies below f_1 or f_2, whichever is larger:

$f_1 = 6000/l$

where f_1 is in hertz and l in meters;

$f_2 = 5000\,(V)^{-1/3}$

where V is the volume of the test room in cubic meters.

tions used. It may be possible to use discrete microphone positions provided an effective rotating diffuser is employed, but usually it will be advisable to use a continuous averaging scheme employing a very long microphone traverse. Circular traverses provide more length in a given space than linear ones and are easier to automate.

At low frequencies, the bottleneck tends to be the small number of modes which can be excited at any given frequency. This can be improved by introducing a certain amount of damping into the room to broaden the frequency response (modal bandwidth) of each mode (see A4 of Appendix A). It is likely, however, that the qualification criteria (see Table 8) can be met at low frequencies only by using a rotating diffuser of the type described in Appendix B. It should be pointed out that, at the present time, there is no way to predict the performance of rotating diffusers. This is the reason that this section describes an experimental procedure for determining the combined effectiveness of all features of the facility.

13.2 General. The procedure described in this section may be used to estimate the uncertainty in the measurement of discrete-frequency sounds in a given reverberation room, with a given microphone array or path. If the standard deviations do not exceed the values given in Table 8 over the frequency range of interest, the test facility (consisting of the room, instrumentation, and microphone array or path) is considered qualified for testing sources whose spectra contain significant discrete-frequency components. No additional evaluations (such as given in Section 12) are then necessary for any particular sound source.

The qualification procedure described in 13.4–13.8 makes use of the fact that irregularities in the frequency response of a reverberation room for a given source position and microphone array or path are indicative of the uncertainties in the coupling of the source to the reverberant field as well as uncertainties in the space/time averaging procedure.

13.3 Instrumentation. In addition to the instrumentation and microphone array or path specified in 6.2, the following items are required for the qualification test:

(1) A high-quality loudspeaker of 200 mm diameter or less, with an airtight back enclosure.

(2) An oscillator, a frequency counter, an amplifier, a voltmeter, and an octave band or one-third octave band filter.

13.4 Loudspeaker Test. Locate the loudspeaker on the floor of a semianechoic room. Place the microphone at a distance of 10 to 20 mm in front of the speaker face. Using the indicating device and frequency analyzer (see Section 4), record the sound pressure level at constant loudspeaker input voltage over the frequency range for which qualification is desired. In each one-third octave band, take measurements to the nearest half decibel at the frequencies or periods shown in Table 7.

NOTE: The loudspeaker is suitable only if measurements at adjacent frequencies do not differ by more than 1 dB.

The loudspeaker input voltage for this test should be low enough to prevent distortion (that is, excessive voice coil and diaphragm excursions, particularly at low frequencies), but high enough to prevent interference from background noise (both acoustical and electrical) during this test, as well as during the following test.

13.5 Room Test. The loudspeaker shall be placed at the location(s) where the equipment is to be tested (see 5.2). The microphone shall be traversing or the array shall be sampled in the same manner as it is for sound pressure level readings (see Section 6). If a revolving or oscillating sound diffuser is to be used, the diffuser shall be in operation.

Record the space/time averaged sound pressure level at the frequencies listed in Table 7. The loudspeaker input voltage shall be the same as for the loudspeaker test (see 13.4).

NOTE: If an array of fixed microphone positions is used, the array may either be scanned and the mean-square sound pressure obtained automatically (see 4.2), or the mean-square value at the individual microphone positions may be obtained by computation.

Frequency variations shall not exceed ± 0.1 Hz during each set of measurements.

13.6 Computational Procedure. Computational procedure is as follows:

(1) Correct the room levels taken under 13.5 to remove the influence of the loudspeaker characteristic by subtracting, at each frequency, the loudspeaker level taken under 13.4.

(2) For each one-third octave band, calculate the arithmetic mean of the room levels corrected according to 13.6 (1), and compute the standard deviation of the difference between the corrected room levels and the mean level.

$$s = (n-1)^{-1/2}\left[\sum_{i=1}^{n} (L_i - L_m)^2\right]^{1/2} \quad \text{(Eq 8)}$$

where

s = standard deviation in decibels

L_i = room sound pressure levels corrected according to 13.6(1) in decibels

L_m = mean of room sound pressure levels corrected according to 13.6(1) in decibels

n = number of measurements in the one-third octave band (see Table 7)

13.7 Qualification. For each frequency band, the test room qualifies for the measurement of sound containing discrete-frequency components if the computed standard deviation does not exceed the limits given in Table 8.

13.8 Multiple Source Locations. If desired, the qualification may be obtained by repeating the room test (see 13.5) with another loudspeaker location and averaging the levels (on a mean-square basis) for each frequency before computing the standard deviation (see 13.6).

If the qualification is based on multiple loudspeaker locations, the same set of locations shall be used in running the equipment sound test, and the results for the several locations shall be averaged.

14. References

14.1 General References

14.1.1 References to American National Standards. When the following American National Standards referred to in this document are superseded by a revision approved by the American National Standards Institute, Inc, the revision shall apply:

American National Standard for Acoustical Terminology (Including Mechanical Shock and Vibration), S1.1-1960 (R1971)

American National Standard Method for the Physical Measurement of Sound, S1.2-1962 (R1971)

American National Standard Specification for Sound Level Meters, S1.4-1971

American National Standard for Preferred Frequencies and Band Numbers for Acoustical Measurements, S1.6-1967 (R1971)

American National Standard Method of Test for Sound Absorption of Acoustical Materials in Reverberation Rooms, S1.7-1970 (ASTM C 423-66)

American National Standard Method for the Calibration of Microphones, S1.10-1966 (R1971)

American National Standard Specification for Octave, Half-Octave, and One-Third Octave Band Filter Sets, S1.11-1966 (R1971)

American National Standard Methods for the Measurement of Sound Pressure Levels, S1.13-1971

14.1.2 References to ISO Recommendations

ISO Recommendation R 495-1966, General Requirements for the Preparation of Test Codes for Measuring the Noise Emitted by Machines[3]

ISO/TC 43 Draft ISO Recommendation No. 2204, Guide to the Measurement of Acoustical Noise and Evaluation of Its Effects on Man[3]

14.2 References to the Text

[1] MALING, G. C., Jr. Guidelines for determination of the average sound power radiated by discrete-frequency sources in a reverberation room. *Proceedings of the 7th International Congress on Acoustics.*

[3]Publications of the International Organization for Standardization are available from the American National Standards Institute, 1430 Broadway, New York, N.Y. 10018.

Budapest: Akademlai, vol 2, 1971, pp 269-272.

[2] BAADE, P. K. Equipment sound power measurements in reverberation rooms. *Journal of Sound and Vibration*, vol 16, no. 1, May 1971, pp 131-135.

[3] PLONER, B. Determining the sound power of rotating electrical machines in a reverberation room. *The Brown Boveri Review*, vol 54, no. 9, Sept 1967, pp 648-654.

NOTE: The above three papers are recent state-of-the-art summaries and contain numerous further references.

[4] WATERHOUSE, R. V. Interference patterns in reverberant sound fields. *Journal of the Acoustical Society of America*, vol 27, no. 2, Mar 1955, p 247.

[5] SCHROEDER, M. R. Die statistischen Parameter der Frequenzkurven von grossen Räumen. *Acustica*, vol 4, no. 4, 1954, pp 594-600.

[6] LYON, R. H. Statistical analysis of power injection and response in structures and rooms. *Journal of the Acoustical Society of America*, vol 45, no. 3, Mar 1969, pp 545-565.

[7] WATERHOUSE, R. V. Power output of a point source exciting a single Cartesian mode. *Journal of the Acoustical Society of America*, vol 49, no. 1, pt 1, Jan 1971, pp 9-16

[8] BERANEK, L. L. *Acoustics*. New York: McGraw-Hill Book Company, 1954, Fig. 5.8.

Appendixes

(These Appendixes are not a part of American National Standard Methods for the Determination of Sound Power Levels of Small Sources in Reverberation Rooms, S1.21-1972, but are included for information purposes only.)

Appendix A

Guidelines for the Design of Reverberation Rooms

A1. General

For accurate determination of the sound power level of a device, machine, component, or subassembly, the reverberation room should have:

(1) Adequate volume
(2) Suitable shape or diffusing elements, or both
(3) Suitably small sound absorption over the frequency range of interest
(4) Sufficiently low background noise levels

A2. Volume of Test Room

Note the requirements of 3.2. The preferred minimum volume of the test room is given in Table A1.

NOTES:
(1) As shown in Table A1, a volume of 200 m^3 is suggested for general-purpose measurements in which the 125-Hz octave band (or 100-Hz third-octave band) is the lowest band in the frequency range of interest.
(2) In large chambers (that is, those with volumes greater than 200 m^3), air absorption may cause an undesirable reduction in the uniformity of the reverberant field in the highest frequency bands within the frequency range of interest.

Table A1
Preferred Minimum Room Volume as a Function of the Lowest Frequency Band of Interest

Lowest Frequency Band of Interest	Preferred Minimum Room Volume m^3
125-Hz octave or 100-Hz one-third octave	200
125-Hz one-third octave	150
160-Hz one-third octave	100
250-Hz octave or 200-Hz one-third octave and higher	70

NOTE: The preferred room volumes given here take into account the requirement of greater accuracy in the 250-Hz octave or 200-Hz one-third octave band given in Table 1.

A3. Shape of Test Room and Diffusing Elements

If the room is not rectangular, no surfaces of the room should be parallel. If the room is rectangular, the room proportions should be selected so that very close spacings between the frequencies of the normal modes of the room are avoided.

NOTE: This condition will be satisified if the ratio of any two dimensions does not equal or closely approximate an integer. The proportions $1:2^{1/3}:4^{1/3}$ are frequently used. Other room dimension ratios that have been found to be satisfactory for rooms having a volume of approximately 200 m³ are given in Table A2.

Large rotating or oscillating vanes may be used to improve the state of diffusion in a room (see Appendix B).

A4. Absorption of Test Room

The sound absorption coefficients of the surfaces of the reverberant room must be small enough to ensure an adequate reverberant field. The sound absorption coefficients must be large enough to minimize the effect of source position on the sound power produced by the source (refer to the qualification procedure of Section 11). The average sound absorption coefficient of all surfaces of the reverberation room should not exceed 0.06 over the frequency range of interest, except that additional absorption below a frequency given by

$$f = 2000/V^{1/3} \qquad \text{(Eq A1)}$$

is usually desirable in order to increase the bandwidth of the resonance curves of the normal modes of the room. The highest value of the average sound absorption coefficient, at any frequency, should not exceed 0.16.

Table A2
Recommended Room Dimension Ratios for Rectangular Rooms

(1) $L_y/L_x = 0.83$	$L_z/L_x = 0.47$
(2) $L_y/L_x = 0.83$	$L_z/L_x = 0.65$
(3) $L_y/L_x = 0.79$	$L_z/L_x = 0.63$
(4) $L_y/L_x = 0.68$	$L_z/L_x = 0.42$
(5) $L_y/L_x = 0.70$	$L_z/L_x = 0.59$

L_x, L_y, and L_z are the length, width, and height of the room.

Appendix B

Guidelines for the Design of Rotating Diffusers

The effectiveness of rotating diffusers depends primarily on their size. The diffuser should therefore be as large as the room dimensions permit. The diffuser panels should not be of lightweight construction. A surface density of at least 5 kg/m² is recommended. The speed of rotation should be high enough so that sound pressures can be averaged over at least one complete revolution of the diffuser.

The practical design problems associated with large, heavy panels rotating at high speed can best be overcome by designing the diffuser as a body of revolution (disk, cone, or cylinder) with about 50% open surface and balancing the reflective surface areas so that the center of gravity is on the diffuser axis. A double conical diffuser, 6 m in diameter, has been operated successfully at 25 revolutions per minute.

Systematic investigations of different diffuser designs are now in progress. Diffuser surfaces which are not parallel to any room surface appear to give the best results.

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