CHAPTER 19

UNITS FOR THE MEASUREMENT OF GAIN AND NOISE

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SECTION 1 : BELS AND DECIBELS

(i) Power relationships expressed in bels and decibels (ii) Voltage and current relationships expressed in decibels (iii) Absolute power and voltage expressed in decibels (iv) Microphone output expressed in decibels (v) Pickup output expressed in decibels (vi) Amplifier gain expressed in decibels (vii) Combined microphone and amplifier gain expressed in decibels (viii) Loudspeaker output expressed in decibels (ix) Sound system rating (x) Tables and charts of decibel relationships (xi) Nomogram for adding decibel-expressed quantities (xii) Decibels, slide rules and mental arithmetic.

(i) Power relationships expressed in bels and decibels

If a sound is suddenly increased in magnitude, the listener receives an impression of increased loudness which is roughly proportional to the logarithm of the ratio of the two acoustical powers. In mathematical form

$$\text{loudness} \propto \log (P_2/P_1) \qquad (1)$$

This is quite general, and holds for a decrease in power as well as for an increase in power. Now the ultimate effect of any change of electrical power in a transmitter, receiver or amplifier is to produce a change of acoustical power from the loudspeaker, so that it is convenient to adopt a logarithmic basis for indicating a change of electrical power.

The common logarithm of the ratio of two powers gives their relationship in **bels**—

$$N_b = \log_{10}(P_2/P_1) \qquad (2)$$

where P_1 is the reference power
and P_2 is the power which is referred back to P_1.

The more commonly used unit is the **decibel,** which is one tenth of a bel. Thus, the difference in level between P_1 watts and P_2 watts is given by

$$N_{db} = 10 \log_{10} (P_2/P_1) \text{ decibels} \qquad (3)$$

If P_2 is less than P_1 the value of N_{db} becomes negative. A negative value of N_{db} thus indicates that the power in which we are interested is less than the reference power.

Note that these relationships (1, 2 and 3) are independent of any other conditions such as impedance.

Applications and examples

Suppose for example that a power valve driving a loudspeaker is delivering 1 watt which is then increased to 2 watts. To say that the power has " increased by one watt " is misleading unless it is also stated that the original level was 1 watt. A far more satisfactory way is to state that a rise of 3 db has occurred. This may be calculated quite simply since the gain in decibels is

$$10 \log_{10} (2/1) = 10 \log_{10} 2 = 10 \times 0.301 = 3.01 \text{ db}$$

or approximately 3 db.

In a similar manner a decrease from 2 watts to 1 watt is a change of approximately − 3 db.

It has been found that a change in level of 1 db is barely perceptible to the ear, while an increase of 2 db is only a slight apparent increment. For this reason variable attenuators are frequently calibrated in steps of 1 db or slightly less. In a similar manner an increase from 3 watts to 4.75 watts is only a slight audible increment, being an increase of 2 db.

In order to simplify the understanding of **barely perceptible changes** the following table has been prepared, and it will be seen that a move from one column to the nearest on left or right is equivalent to a change of 2 db. In this table 0 db is taken as 3 watts.

db :	−10	−8	−6	−4	−2	0	+2	+4	+6	+8	+10	+12
watts :	0.30	0.47	0.75	1.2	1.9	3.0	4.75	7.5	12	19	30	47.5

In addition to the application of decibels to indicate a change in level at one point, they may also be used to indicate a difference in level between two points such as the input and output terminals of a device such as an amplifier or attenuator. For example, consider an amplifier having an input power of 0.006 watt and an output power of 6 watts. The power gain is 6/0.006 or 1000 times, and reference to the tables shows that this is equivalent to 30 db. The amplifier may therefore be described as having a gain of 30 db, this being irrespective of the input or output impedance.

References 1, 8, 9, 16 (Chap. 32).

(ii) Voltage and current relationships expressed in decibels

Since $P_1 = E_1 I_1 = E_1^2/R_1 = I_1^2 R_1$

and $P_2 = E_2 I_2 = E_2^2/R_2 = I_2^2 R_2$

where R_1 = resistance dissipating power P_1

and R_2 = resistance dissipating power P_2,

it is obvious that the decibel relationship between E_1 and E_2 or between I_1 and I_2 must involve the resistance.

If $R_1 = R_2 = R$, then $P_2/P_1 = E_2^2/E_1^2 = I_2^2/I_1^2$ and the difference in level is given by

$$N_{db} = 10 \log_{10}(E_2^2/E_1^2) = 20 \log_{10}(E_2/E_1) \text{ decibels,} \tag{4}$$

$$\text{or } N_{db} = 10 \log_{10}(I_2^2/I_1^2) = 20 \log_{10}(I_2/I_1) \text{ decibels,} \tag{5}$$

provided that R remains constant.

If R does not remain constant the difference of level is

$$N_{db} = 20 \log_{10}(E_2/E_1) + 10 \log_{10}(R_1/R_2) \tag{6}$$

$$\text{or } N_{db} = 20 \log_{10}(I_2/I_1) + 10 \log_{10}(R_2/R_1) \tag{7}$$

In the general case with an impedance $\mathbf{Z} = R + jX$ which is the same for both P_1 and P_2, equations (4) and (5) also hold.

When the two impedances are not identical, the difference in level in decibels is

$$N_{db} = 20 \log_{10}(E_2/E_1) + 10 \log_{10}(Z_1/Z_2) + 10 \log_{10}(k_2/k_1) \tag{8}$$

$$= 20 \log_{10}(I_2/I_1) + 10 \log_{10}(Z_2/Z_1) + 10 \log_{10}(k_2/k_1) \tag{9}$$

where k_1 = power factor of $Z_1 = R_1/Z_1 = \cos \phi_1$

and k_2 = power factor of $Z_2 = R_2/Z_2 = \cos \phi_2$.

References 7, 8, 9, 16 (Chap. 32).

(iii) Absolute power and voltage expressed in decibels

(A) Power

Although the decibel is a unit based on the ratio between two powers, it may also be used as an indication of absolute power provided that the reference level (or " zero level ") is known. There have been many so-called " standard " reference levels, including 1, 6, 10, 12.5 and 50 milliwatts, but the 1 milliwatt reference level is very widely used at the present time. As an example, a power of 1 watt may be described as

30 db (reference level 1 mW)
or 30 db (0 db = 1 mW).
or 30 dbm*.

The abbreviation db 6m is sometimes used to indicate a level in decibels with a 6 milliwatt reference level.

To convert from a reference level of 1 mW to 6 mW, add − 7.78 db.
To convert from a reference level of 1 mW to 10 mW, add − 10.00 db.
To convert from a reference level of 1 mW to 12.5 mW, add − 10.97 db.
To convert from a reference level of 6 mW to 1 mW, add + 7.78 db.
To convert from a reference level of 10 mW to 1 mW, add + 10.00 db.
To convert from a reference level of 12.5 mW to 1 mW, add + 10.97 db.

With any reference level, a power with a positive sign in front of the decibel value indicates that this is greater than the reference power, and is spoken of as so many " decibels up." A negative sign indicates less power than the reference power, and is spoken of as so many " decibels down." 0 db indicates that the power is equal to the reference power.

A statement of power expressed in decibels is meaningless unless the reference level is quoted.

References 1, 5, 8, 9, 10.

(B) Voltage

A reference level of 1 volt has been standardized in connection with high impedance microphones. The abbreviation dbv has been standardized (Ref. 38) to indicate decibels referred to 1 volt.

(iv) Microphone output expressed in decibels

The output of a microphone may be expressed either in terms of voltage or power.

(A) In terms of output voltage

The response of a microphone at a given frequency may be stated in decibels with respect to a reference level 0 db = 1 volt (open-circuit) with a sound pressure of 1 dyne per square centimetre (Ref. 36). The abbreviation dbv is used to indicate a voltage expressed in decibels, with reference level 1 volt (Ref. 38).

For example, the output of a microphone may be stated as − 74 dbv with a sound pressure of 1 dyne per square centimetre. This is the open-circuit voltage developed without any loading such as would be provided by the input resistance of the amplifier. Table 1 [Section 1(x)] may be used to determine the corresponding open-circuit voltage, which for the example above is approximately 0.0002 volt r.m.s. (Column 1). If the input resistance of the amplifier is equal to the internal impedance of the microphone (here assumed to be resistive as the worst possible case) the voltage across the input terminals will be only half the generated voltage, giving a loss of 6 db or an effective input voltage of − 80 dbv.

FIG. 19.1

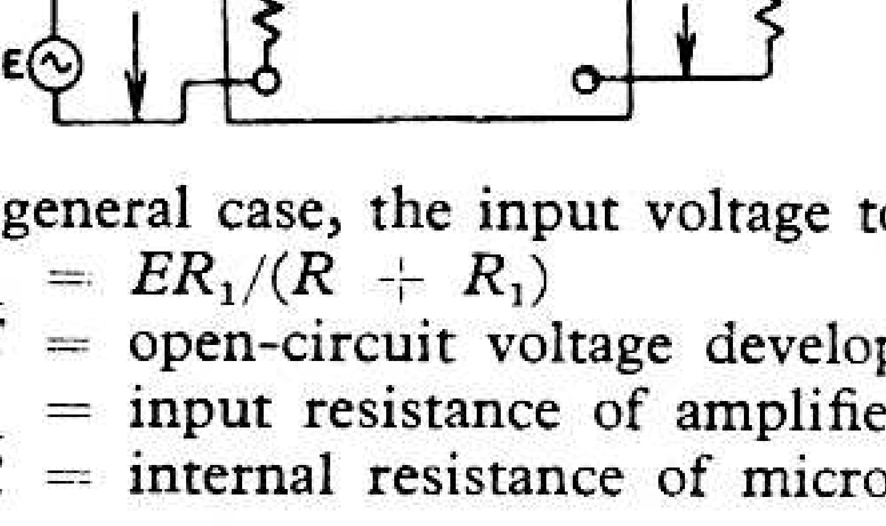

Fig. 19.1. *Amplifier with source of input voltage E having internal resistance R.*

In the general case, the input voltage to the amplifier will be (Fig 19.1) :

$$E_1 = ER_1/(R + R_1)$$

where E = open-circuit voltage developed by the microphone
R_1 = input resistance of amplifier
and R = internal resistance of microphone (here assumed purely resistive).

(B) In terms of output power

Alternatively the output of a microphone may be given in terms of output power for a stated sound pressure.

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*dbm indicates a power expressed in decibels with a reference level 1 mW.

For example, the output of a microphone may be stated as − 65 dbm into a load of 150 ohms, with an input sound pressure of 1 dyne per square centimetre. From Table 3—Sect. 1(x)—the power is 3.2×10^{-7} milliwatt. If desired this may be converted into voltage across 150 ohms.

(C) In terms of effective output level

When a microphone is connected to an unloaded input transformer, its output cannot be expressed in terms of power delivered, as no appreciable power is delivered by the microphone. For this reason, microphone output ratings are sometimes given in terms of effective output level, expressed in dbm. The effective output level is so calculated that when the amplifier power gain in db is added to the microphone effective output level in dbm the correct output level from the amplifier (in dbm) will be obtained. The effective output level rating is based upon the assumption that the microphone works into a load impedance equal to its own rated impedance. The voltage corresponding to this effective output level is actually 6 decibels below that which is actually obtained when the microphone is worked into a high impedance pre-amplifier input. This 6 db difference is a function of the pre-amplifier input termination and not of the microphone itself. The " power gain "* ratings of pre-amplifiers take into account this 6 db increase in gain where it occurs, so that it is not necessary to apply any coupling factor.

If the effective output level of a microphone is not known, it may be derived from available data :

(1) The output power may be converted to dbm, or

(2) Where the microphone open-circuit voltage output is known in dbv (0 db = 1 volt), this may be converted to volts (E_G) and the effective output level in milliwatts is given by

$$1000\ E_G^2/(4R_M) \text{ milliwatts}$$

where R_M is the nominal microphone impedance. The power in milliwatts may then be converted into dbm.

(D) R.M.A. microphone system rating (RMA Standard SE-105)

This is particularly useful when it is desired to calculate the combined " system gain " of a microphone, amplifier and loudspeaker. The R.M.A. microphone system rating is defined as the ratio in db relative to 0.001 watt and 0.0002 dyne per square centimetre of the electric power available from the microphone to the square of the undisturbed sound field pressure in a plane progressive wave at the microphone position.

The R.M.A. microphone system rating (Ref. 35) is given by

$$G_M = \left(10 \log_{10} \frac{E^2/4R_{MR}}{p^2}\right) - 44 \text{ db} \qquad (10)$$

which reduces for practical applications to

$$G_M = (20 \log_{10} (E/p) - 10 \log_{10} R_{MR}) - 50 \text{ db} \qquad (11)$$

where G_M = microphone system rating
E = open-circuit voltage generated by the microphone
p = sound pressure in dynes per sq. cm.
R_{MR} = microphone rating impedance—see Chapter 18 Sect. 1(xiv). This may differ from the actual microphone impedance.

The R.M.A. Microphone System Rating is essentially the same as expressing the microphone output in terms of Effective Output Level, except that the acoustical pressure at the microphone is 0.0002 dyne/cm^2 (the limit of audibility). To convert from R.M.A. Microphone System Rating to the Effective Output Level Rating, it is only necessary to allow for the change of acoustical pressure. For example, if a microphone has an R.M.A. Microphone System Rating of − 154 db, the Effective Output-Level Rating for an acoustical pressure of 10 dynes/cm^2 will be − 60 dbm, and for 1 dyne/cm^2 will be − 80 dbm.

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* An amplifier is normally tested as described in Chapter 37 Sect. 3(ii)C with an input voltage from a generator applied through a constant impedance attenuator, which combination effectively applies a constant voltage through a resistance equal to the rated source impedance of the amplifier as in Fig. 19.3.

Microphone system ratings are most commonly used in a complete sound system—sound, microphone, amplifier, loudspeaker, sound—see (ix) below.

See Chapter 18 Sect. 1 for the relationships between various forms of microphone ratings.

(v) Pickup output expressed in decibels

Although many pickups are rated on the basis of output voltage, some are rated on a power basis with respect to a specified reference level. The procedure is the same as for microphones.

Reference 9.

(vi) Amplifier gain expressed in decibels

Much confusion has been caused by the incorrect or careless use of decibels to indicate the gain of a voltage amplifier. Decibels may be used in various ways to indicate the gain of an amplifier—

(A) In terms of voltage gain (Fig. 19.4)

This is really an arbitrary use of decibels, but it is so convenient that it cannot be suppressed.

Gain in decibels of voltage gain $= 20 \log E_2/E_1$ (12)

where E_2 = voltage across output terminals of voltage amplifier
and E_1 = voltage across input terminals of amplifier.

It is important to distinguish these decibels from decibels of power, which have an entirely different meaning. *The abbreviation* dbvg *is suggested as indicating decibels of voltage gain.*

Some engineers express the gain of an amplifier in terms of voltage by taking E_1 (eqn. 12) as the open circuit generator voltage (E in Fig. 19.1). If the load resistance (R_1 in Fig. 19.1) is equal to the generator resistance (R), the indicated gain by this method will be 6 db less than that given by eqn. (12). If R_1 is greater than $10R$, both methods give approximately the same result. If the generator impedance has an appreciable reactive component, the difference between the two methods will be less than indicated above.

(B) Amplifier gain in terms of power

Amplifier gain is defined as the ratio expressed in db of the power delivered to the load, to the power which would be delivered to the same load if the amplifier were replaced by an ideal transformer which matches both the load and source impedances (R.M.A. Standard SE-101-A, Amplifiers for sound equipment—Ref. 35).

In Fig. 19.1 the power delivered to the load is

$$P_2 = E_2^2/R_2 \tag{13}$$

The power which would be delivered to the same load if the amplifier were replaced by an ideal transformer which matches both the load and source impedances is

$$P_1 = E_1^2/R_1 \tag{14}$$

Therefore gain in decibels $= 10 \log_{10}(P_2/P_1)$. (15)

If the input resistance of the amplifier is made equal to the internal resistance of the source,

i.e. $R_1 = R$,
then $E_1 = E/2$ and $P_1 = E^2/4R_1 = E^2/4R$.
Gain in decibels $= 10 \log_{10} (4RE_2^2/R_2E^2)$

$$= 20 \log_{10} \frac{2E_2}{E}\sqrt{\frac{R}{R_2}} = 6 + 20 \log_{10} \frac{E_2}{E}\sqrt{\frac{R}{R_2}} \tag{16}$$

If, in addition, $R_2 = R_1 = R$, then
gain in decibels $= 6 + 20 \log_{10} (E_2/E)$ (17)

(C) Gain of a bridging amplifier

A bridging amplifier is one whose internal input impedance is such that it may be connected across a circuit without appreciably affecting the circuit performance in any respect. Its function is to operate into programme circuits or similar loads (Ref. 33).

Bridging gain is the ratio, expressed in db, of the power delivered to the bridging amplifier load to the power in the load across which the input of the amplifier is bridged (Ref. 33).

The commonest case is that of the input to an amplifier having a load of 600 ohms, with the input terminals of the bridging amplifier connected across it. The output load of the bridging amplifier is most commonly 600 ohms.

(vii) Combined microphone and amplifier gain expressed in decibels

(A) When a microphone, rated in terms of voltage, is connected to a voltage amplifier which is rated in decibels of voltage gain (dbvg), the output may be calculated as under :

Output in dbv* = microphone rating in dbv* + coupling factor + amplifier gain in decibels of voltage gain (dbvg). (18)

The coupling factor = 20 log $[R_1/(R + R_1)]$ (Fig. 19.1). (19)

Typical values of the coupling factor are tabulated below :

$R_1/(R + R_1)$	=	0.5	0.56	0.63	0.71	0.79	0.89
Coupling factor	=	−6	−5	−4	−3	−2	−1 db

Example : Microphone −54 dbv*

Amplifier + 80 dbvg

$R_1/(R + R_1) = 0.5$

Output = −54 − 6 + 80 = + 20 dbv* = 10 volts.

It should be noted that the calculated output applies for the rated sound pressure, for example 1 dyne per square centimetre. At other sound pressures the voltage will be proportional to the sound pressure.

(B) When a microphone, rated in terms of effective output level, is connected to an amplifier having its gain expressed in terms of power in accordance with R.M.A. Standard SE-101-A :

The amplifier power gain is measured effectively with a constant input voltage in series with a resistance equal to the rated source impedance of the amplifier as in Fig. 19.3. Under these conditions no correction factor is necessary and the output from the amplifier in dbm is equal to the sum of the microphone effective output level in dbm and the amplifier power gain in decibels. This output level will only be attained when the pressure at the microphone is equal to the rated pressure—e.g. 10 dynes/sq. cm.

FIG. 19.3

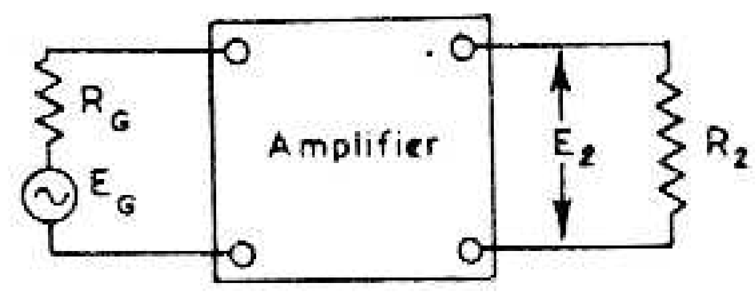

Fig. 19.3. *Method of testing amplifier for gain.*

FIG. 19.4

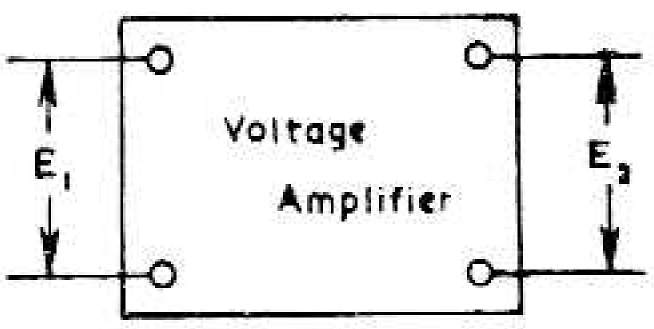

Fig. 19.4. *Voltage amplifier showing input and output voltages.*

For example, a ribbon microphone has an effective output level of −59 dbm with an acoustical pressure of 10 dynes/cm^2. If this is connected to an amplifier with a power gain of 40 db, the output level will be −59 + 40 = −19 dbm with an acoustical pressure of 10 dynes/cm^2.

(C) When a microphone, rated in accordance with the R.M.A. microphone system rating is connected to an amplifier having its gain expressed in terms of power in accordance with R.M.A. Standard SE-101-A :

For general remarks see (B) above.

The output from the amplifier in dbm is equal to the sum of the R.M.A. microphone system rating, the amplifier power gain in decibels, and the sound pressure in decibels.

For example, a ribbon microphone with a R.M.A. system rating (G_M) of −153 db, operating with a sound pressure of 10 dynes/sq. cm. (i.e. +94 db) and connected to

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*0 db = 1 volt

an amplifier with a power gain of 40 db will give an output level $-153 + 40 + 94 = -19$ dbm. The microphone amplifier and sound pressure in this example are the same as for (B) above.

(viii) Loudspeaker output expressed in decibels, in terms of acoustical pressure

In accordance with the American R.M.A. Standard SE-103 (Ref. 29) the loudspeaker pressure rating is the difference between the axial sound pressure level (referred to a distance of 30 feet) and the available input power level, and is expressed in db.

It is expressed by the following forms (equations 20, 21, 22, 23) :

$$G_{SP} = 10 \log_{10} [(p_S/p_0)^2/(W_{AS}/W_0)] \tag{20}$$

$$G_{SP} = 44 + 20 \log_{10} p_S - 10 \log_{10} W_{AS} \tag{21}$$

$$G_{SP} = 44 + 20 \log_{10} p_S - 20 \log_{10} E_G + 10 \log_{10} R_{SR} + 20 \log_{10} [1 + (R_{SG}/R_{SR})] \tag{22}$$

$$(\text{pressure in db above } p_0) = G_{SP} + (\text{power in dbm}) \tag{23}$$

where G_{SP} = loudspeaker pressure rating in db
p_S = axial, free-space, r.m.s. sound pressure at 30 feet, in dynes/cm^2
p_0 = reference r.m.s. sound pressure = 0.0002 dyne/cm^2
W_{AS} = electrical power available to the speaker, in watts, and is equal to $E_G{}^2R_{SR}/(R_{SG} + R_{SR})^2$ (Fig. 19.5)
W_0 = reference power = 0.001 watt
E_G = r.m.s. value of the constant voltage of the source, in volts
R_{SR} = loudspeaker rating impedance, in ohms*
R_{SG} = speaker measurement source impedance, in ohms*
and dbm = power in decibels referred to 1 milliwatt.

FIG. 19.5

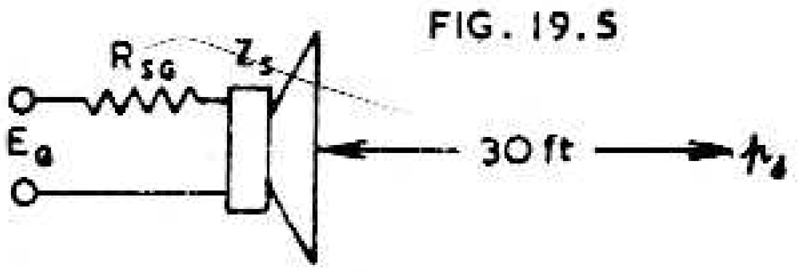

Fig. 19.5. *Loudspeaker testing conditions (R.M.A. Standard SE-*103).

The sound pressure (p_d) at any distance d feet may be used to compute the pressure p_s at 30 feet by the relation

$$p_s = (d/30)p_d \tag{24}$$

See also Ref. 34.

Example : If the loudspeaker pressure rating (G_{SP}) is 46 db, what is the axial sound pressure level at 30 feet, with an available power input of 10 watts, using a standard test signal ?

$G_{SP} = 46$ db $\qquad W_{AS} = 10$ watts $= 40$ dbm

From equation (21),

$20 \log_{10} p_S = 46 - 44 + 10 \log_{10} 10 = 12$ db.

Therefore $p_S = 4$ dynes/cm^2 (i.e. 86 db above p_0).

The same result may be derived more directly from equation (23), pressure $= 46 + 40 = 86$ db above p_0.

(ix) Sound system rating

The total gain of a system from sound, through microphone, amplifier and loudspeaker to sound again may be calculated by adding the system ratings of the several sections and coupling factors (if any).

(A) **Using the American R.M.A. system ratings** for microphone, amplifier and loudspeaker we may put

$$SR = G_M + G + G_{SP} \tag{25}$$

where SR = sound system rating (gain in db)
G_M = R.M.A. microphone system rating (equations 10 and 11)
G = amplifier power gain (equation 15)
and G_{SP} = loudspeaker pressure rating in db (equations 20, 21 and 22).

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*See Chapter 20 Sect. 6(x)B for definitions of R_{SR} and R_{SG}.

A system rating of 0 db indicates that the sound pressure 30 feet from the loudspeaker is the same as that at the microphone. Similarly a system gain of *x* db indicates that the sound pressure 30 feet from the loudspeaker is *x* db greater than that at the microphone.

(B) Proposed method of rating microphones and loudspeakers for systems use by Romanow and Hawley (Ref. 11)

This proposed method has not been adopted generally in the precise form expounded, but the article gives a most valuable analysis of the whole subject of system gain. This method is also described in Ref. 34.

(x) Tables and charts of decibel relationships

Table 1 : Decibels expressed as power and voltage or current ratios

Note that the Power Ratio columns give power values in milliwatts when the reference level is 1 mW. The Power Ratio columns also give power values in milliwatts when the centre column represents dbm*.

The Voltage Ratio columns also give values in volts when the centre column represents dbv.†

FIG. 19.6

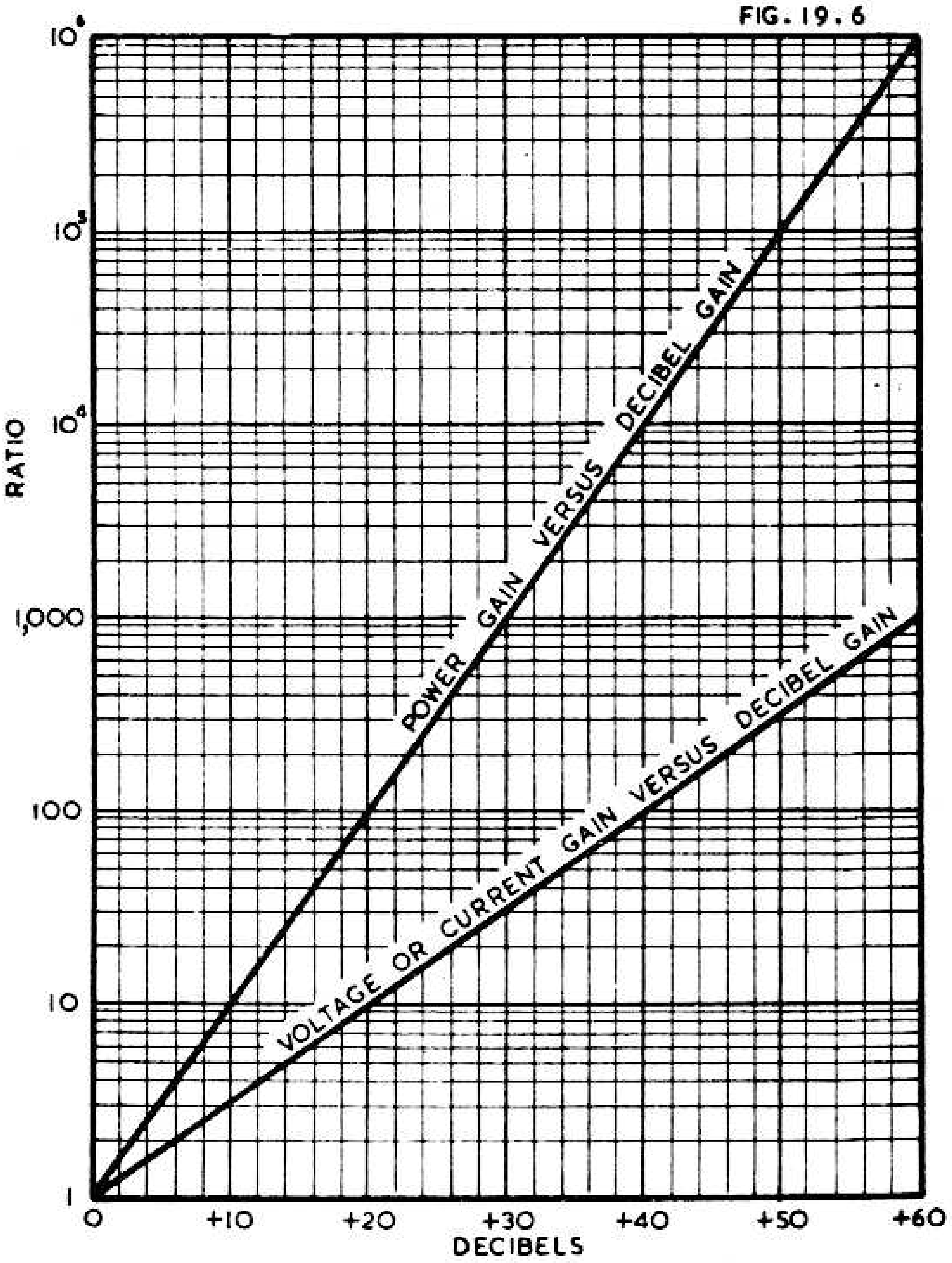

Fig. 19.6. *Gain ratio plotted against decibel gain. This chart may also be used for attenuation by inverting the ratio and making the decibels negative.*

Interpolation : If it is required to find the power ratio corresponding to 22.5 db, or any other value which is not included in the table, the following procedure may be adopted :—

1. Take the next lowest multiple of 20 db (in this case 20 db), and note the corresponding power ratio (in this case 100).

*dbm is unit of power expressed in decibels with 0 db = 1 mW.

†dbv is unit of voltage expressed in decibels with 0 db = 1 volt.

2. Take the difference between the specified level and the multiple of 20 db (in this case 22.5 − 20 = 2.5 db) and note the corresponding power ratio (in this case 1.778).
3. Multiply the two power ratios so determined (in this case 100 × 1.778 = 177.8).

TABLE 1 : DECIBELS EXPRESSED AS POWER AND VOLTAGE RATIOS

Voltage or Current Ratio	Power Ratio (= mW to Reference Level 1 mW)	db	Voltage or Current Ratio	Power Ratio (= mW to Reference Level 1 mW)
1.000 0	1.000 0	−0+	1.000	1.000
.988 6	.977 2	0.1	1.012	1.023
.977 2	.955 0	0.2	1.023	1.047
.966 1	.933 3	0.3	1.035	1.072
.955 0	.912 0	0.4	1.047	1.096
.944 1	.891 3	0.5	1.059	1.122
.933 3	.871 0	0.6	1.072	1.148
.912 0	.831 8	0.8	1.096	1.202
.891 3	.794 3	1.0	1.122	1.259
.841 4	.707 9	1.5	1.189	1.413
.794 3	.631 0	2.0	1.259	1.585
.749 9	.562 3	2.5	1.334	1.778
.707 9	.501 2	3.0	1.413	1.995
.631 0	.398 1	4	1.585	2.512
.562 3	.316 2	5	1.778	3.162
.501 2	.251 2	6	1.995	3.981
.446 7	.199 5	7	2.239	5.012
.398 1	.158 5	8	2.512	6.310
.354 8	.125 9	9	2.818	7.943
.316 2	.100 0	10	3.162	10.000
.281 8	.079 43	11	3.548	12.59
.251 2	.063 10	12	3.981	15.85
.223 9	.050 12	13	4.467	19.95
.199 5	.039 81	14	5.012	25.12
.177 8	.031 62	15	5.623	31.62
.158 5	.025 12	16	6.310	39.81
.141 3	.019 95	17	7.079	50.12
.125 9	.015 85	18	7.943	63.10
.112 2	.012 59	19	8.913	79.43
.100 0	.010 00	20	10.000	100.00
.089 13	.007 943	21	11.22	125.9
.079 43	.006 310	22	12.59	158.5
.070 79	.005 012	23	14.13	199.5
.063 10	.003 981	24	15.85	251.2
.056 23	.003 162	25	17.78	316.2
.050 12	.002 512	26	19.95	398.1
.044 67	.001 995	27	22.39	501.2
.039 81	.001 585	28	25.12	631.0
.035 48	.001 259	29	28.18	794.3
.031 62	.001 000	30	31.62	1 000
.028 18	7.943×10^{-4}	31	35.48	1 259
.025 12	6.310×10^{-4}	32	39.81	1 585
.022 39	5.012×10^{-4}	33	44.67	1 995
.019 95	3.981×10^{-4}	34	50.12	2 512
.017 78	3.162×10^{-4}	35	56.23	3 162

Voltage or Current Ratio	Power Ratio (= mW to Reference Level 1 mW)	db	Voltage or Current Ratio	Power Ratio (= mW to Reference Level 1 mW)
.015 85	2.512×10^{-4}	36	63.10	3 981
.014 13	1.995×10^{-4}	37	70.79	5 012
.012 59	1.585×10^{-4}	38	79.43	6 310
.011 22	1.259×10^{-4}	39	89.13	7 943
.010 000	1.000×10^{-4}	40	100.0	10 000
.008 913	7.943×10^{-5}	41	112.2	12 590
.007 943	6.310×10^{-5}	42	125.9	15 850
.007 079	5.012×10^{-5}	43	141.3	19 950
.006 310	3.981×10^{-5}	44	158.5	25 120
.005 623	3.162×10^{-5}	45	177.8	31 620
.005 012	2.512×10^{-5}	46	199.5	39 810
.004 467	1.995×10^{-5}	47	223.9	50 120
.003 981	1.585×10^{-5}	48	251.2	63 100
.003 548	1.259×10^{-5}	49	281.8	79 430
.003 162	1.000×10^{-5}	50	316.2	100 000
.002 818	7.943×10^{-6}	51	354.8	125 900
.002 512	6.310×10^{-5}	52	398.1	158 500
.002 239	5.012×10^{-6}	53	446.7	199 500
.001 995	3.981×10^{-6}	54	501.2	251 200
.001 778	3.162×10^{-6}	55	562.3	316 200
.001 585	2.512×10^{-6}	56	631.0	398 100
.001 413	1.995×10^{-6}	57	707.9	501 200
.001 259	1.585×10^{-6}	58	794.3	631 000
.001 122	1.259×10^{-6}	59	891.3	794 300
.001 000	1.000×10^{-6}	60	1 000	1 000 000
8.91×10^{-4}	7.943×10^{-7}	61	1 122	1.259×10^{6}
7.94×10^{-4}	6.310×10^{-7}	62	1 259	1.585×10^{6}
7.08×10^{-4}	5.012×10^{-7}	63	1 413	1.995×10^{6}
6.31×10^{-4}	3.981×10^{-7}	64	1 585	2.512×10^{6}
5.62×10^{-4}	3.162×10^{-7}	65	1 778	3.162×10^{6}
5.01×10^{-4}	2.512×10^{-7}	66	1 995	3.981×10^{6}
4.47×10^{-4}	1.995×10^{-7}	67	2 239	5.012×10^{6}
3.98×10^{-4}	1.585×10^{-7}	68	2 512	6.310×10^{6}
3.55×10^{-4}	1.259×10^{-7}	69	2 818	7.943×10^{6}
3.16×10^{-4}	1.000×10^{-7}	70	3 162	1.000×10^{7}
2.82×10^{-4}	7.943×10^{-8}	71	3 548	1.259×10^{7}
2.51×10^{-4}	6.310×10^{-8}	72	3 981	1.585×10^{7}
2.24×10^{-4}	5.012×10^{-8}	73	4 467	1.995×10^{7}
1.99×10^{-4}	3.981×10^{-8}	74	5 012	2.512×10^{7}
1.78×10^{-4}	3.162×10^{-8}	75	5 623	3.162×10^{7}
1.58×10^{-4}	2.512×10^{-8}	76	6 310	3.981×10^{7}
1.41×10^{-4}	1.995×10^{-8}	77	7 079	5.012×10^{7}
1.26×10^{-4}	1.585×10^{-8}	78	7 943	6.310×10^{7}
1.12×10^{-4}	1.259×10^{-8}	79	8 913	7.943×10^{7}
1.00×10^{-4}	1.000×10^{-8}	80	10 000	1.000×10^{8}
8.91×10^{-5}	7.943×10^{-9}	81	11 220	1.259×10^{8}
7.94×10^{-5}	6.310×10^{-9}	82	12 590	1.585×10^{8}
7.08×10^{-5}	5.012×10^{-9}	83	14 130	1.995×10^{8}
6.31×10^{-5}	3.981×10^{-9}	84	15 850	2.512×10^{8}
5.62×10^{-5}	3.162×10^{-9}	85	17 780	3.162×10^{8}
5.01×10^{-5}	2.512×10^{-9}	86	19 950	3.981×10^{8}
4.47×10^{-5}	1.995×10^{-9}	87	22 390	5.012×10^{8}

Voltage or Current Ratio	Power Ratio (= mW to Reference Level 1 mW)	db	Voltage or Current Ratio	Power Ratio (= mW to Reference Level 1 mW)
3.98×10^{-5}	1.585×10^{-9}	88	25 120	6.310×10^{8}
3.55×10^{-5}	1.259×10^{-9}	89	28 180	7.943×10^{8}
3.16×10^{-5}	1.000×10^{-9}	90	31 620	1.000×10^{9}
2.82×10^{-5}	7.943×10^{-10}	91	35 480	1.259×10^{9}
2.51×10^{-5}	6.310×10^{-10}	92	39 810	1.585×10^{9}
2.24×10^{-5}	5.012×10^{-10}	93	44 670	1.995×10^{9}
1.99×10^{-5}	3.981×10^{-10}	94	50 120	2.512×10^{9}
1.78×10^{-5}	3.162×10^{-10}	95	56 230	3.162×10^{9}
1.58×10^{-5}	2.512×10^{-10}	96	63 100	3.981×10^{9}
1.41×10^{-5}	1.995×10^{-10}	97	70 790	5.012×10^{9}
1.26×10^{-5}	1.585×10^{-10}	98	79 430	6.310×10^{9}
1.12×10^{-5}	1.259×10^{-10}	99	89 130	7.943×10^{9}
1.00×10^{-5}	1.000×10^{-10}	100	100 000	1.000×10^{10}

TABLE 2: POWER AND VOLTAGE OR CURRENT RATIOS EXPRESSED IN DECIBELS

Ratio	db (Power Ratio)	db (Voltage* Ratio)	Ratio	db (Power Ratio)	db (Voltage* Ratio)
1.0	0	0	5.7	7.559	15.117
1.1	0.414	0.828	5.8	7.634	15.269
1.2	0.792	1.584	5.9	7.709	15.417
1.3	1.139	2.279	6.0	7.782	15.563
1.4	1.461	2.923	6.1	7.853	15.707
1.5	1.761	3.522	6.2	7.924	15.848
1.6	2.041	4.082	6.3	7.993	15.987
1.7	2.304	4.609	6.4	8.062	16.124
1.8	2.553	5.105	6.5	8.129	16.258
1.9	2.788	5.575	6.6	8.195	16.391
2.0	3.010	6.021	6.7	8.261	16.521
2.1	3.222	6.444	6.8	8.325	16.650
2.2	3.424	6.848	6.9	8.388	16.777
2.3	3.617	7.235	7.0	8.451	16.902
2.4	3.802	7.604	7.1	8.513	17.025
2.5	3.979	7.959	7.2	8.573	17.147
2.6	4.150	8.299	7.3	8.633	17.266
2.7	4.314	8.627	7.4	8.692	17.385
2.8	4.472	8.943	7.5	8.751	17.501
2.9	4.624	9.248	7.6	8.808	17.616
3.0	4.771	9.542	7.7	8.865	17.730
3.1	4.914	9.827	7.8	8.921	17.842
3.2	5.051	10.103	7.9	8.976	17.953
3.3	5.185	10.370	8.0	9.031	18.062
3.4	5.315	10.630	8.1	9.085	18.170
3.5	5.441	10.881	8.2	9.138	18.276
3.6	5.563	11.126	8.3	9.191	18.382
3.7	5.682	11.364	8.4	9.243	18.486
3.8	5.798	11.596	8.5	9.294	18.588
3.9	5.911	11.821	8.6	9.345	18.690
4.0	6.021	12.041	8.7	9.395	18.790
4.1	6.128	12.256	8.8	9.445	18.890
4.2	6.232	12.465	8.9	9.494	18.988
4.3	6.335	12.669	9.0	9.542	19.085
4.4	6.435	12.869	9.1	9.590	19.181
4.5	6.532	13.064	9.2	9.638	19.276
4.6	6.628	13.255	9.3	9.685	19.370
4.7	6.721	13.442	9.4	9.731	19.463
4.8	6.812	13.625	9.5	9.777	19.554
4.9	6.902	13.804	9.6	9.823	19.645
5.0	6.990	13.979	9.7	9.868	19.735
5.1	7.076	14.151	9.8	9.912	19.825
5.2	7.160	14.320	9.9	9.956	19.913
5.3	7.243	14.486	10.0	10.000	20.000
5.4	7.324	14.648	100	20	40
5.5	7.404	14.807	1000	30	60
5.6	7.482	14.964	10000	40	80

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*Or Current Ratio.

To find the decibels corresponding to ratios above 10, break the ratio into two factors and add the decibels of each. For example—

Voltage ratio = 400 = 4 × 100. Decibels = 12.041 + 40 = 52.041.

TABLE 3: DECIBELS ABOVE AND BELOW REFERENCE LEVEL 6 mW INTO 500 OHMS

Note that the power in watts holds for any impedance, but the voltage holds only for 500 ohms.

db down		Level	db up	
Volts	Watts	db	Volts	Watts
1.73	6.00×10^{-3}	−0+	1.73	.006 00
1.54	4.77×10^{-3}	1	1.94	.007 55
1.38	3.79×10^{-3}	2	2.18	.009 51
1.23	3.01×10^{-3}	3	2.45	.012 0
1.09	2.39×10^{-3}	4	2.75	.015 1
.974	1.90×10^{-3}	5	3.08	.019 0
.868	1.51×10^{-3}	6	3.46	.023 9
.774	1.20×10^{-3}	7	3.88	.030 1
.690	9.51×10^{-4}	8	4.35	.037 9
.615	7.55×10^{-4}	9	4.88	.047 7
.548	6.00×10^{-4}	10	5.48	.060 0
.488	4.77×10^{-4}	11	6.15	.075 5
.435	3.79×10^{-4}	12	6.90	.095 1
.388	3.01×10^{-4}	13	7.74	.120
.346	2.39×10^{-4}	14	8.68	.151
.308	1.90×10^{-4}	15	9.74	.190
.275	1.51×10^{-4}	16	10.93	.239
.245	1.20×10^{-4}	17	12.26	.301
.218	9.51×10^{-5}	18	13.76	.379
.194	7.55×10^{-5}	19	15.44	.477
.173	6.00×10^{-5}	20	17.32	.600
.097 4	1.90×10^{-5}	25	30.8	1.90
.054 8	6.00×10^{-6}	30	54.8	6.0
.030 8	1.90×10^{-6}	35	97.4	19.0
.017 3	6.00×10^{-7}	40	173	60.0
.009 74	1.90×10^{-7}	45	308	190
.005 48	6.00×10^{-8}	50	548	600
.003 08	1.90×10^{-8}	55	974	1 900
.001 73	6.00×10^{-9}	60	1 730	6 000
.000 974	1.90×10^{-9}	65	3 080	19 000
.000 548	6.00×10^{-10}	70	5 480	60 000
.000 308	1.90×10^{-10}	75	9 740	190 000
.000 173	6.00×10^{-11}	80	17 300	600 000

References: Nomographs Refs. 3, 6; Tables Ref. 9.

TABLE 4: DECIBELS ABOVE AND BELOW REFERENCE LEVEL 6 mW INTO 600 OHMS

Note that the power holds for any impedance, but the voltage holds only for 600 ohms.

db down		Level	db up	
Volts	Watts	db	Volts	Watts
1.90	6.00×10^{-3}	−0+	1.90	006 00
1.69	4.77×10^{-3}	1	2.13	.007 55
1.51	3.79×10^{-3}	2	2.39	.009 51
1.34	3.01×10^{-3}	3	2.68	.012 0
1.20	2.39×10^{-3}	4	3.01	.015 1
1.07	1.90×10^{-3}	5	3.37	.019 0
.951	1.51×10^{-3}	6	3.78	.023 9
.847	1.20×10^{-3}	7	4.25	.030 1
.775	9.51×10^{-4}	8	4.77	.037 9
.673	7.55×10^{-4}	9	5.35	.047 7
.600	6.00×10^{-4}	10	6.00	.060 0
.535	4.77×10^{-4}	11	6.73	.075 5
.477	3.79×10^{-4}	12	7.55	.095 1
.425	3.01×10^{-4}	13	8.47	.120
.378	2.39×10^{-4}	14	9.51	.151
.337	1.90×10^{-4}	15	10.7	.190
.301	1.51×10^{-4}	16	12.0	.239
.268	1.20×10^{-4}	17	13.4	.301
.239	9.51×10^{-5}	18	15.1	.379
.213	7.55×10^{-5}	19	16.9	.477
.190	6.00×10^{-5}	20	19.0	.600
.107	1.90×10^{-5}	25	33.7	1.90
.060 0	6.00×10^{-6}	30	60.0	6.0
.033 7	1.90×10^{-6}	35	107	19.0
.019 0	6.00×10^{-7}	40	190	60.0
.010 7	1.90×10^{-7}	45	337	190
.006 00	6.00×10^{-8}	50	600	600
.003 37	1.90×10^{-8}	55	1 070	1 900
.001 90	6.00×10^{-9}	60	1 900	6 000
.001 07	1.90×10^{-9}	65	3 370	19 000
.000 600	6.00×10^{-10}	70	6 000	60 000
.000 337	1.90×10^{-10}	75	10 700	190 000
.000 190	6.00×10^{-11}	80	19 000	600 000

TABLE 5 : DECIBELS ABOVE AND BELOW REFERENCE LEVEL 1 mW INTO 600 OHMS

Note that the power holds for any impedance, but the voltage holds only for 600 ohms.

db down		Level	db up	
Volts	Milliwatts	dbm	Volts	Milliwatts
0.774 6	1.000	−0+	0.774 6	1.000
0.690 5	.794 3	1	0.869 1	1.259
0.616 7	.631 0	2	0.975 2	1.585
0.548 4	.501 2	3	1.094	1.995
0.488 7	.398 1	4	1.228	2.512
0.435 6	.316 2	5	1.377	3.162
0.388 2	.251 2	6	1.546	3.981
0.346 0	.199 5	7	1.734	5.012
0.308 4	.158 5	8	1.946	6.310
0.274 8	.125 9	9	2.183	7.943
0.244 9	.100 0	10	2.449	10.000
0.218 3	.079 43	11	2.748	12.59
0.194 6	.063 10	12	3.084	15.85
0.173 4	.050 12	13	3.460	19.95
0.154 6	.039 81	14	3.882	25.12
0.137 7	.031 62	15	4.356	31.62
0.122 8	.025 12	16	4.887	39.81
0.109 4	.019 95	17	5.484	50.12
0.097 52	.015 85	18	6.153	63.10
0.086 91	.012 59	19	6.905	79.43
0.077 46	.010 00	20	7.746	100.00
0.043 56	.003 16	25	13.77	316.2
0.024 49	.001 00	30	24.49	1.000W
0.013 77	.000 316	35	43.56	3.162W
0.007 746	.000 100	40	77.46	10.00W
0.004 356	3.16×10^{-5}	45	137.7	31.62W
0.002 449	1.00×10^{-5}	50	244.9	100W
0.001 377	3.16×10^{-6}	55	435.6	316.2W
0.000 774 6	1.00×10^{-6}	60	774.6	1 000W
0.000 435 6	3.16×10^{-7}	65	1 377	3 162W
0.000 244 9	1.00×10^{-7}	70	2 449	10 000W
0.000 137 7	3.16×10^{-8}	75	4 356	31 620W
0.000 077 46	1.00×10^{-8}	80	7 746	100 000W

TABLE 6: WATTS, DBM AND VOLTS ACROSS 5000 OHMS

Watts	dbm	volts across 5000Ω	milli-watts	dbm	volts across 5000Ω	micro-watts	dbm	milli-volts across 5000Ω
20	+43	315	63	+18	17.8	1.0	−30	71
15.8	+42	280	40	+16	14.0	0.63	−32	56
12.6	+41	250	25	+14	11.2	0.40	−34	45
10	+40	213	16	+12	8.9	0.25	−36	35
7.9	+39	200	10	+10	7.1	0.16	−38	28
6.3	+38	178	6.3	+ 8	5.6	0.10	−40	21.3
5.0	+37	158	4.0	+ 6	4.5	0.063	−42	17.8
4.0	+36	140	2.5	+ 4	3.5	0.040	−44	14.0
3.16	+35	126	1.6	+ 2	2.8	0.025	−46	11.2
2.5	+34	112	1.0	0	2.13	0.016	−48	8.9
2.0	+33	100	0.63	− 2	1.78	0.010	−50	7.1
1.59	+32	89	0.40	− 4	1.40	0.006 3	−52	5.6
1.26	+31	79	0.25	− 6	1.12	0.004 0	−54	4.5
1.0	+30	71	0.16	− 8	0.89	0.002 5	−56	3.5
0.79	+29	63	0.10	−10	0.71	0.001 6	−58	2.8
0.63	+28	56	63 μW	−12	0.56	0.001 0	−60	2.13
0.50	+27	50	40 μW	−14	0.45	0.000 63	−62	1.78
0.40	+26	45	25 μW	−16	0.35	0.000 40	−64	1.40
0.32	+25	39	16 μW	−18	0.28	0.000 25	−66	1.12
0.25	+24	35	10 μW	−20	0.213	0.000 16	−68	0.89
0.20	+23	31.5	6.3μW	−22	0.178	0.000 10	−70	0.71
0.16	+22	28	4.0μW	−24	0.140	3.2×10^{-5}	−75	0.39
0.13	+21	25	2.5μW	−26	0.112	1.00×10^{-5}	−80	0.21
0.10	+20	21.3	1.6μW	−28	0.089	3.2×10^{-6}	−85	0.13

(xi) Nomogram for adding decibel-expressed quantities

Two or more sounds combine to give a total sound whose acoustical power is the sum of the powers of the individual components. This nomogram* (Fig. 19.6A) may be used to determine the resultant level in db when the two component sound levels are also expressed in db, or for adding any decibel-expressed quantities.

The difference between the two component values in decibels is first determined by algebraic subtraction, and this difference value is found on Scale A. The corresponding figure on Scale B then indicates the number of decibels to be added to the greater original quantity to give the required resultant.

For example take two sound levels of 35.2 db and 37.0 db. The difference is 1.8 db which, when located on Scale A, indicates 2.2 db on Scale B. This value is then added to 37.0 db to give the resultant sound level of 39.2 db.

When the difference in level exceeds 20 db, disregarding the smaller quantity produces an error of less than 1%.

The nomograph scales are based on the formula :

$$B = \left[10 \log_{10}\left(1 + \log_{10}{}^{-1}\frac{A}{10}\right)\right] - A \qquad (26)$$

where A and B correspond to points on the respective scales. Ref. 37.

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* For Nomogram see page 822.

(xii) Decibels, slide rules and mental arithmetic

The following holds for power calculations under all conditions, and for voltage and current calculations when the impedance is constant.

Use of log-log slide rule

For voltage ratios, set the cursor to 10 on the log-log scale, and set the C scale to 20 on the cursor. Then set the cursor to the required voltage ratio on the log-log scale and read the decibels on the C scale. To obtain good accuracy it is advisable to use the section of the log-log scale between 3 and 100, dealing with powers of 10 separately.

For power ratios, set cursor to 10 on the log-log scale, set the C scale to 10 on the cursor and then proceed as before.

Decibel calculations by mental arithmetic

For occasions when a rule is not available, it is useful to be able to perform conversions mentally. It is possible to memorize a conversion table, but this is unnecessary because, starting with the knowledge that an increase of two times in a voltage ratio is equivalent to 6 db, and 10 times to 20 db, it is comparatively simple to build up such a table mentally as required. The backbone of the table is as follows—

db	0	2	6	8	12	14	18	20
factor	1	1.25	2	2.5	4	5	8	10

This is built up simply by adding 6 db for each two times increase from a ratio of unity, i.e. 2, 4 and 8 times represent 6, 12 and 18 db, and by subtracting 6 db for each halving of a multiplying factor of 10 times i.e. 10, 5, $2\frac{1}{2}$ and $1\frac{1}{4}$ times are represented by 20, 14, 8 and 2 db.

The next step in the table can be built up from noticing that a 2 db decrease represents a multiplying factor of 0.8 times. From this fact we can add the values for 4, 10 and 16 db—

db	4	10	16
factor	1.6 (2×0.8)	3.2 (4×0.8)	6.4 (8×0.8)

To complete the table we need values for each of the odd numbers of db. Noticing that 2 db down is equivalent to multiplying by 0.8 we can assume that the error in taking 1 db down as 0.9 is small, and the table can then be written in full.

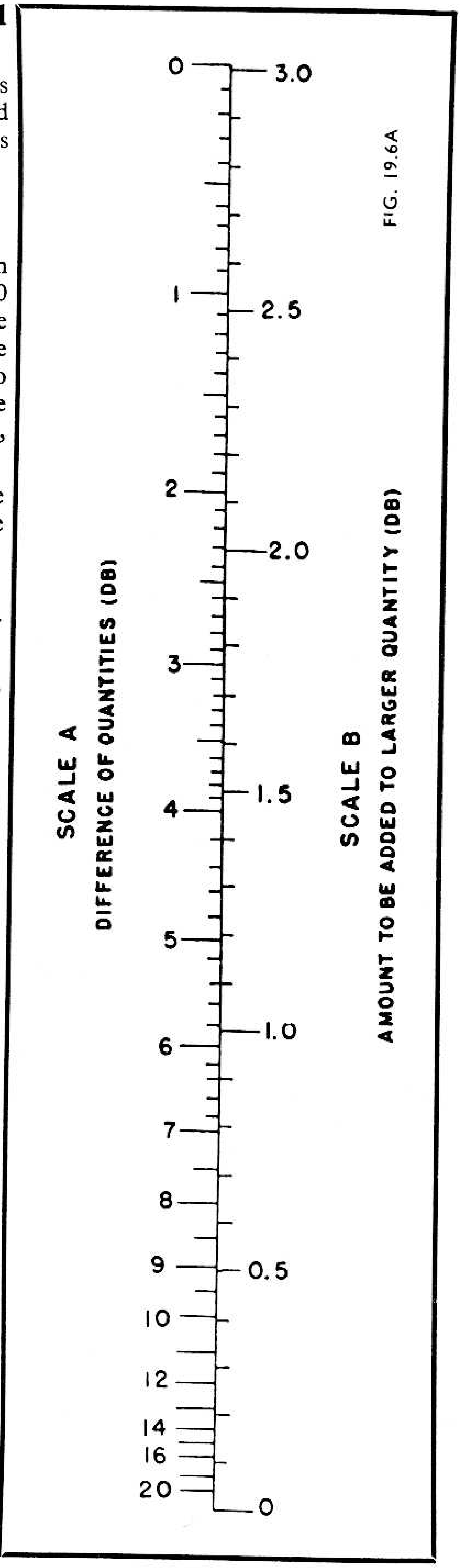

Fig. 19.6*A*.

Accurate values are recorded in the third line for comparison.

db—	0	1	2	3	4	5	6	7	8	9	10
factor—	1	1.12	1.25	1.4	1.6	1.8	2	2.3	2.5	2.9	3.2
true factor—	1.00	1.12	1.26	1.41	1.59	1.78	2.00	2.24	2.51	2.82	3.16

db—	11	12	13	14	15	16	17	18	19	20
factor—	3.6	4	4.5	5	5.8	6.4	7.2	8	9	10
true factor—	3.55	3.98	4.47	5.01	5.62	6.31	7.08	7.94	8.91	10.0

Comparing the multiplying factors computed in this manner with the true factors it will be seen that the greatest error (at 15 db) is just over 3% which is negligible for the type of calculation intended to be performed by this method.

When working with " db down," the number of db can be subtracted from 20 and the multiplying factor from the table can be divided by 10, e.g. 7 db (20-13) down is equivalent to a multiplying factor of 0.45. A small amount of practice at such mental conversions soon results in many of the factors being memorized (or else becoming immediately obvious) without any conscious effort in this direction.

SECTION 2: VOLUME INDICATORS AND VOLUME UNITS

(i) Volume indicators (ii) Volume units.

(i) Volume indicators

When an instrument is required merely to measure power under steady conditions, no particular difficulties are encountered and the scale may be calibrated in decibels with respect to any desired reference level. In studio programmes, however, the power is constantly fluctuating and the indication of the instrument will depend upon its speed of response and damping.

Volume is here applied to the indications of a device known as a Volume Indicator, which is calibrated and read in a prescribed manner.

The **Volume Indicator** is a standardized instrument (Ref. 19) which has been developed primarily for the control and monitoring of radio programmes. The Volume Indicator is a root-mean-square type of instrument with a full-wave copper-oxide type of rectifier. The rectifier law is intermediate between linear and square-law, having an exponential of 1.2 ± 0.2. Its dynamic characteristics are such that, if a sinusoidal voltage of frequency between 35 and 10 000 c/s and of such amplitude as to give reference deflection under steady-state conditions is suddenly applied, the pointer will reach 99% of reference deflection in 0.3 second (± 10%) and should then overswing reference deflection by at least 1.0% and not more than 1.5% (Ref. 19). It will give a reading of 80% on an impulse of sine wave form as short as 0.025 second (Ref. 18).

It is fitted with two scales, a vu scale marked 0 (" reference deflection ") at about 71% maximum scale reading, extending to + 3 (maximum) and − 20 (minimum) and a percentage voltage scale with 100% corresponding to 0 vu reading, calibrated downwards to 0%.

The instrument is available with the scales marked differently: With " Scale A " the vu scale is made more prominent, being situated above the percentage scale—

this is for use in measuring instruments etc. where the reading of the meter together with the reading of an associated attenuator (where necessary) give the actual power level. With " Scale B " the percentage scale is made more prominent being situated above the vu scale—this is for use in studio controls etc. where the operator is non-technical and is not interested in actual levels.

The sensitivity shall not depart from that at 1000 c/s by more than 0.2 db between 35 and 10 000 c/s at an input level of 0 vu, nor more than 0.5 db between 25 and 16 000 c/s (Ref. 19).

The instrument is calibrated by connecting it in shunt with a resistance of 600 ohms through which is flowing 1 milliwatt of sine-wave power at 1000 c/s, when a reading shall be 0 vu (or n vu when the calibrating power is n db above 1 milliwatt).

If the instrument is connected across any impedance other than 600 ohms, the volume indicated must be corrected by adding $10 \log_{10} (600/Z)$, where Z is the actual impedance in ohms.

The total impedance of the volume indicator is usually about 7500 ohms, of which about 3600 ohms is external to the instrument.

The Volume Indicator is intended to be read as deviations from the reference volume (0 vu), after making allowance for the sensitivity control (attenuator) which is also calibrated in vu. The reading is determined by the greatest deflections occurring in a period of about a minute for programme waves, or a shorter period (e.g. 5 to 10 seconds) for message telephone speech waves, excluding not more than one or two occasional deflections of unusual amplitude.

References 18, 19, 39, 49.

(ii) Volume units

The **volume unit** (abbreviated vu and pronounced " vee-you ") is a unit to express the level of a complex wave in terms of decibels above or below a reference volume as defined below. A level referred to as x vu means a complex wave power reading on a standard vu meter. Volume units should never be used to indicate the level of a sine-wave signal—the latter should always be referred to as so many dbm. Even if a vu meter is used to read the level of a steady single-frequency sine-wave signal, which is quite permissible, the reading should be referred to as so many dbm.

A volume unit implies a complex wave—a programme waveform with high peaks. The usual convention is to assume that the peak value is 10 db above the sine-wave peak.* For this reason an amplifier for radio broadcasting systems is tested with sine-wave input at a level 10 db above the maximum vu level at which it is intended to be used. For example, a system working at a level of + 12 vu would be tested for distortion at a level of + 22 dbm sine-wave.

Reference volume is defined as that strength of electrical speech or programme waves which gives a reading of 0 vu on a volume indicator as described above, and which is calibrated to read 0 vu on a steady 1000 c/s wave whose power is 1 milliwatt in 600 ohms. Care should be taken to distinguish between this definition of reference volume, which is arbitrary and not definable in fundamental terms, and a reference level of 1 milliwatt used for power measurements under steady conditions with a single frequency.

References 18, 19, 39, 49.

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*Occasional peaks under certain conditions may be somewhat higher.

SECTION 3: INDICATING INSTRUMENTS

(i) Decibel meters (ii) Power output meters (iii) Volume indicators (iv) Acoustical instruments.

(i) Decibel meters

A decibel meter is usually a rectifier type of instrument calibrated in decibels, with 0 db situated somewhere near the centre of the scale. The scale is usually marked to indicate the reference level and the line impedance, e.g. " 0 db = 6 mW ; calibrated for 500 ohm lines."

These instruments are frequently provided with attenuators to extend their range and are then sometimes called **power-level indicators.** They are actually voltmeters intended to be connected across a line of known impedance.

If a decibel meter is connected across a resistance other than the correct value the error will be

$$\text{error in db} = 10 \log_{10} (R_x/R) \qquad (1)$$

where R_x = resistance across which the meter is connected
and R = correct resistance for which the meter is calibrated.

A chart of corrections based on equation (1) is given in Ref. 4.

(ii) Power output meters

These differ from decibel meters in that the instrument dissipates and measures power. The input impedance is usually variable by means of a selector switch, and the scale of the instrument may be calibrated both in milliwatts and decibels.

(iii) Volume indicators

See Section 2 above.

(iv) Acoustical instruments

Sound level meters—see Section 5 below.

Noise meters—see Section 6 below.

References to indicating instruments—1, 4, 9, 17, 18, 19, 20, 21, 23, 25, 26, 27, 39.

SECTION 4 : NEPERS AND TRANSMISSION UNITS

(i) Nepers (ii) Transmission units.

(i) Nepers

Just as there are two systems of logarithms in general use, so there are two logarithmic units for the measurement of difference of power levels. The bel and the decibel are based on the system of Common Logarithms (to the base 10).

The neper is based on the system of Naperian Logarithms (to the base ϵ).

Nepers are not commonly used in English-speaking countries, but are used by some European countries.

Equation (1) below should be compared with Section 1, equation (2) above :

$$N_n = \tfrac{1}{2} \log_\epsilon (P_2/P_1) \qquad (1)$$

where N_n is the ratio of two powers expressed in nepers
P_1 = reference power
and P_2 = power which is referred back to P_1.

When the impedances relating to P_1 and P_2 are the same,

$$N_n = \log_\epsilon (E_2/E_1) \doteq \log_\epsilon (I_2/I_1) \qquad (2)$$

Equation (2) should be compared with equations (4) and (5) in Section 1 above.

Relationship between decibels and nepers

1 neper = 8.686 db
1 db = 0.1151 neper

Power ratio	1	1.259	1.585	3.162	10	100	10^5
db	0	1	2	5	10	20	50
nepers	0	0.1151	0.2303	0.5757	1.151	2.303	5.757

References 1, 9.

(ii) Transmission units

A transmission unit was the early name of the decibel, but is no longer used.

1 TU = 1 db

SECTION 5 : LOUDNESS

(i) Introduction to loudness (ii) The phon (iii) Loudness units.

(i) Introduction to loudness

The loudness of any tone is a function, not only of its intensity, but also of its frequency. This is indicated by the contour curves of equal loudness as shown in Fig. 19.7.

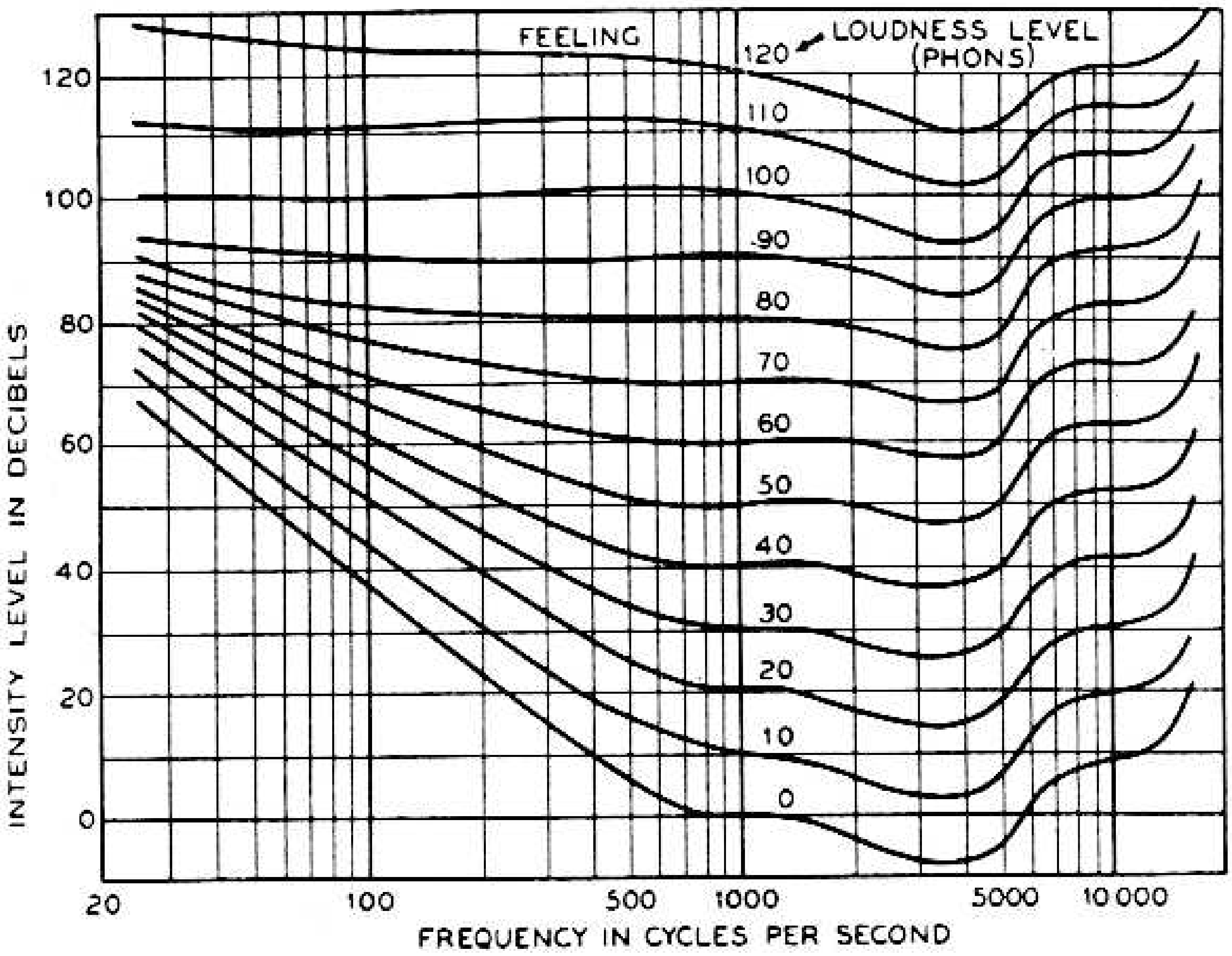

FIG. 19. 7

Fig. 19.7. *Contours of equal loudness level* (0 *db* = 10^{-16} *watt/cm*^{2})—*Ref.* 28, *after Fletcher and Munson* (*Ref.* 40).

(ii) The Phon

The phon is the unit of loudness level. The loudness level, in phons, of a sound is numerically equal to the intensity level in decibels of the 1000 c/s pure tone which is judged by the listeners to be equally loud. The reference intensity is 10^{-16} watt per square centimetre*, which is near the value of the threshold of audibility for a 1000 c/s pure tone (Ref. 22).

When listening to a 1000 c/s pure tone, the loudness level in phons is equal to the number of decibels above the reference intensity, but with any other frequency the loudness level in phons will normally differ from the intensity in decibels (Fig. 19.7).

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*The equivalent reference pressure for sound pressure measurements is 0.0002 dyne per square centimetre. The equivalent reference velocity for sound velocity measurements is 0.000 005 centimetre per second.

(iii) Loudness units

For purposes of noise measurement, the **loudness unit** has been standardized (Ref. 28), and is based on the principle that doubling the number of loudness units is equivalent to a sensation of twice the loudness. The relation between loudness level in phons and loudness in loudness units is given in Fig. 19.8.

References 40, 41, 28.

See also Supplement.

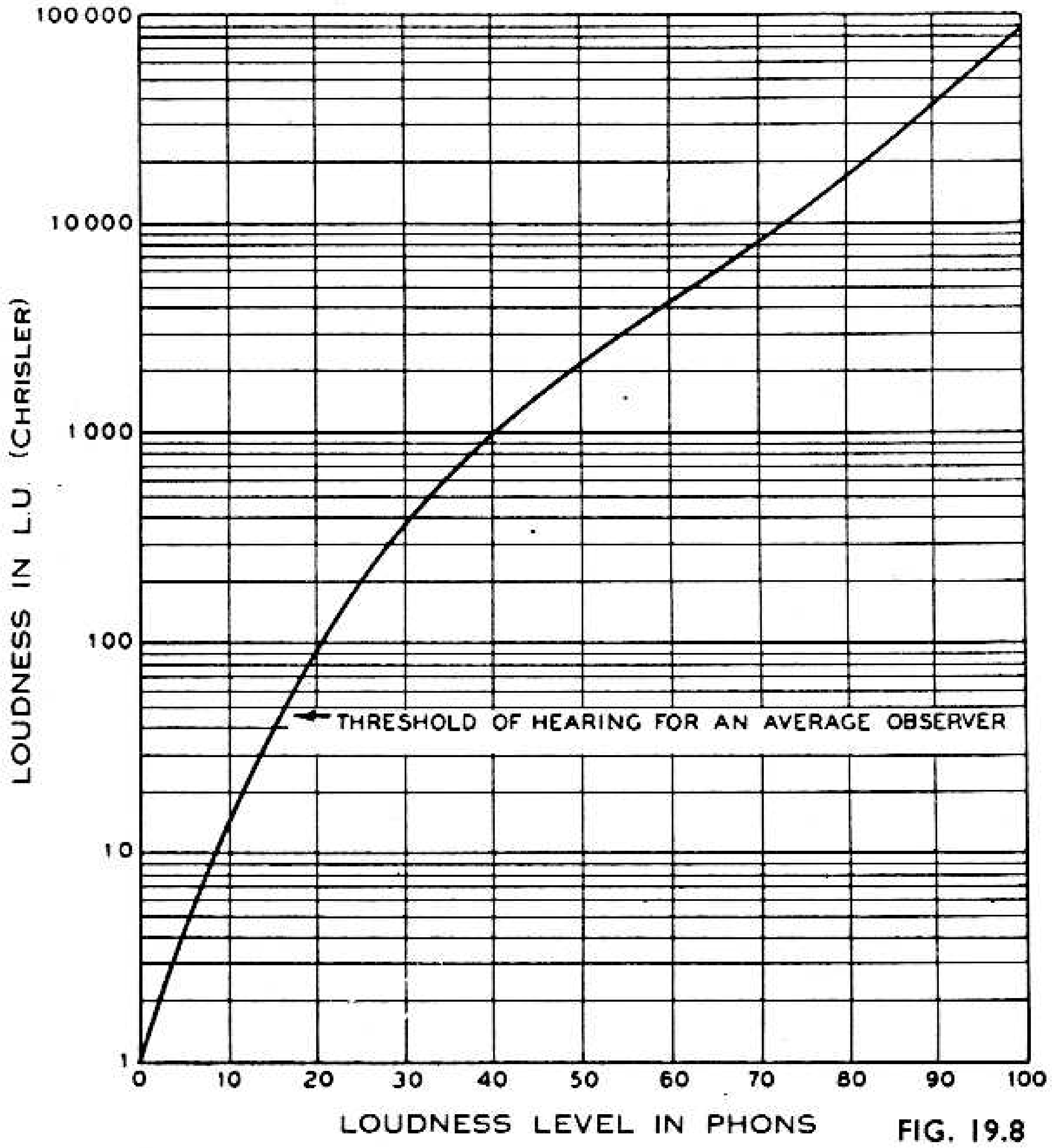

FIG. 19.8

Fig. 19.8. *Relation between loudness and loudness level ; reference frequency* 1000 *c/s— Ref.* 28, *after Fletcher and Munson* (*Ref.* 41).

SECTION 6 : THE MEASUREMENT OF SOUND LEVEL AND NOISE

(*i*) *Introduction* (*ii*) *The sound level meter* (*iii*) *The measurement of noise in amplifiers* (*iv*) *The measurement of radio noise.*

(i) Introduction

Sound includes wanted sound—music or speech—and also unwanted sound—noise. Noise may be measured acoustically, as for example by a sound level meter, or electrically. Acoustical methods of measuring noise and other sounds are described in (ii) below. Electrical noise may be measured either with or without a weighting network. If a weighting network is used, there will be appreciable attenuation of the lower frequencies, including hum frequencies. It is normally assumed in good engineering practice that the hum components have negligible effect on the noise reading ; if this is not so, they should be filtered out before the noise voltage is applied to the measuring equipment.

(ii) The sound level meter

Sound measurements, when made with an American standard sound level meter (Ref. 23) are determinations of sound intensity levels and are expressed in decibels—the reference sound pressure level is 0.0002 dyne/cm^2 at 1000 c/s. The standard sound level meter has a scale calibrated in decibels, and the readings should be referred to as e.g. " 60 decibels sound level " or " sound level of 60 decibels." A sound level meter may provide a choice of frequency response characteristics :

(A) The 40 decibel equal loudness contour*
(B) The 70 decibel equal loudness contour*
(C) Flat frequency response.

In all cases the frequency response should be stated in connection with any measurements. If only one frequency response is provided, this should be (A) above. Curve (A) is recommended for measurements up to 55 db, curve (B) for measurements from 55 to 85 db, and curve (C) for very loud sounds (85 to 140 db).

Within certain tolerances the sound level meter will indicate the sum of the equivalent 1000 c/s intensities of the different single frequency components in a complex wave—that is the power indicated for a complex wave will be the sum of the powers which would be indicated for each of the single frequency components of the complex wave acting alone.

The dynamic characteristics of the indicating instrument are specified in detail (Ref. 23).

The American sound level meter is a very simple instrument giving only approximate indications of loudness levels. However the ear does not judge the loudness of wide-band noises in the same way that it judges the loudness of pure tones. Consequently the use of the equal-loudness contours based on pure tones introduces errors which may be as great as 22 phons between the readings of an American sound level meter and subjectively measured loudness levels in phons (Ref. 42).

British objective noise meter

A more accurate acoustical noise meter has been designed by King and associates (Ref. 42) which includes a phase-shifting network, a peak-indicating meter and a larger number of weighting networks. See also Ref. 34 (pp. 894-896).

References to sound level meters : 12, 23, 24 (pp. 392-393), 34 (pp. 888-896), 42.

TABLE 7 : TYPICAL SOUND LEVELS

measured with American Standard Sound Level Meter

(after H. F. Olson, Ref. 24, by kind permission of the author and publishers—copyright by D. Van Nostrand Company, Inc., New York, U.S.A.)

Source or Description of Noise		Noise Level in Decibels
Threshold of Pain		130
Hammer Blows on Steel Plate	2 ft.	114
Riveter	35 ft.	97
7-passenger sedan car†		87
Factory		78
Busy street traffic		68
Large office		65
Ordinary conversation	3 ft.	65
Large store		63
Factory office		63
Medium store		62
Restaurant		60
Residential street		58
Medium office		58
Garage		55

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*Each modified by the differences between random and normal free field thresholds.

†Data from G. L. Bonvallet " Levels and spectra of transportation vehicle noise " J. Acous. Soc. Am. 22.2 (March 1950) 201.

Small store		52
Theatre (with audience)		42
Hotel		42
Apartment		42
House, large city		40
House, country		30
Average whisper	4 ft.	20
Quiet whisper	5 ft.	10
Rustle of leaves in gentle breeze		10
Threshold of hearing		0

(iii) The measurement of noise in amplifiers*

(A) Amplifiers for sound equipment

(based on R.M.A. Standard SE-101-A—Ref. 35).

This is an interim standard for the measurement of steady-state noise, and of pulse noise waves having a peak factor (ratio of peak to r.m.s.) approximating the maximum obtainable in speech (20 db).

Noise level is the level of any noise signals appearing at the output terminals with no signal applied to the input.

The weighted noise level is the noise level weighted in accordance with the 70 decibel equal-loudness contour of the human ear and expressed in dbm. The weighted noise level shall be measured under test conditions specified in Ref. 35. The measuring amplifier shall be one whose a-f response is weighted with the 70 db equal-loudness contour in accordance with Curve B of A.S.A. Specification Z24.3-1944 (Ref. 23) with a standard vu meter as defined by A.S.A. Specification C16.5-1942 (Ref. 19) as an indicator.

A properly weighted amplifier may be obtained by applying a r.c. network with a 1 millisecond time constant to an amplifier having a frequency response of ± 1 db from 50 to 15 000 c/s. This will give an attenuation of 1 db at 300 c/s, 5.7 db at 100 c/s and 9 db at 60 c/s.

(B) Audio facilities for radio broadcasting systems

(Based on R.M.A. Standard TR-105-B—Ref. 33).

Measurement of **steady state noise** shall be made with a device having an a-f response flat within ± 2 db from 50 to 15 000 c/s and having the ballistic characteristics of the standard vu meter (Ref. 19) but reading the r.m.s. value of a complex wave. Measurement of pulse noise conditions has not been included because of lack of definition and equipment.

Measurement made on those instruments incorporating average rather than r.m.s. rectifiers will give indications differing in general less than 1 db from the latter due to this difference. This is within the overall accuracy ordinarily obtained on this type of measurement.

Audio frequency signal to noise ratio—definition

The a-f signal to noise ratio is the numerical ratio between the sine-wave signal power required for standard output and the noise power measured with zero applied signal, received by the rated load impedance from the output of the equipment under test, expressed as a power ratio in decibels (Ref. 33).

(iv) The measurement of radio noise

Radio noise is any electrical disturbance which excites a radio receiver in such a way as to produce acoustical noise.

" A major objective of radio-noise-meter design is to provide an instrument which will give, for all kinds of radio noise, indications which are proportional to the annoyance factor or nuisance capability of the noise." Instruments complying with the specification of the Joint Co-ordination Committee (Ref. 25) are stated to be very satisfactory in this regard (Ref. 21). A useful review of the progress made up to 1941

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* For noise audibility test for radio receivers see Chapter 37 Sec. 1 (vi) K.

is given in Reference 26 with an extensive bibliography. The equivalent British Standard is described in Ref. 27.

References to noise—2, 9, 10, 12, 15 (Sect. 10-35), 20, 21, 24 (pp. 419-420,483-487), 25, 26, 27, 28, 33, 34, 35, 42.

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