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# The Measurement of Audio Volume

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## Part II—A comprehensive discussion of the problems involved and the instruments employed to indicate program level and sine-wave tones in broadcast and recording circuits.

**A** THOROUGH COMPREHENSION of the connotations of the term "reference volume" is fundamental to any studio engineering endeavor. Unfortunately, experience has shown that this subject is often completely misunderstood. It is hoped that the following will dispel the vague understanding that sometimes surrounds this simple subject.

It is important to appreciate that reference volume is a practical and useful concept, but one which is quite arbitrary and not definable in fundamental terms. As already mentioned, it cannot be expressed in any single way in terms of the ordinary electrical units of power, potential, or current. Reference volume is describable only in terms of the electrical and dynamic characteristics of an instrument, its sensitivity as measured by its single-frequency calibration, and the technique of reading it. In other words, reference volume may be defined as that level of program which causes a standard volume indicator, when calibrated and used in the accepted way, to read zero vU.

The sensitivity of the standard volume indicator is such that reference volume corresponds to the indication of the instrument when it is bridged across a 600-ohm resistor<sup>3</sup> in which is flowing one milliwatt of sine-wave power.

It is especially cautioned that *reference volume should not be confused with the single-frequency power* used to calibrate the zero volume setting of the volume indicator. If a volume indicator

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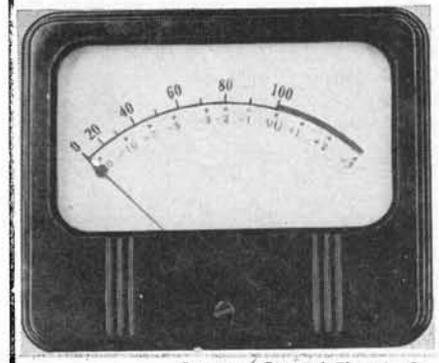
<sup>3</sup> A standard impedance of 600 ohms was chosen originally since, keeping in mind the telephone plant, there was more audio equipment designed to this impedance than to any other.

is calibrated so as to read zero vU on a sine wave power of, say, one milliwatt in a stated impedance, a speech or program wave in the same impedance whose intensity is such as to give also a reading of zero vU will have instantaneous peaks of power which are several times one milliwatt and an average power which is only a small fraction of a milliwatt. It is therefore erroneous to say that reference volume is one milliwatt.

Moreover, it should be emphasized that although it is convenient to measure the performance of amplifiers and systems by means of single frequencies there is no *exact* universal relationship between the single-frequency load-carrying capacity indicated by such measurements, and the load-carrying capacity for speech and program waves expressed in terms of volume level. This relationship depends upon a number of factors such as the rapidity of cutoff at the overload point, the frequency bandwidth being transmitted, the quality of service to be rendered, and similar factors.

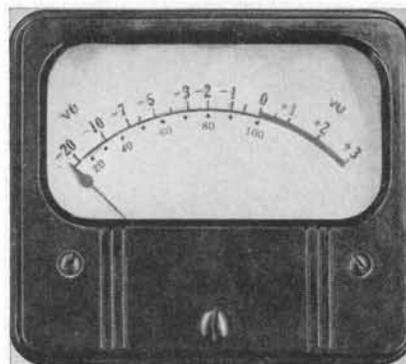
The question may well be raised why reference volume has been related to a calibrating *power* rather than to a cali-

brating *voltage*, inasmuch as a volume indicator is generally a high-impedance, voltage-responsive device. A reference level could conceivably be established based on voltage and the unit of measurement might be termed "volume-volts." However, volume measurements are a part of the general field of transmission measurements, and the same reasons apply here for basing them on power considerations as in the case of ordinary transmission measurements using sine waves. If the fundamental concept were voltage, apparent gains or losses would appear wherever impedance



Courtesy General Electric Co.

Fig. 3. The "B" type standard volume indicator scale emphasizes the percentage scale. This scale is used extensively for program transmission applications.



Courtesy General Electric Co.

Fig. 2. The "A" type standard volume indicator scale emphasizes the VU markings and has an inconspicuous voltage scale. This type of scale is commonly used for transmission measuring sets.

transforming devices (such as transformers) occur in a circuit. This difficulty is avoided by adopting the power concept, making suitable corrections in the readings when the impedance is other than 600 ohms.

### Volume Measurement Terminology

(a) VU. The terminology that is used to express volume measurements was created to avoid confusion as to the type of volume indicator used and the reference level. The term "vU" (pronounced "vee-you") is used; the number of vU

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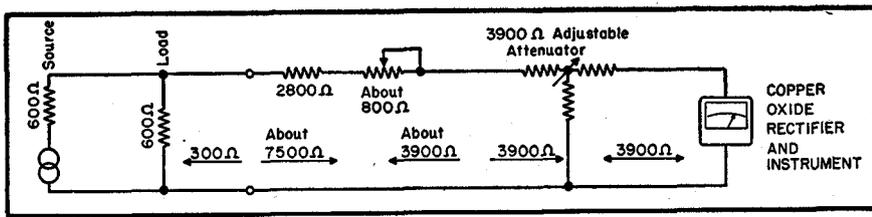


Fig. 4. The basic circuit for the standard volume indicator has an input impedance of 7500 ohms. For maximum sensitivity the loss in the adjustable attenuator is reduced to zero, but in order to maintain proper dynamic characteristics the indicating instrument itself must always face approximately 3900 ohms.

being numerically the same as the number of *db* above or below the reference volume level. The use of this term is restricted to the ASA standard volume indicator described herein. A volume level reading can be correctly expressed in terms of *vu* only when it has been made with an instrument having the electrical and dynamic characteristics described.

(b) *DBM*. For steady-state measurements a reading in "*vu*" would denote a specific single-frequency audio power, for dynamic program indications "*vu*" denotes only a volume level. This dual meaning of "*vu*" is avoided by the use of the term "*dbm*" for all steady-state measurements. As defined, a reading expressed in "*dbm*" at once indicates the power level of a steady, single-frequency signal where the number of "*dbm*" is equal to the number of decibels above or below a reference power of 1 milliwatt.

(c) *DBM* vs. *VU*. It is to be noted that a "*vu*" reading can be made only on a standard volume indicator whereas *sine-wave* power measured with the standard volume indicator or with any other suitable a.c. instrument can be expressed in "*dbm*".<sup>4</sup>

*DBM* is a unit of finite power whereas "*vu*" is a measure of volume level and, as already discussed, has no connotation of finite power level. Thus no direct relationship between "*dbm*" and "*vu*" can be established.

From a practical standpoint, however, some relationship is desirable between

the "*vu*" level used for program transmission peaks and the "*dbm*" level used for system measurements. In practice it has been found that with typical program material of a given crest amplitude, the standard volume indicator reaches an indication 8 to 14 *db* below that reached with a steady tone of the same crest amplitude. To nominally take into account this 8 to 14 *db* difference in response, the established practice is that

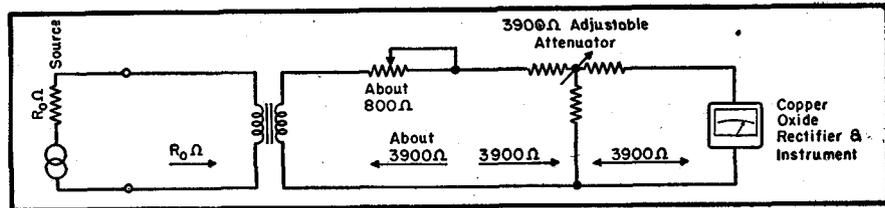


Fig. 6. Volume indicator circuit having low input impedance which terminates source and also provides increased volume indicator sensitivity.

performance requirements must be met at a single-frequency test-tone level that is at least 10 *db* higher than the normal program peaking level (for example, in a system that is to transmit program material at +8 *vu*, all single-frequency measurements would be made at +18 *dbm* test-tone level). This procedure reasonably insures that system performance is within standards under normal operating conditions.

#### Reading the Volume Indicator

Since program material is of a rapidly varying nature, a reading of a volume indicator cannot be obtained instantly. Rather, the gyrations of the needle must be watched for an appreciable period of

time, the length of time depending upon the program material. For speech a 5 to 10 second period of observation may be sufficient whereas for symphonic music 1 to 2 minutes may be necessary. During this time the adjustable attenuator, which is a part of the volume indicator, is adjusted so that the extreme deflections of the instrument needle just reaches the reference point; i.e., a scale reading of zero on the *vu* scale or 100 on the percent voltage scale (see Figs. 2 and 3). The volume level is then given by the designations numbered on the attenuator. If, because of the coarseness of the adjustments provided or for other reasons the deflections cannot be brought exactly to the 0 *vu* or 100 per cent mark, the reading obtained from the setting of the attenuator may, if desired, be corrected by adding the departure from 0 shown on the *vu* scale of the instrument. In the interests of accuracy the steps on the adjustable attenuator should not ex-

ceed 2 *db*, so that the departure from the reference point never need exceed this amount. Particular attention is called to the fact that, unlike almost any other electrical indicating instrument, the volume indicator reading is determined primarily from the setting of the associated range switch and, in effect, only a secondary correction is obtained by observing the deviation of the needle from exact coincidence with the reference point on the scale.

#### Features of the Standard Volume Indicator

The volume indicator that has been described has the stature of an American Standard.<sup>5</sup> In the many years since it was first placed into service there have been no changes, whatsoever, in either the fundamental requirements or the specific features of the instrument that was developed to meet the basic needs. Because of the importance and the widespread use of the instrument some of the detailed characteristics that are of concern to the design engineer are presented below.

(a) *Response vs. Frequency Characteristic*. The sensitivity of the volume indicator instrument shall not depart from that at 1000 cps by more than 0.2 *db* between 35 and 10,000 cps nor more than 0.5 *db* between 25 and 16,000 cps.

(b) *Input Impedance*. The impedance of the volume indicator arranged for bridging across a line is about 7500

[Continued on page 48]

<sup>4</sup> H. A. Chinn, *AUDIO ENGINEERING*, Vol. 32, No. 3, p. 28, March 1948

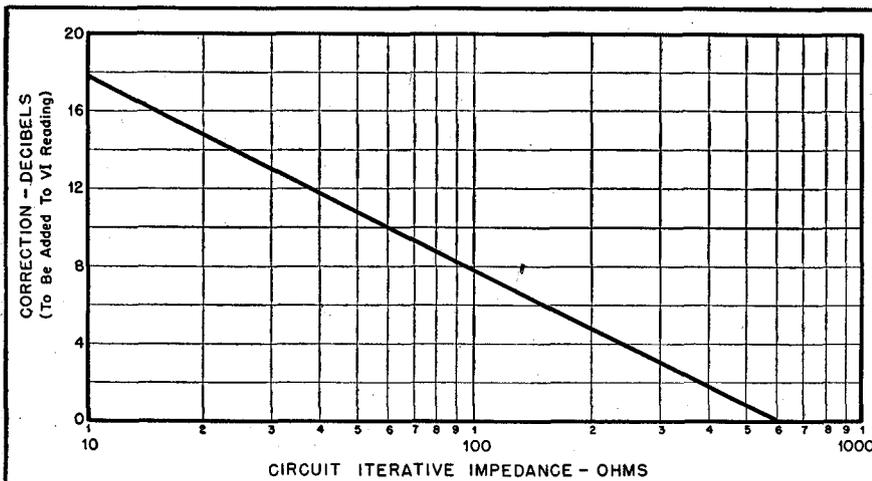


Fig. 5. Volume indicator correction factors (to be added to volume indicator reading) for use when instrument is bridged across circuits having iterative impedances other than 600 ohms.

<sup>5</sup> Volume measurements of electrical speech and program waves, American Standards Association C16.5-1942

## AUDIO VOLUME MEASUREMENT

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ohms when measured with a sinusoidal voltage sufficient to deflect the pointer to the 0 vu or the 100 per cent scale marking. Of this impedance, 3900 ohms is in the meter and about 3600 ohms must be supplied externally to the meter, this value of series resistance being required in order to meet the above dynamic characteristics.

(c) *Sensitivity.* The application of a 1000-cps potential of 1.228 volts r.m.s. (4 db above 1 milliwatt in 600 ohms) to the instrument in series with the proper external resistance (3600 ohms) causes a deflection to the 0 vu or 100 point on the scale. The instrument, therefore, has only sufficient sensitivity at its normal reference point (0 vu or 100) to indicate a volume level of +4 vu. It has not been found possible to design more sensitive instruments while meeting other requirements.

There should be no confusion because the instrument deflects to a scale marking of 0 vu when a level of +4 vu is applied to it. The 0 point on the vu scale is merely an arbitrary point at which it is intended nominally to read the instrument, and the rest of the vu scale represents deviations from the 0 point. The volume level is read, not from the scale, but from the indications on the associated sensitivity control when the latter is set so as to give a scale deflection of zero (as detailed in a foregoing section).

(d) *Overload Capacity.* The instrument is capable of withstanding, without injury or effect on calibration, peaks of 10 times the voltage equivalent to a deflection to the 0 vu or 100 scale point for 0.5 second and a continuous overload of 5 times the same voltage.

(e) *Presence of Magnetic Material.* It should be cautioned that the presence of magnetic material near the movement of the instrument may affect its calibration and dynamic characteristics. This is because, to obtain the desired sensitivity and dynamic characteristics, it has been necessary to employ more powerful magnets than usually required for such instruments, and any diversion of flux to nearby magnetic objects effectively weakens the useful magnetic field beyond the point where these characteristics can be met. The instruments should not, therefore, be mounted on steel panels. (The effect is only slight, however, if they are mounted on 1/16-in. steel panels with the mounting hole cut away as far as possible without extending beyond the face of the meter case.)

In the instruments as now available, the deviation of the sensitivity with temperature is less than 0.1 db for temperatures between 50° F. and 120° F., and is less than 0.5 db for temperatures as low as 32° F.

The instrument by itself does not con-

stitute a complete volume indicator but must have certain simple circuits associated with it. The basic form which this circuit takes is illustrated in *Fig. 4*. This is a high-impedance (7500-ohm) arrangement intended for bridging across low impedance lines. As noted above, about 3600 ohms of series resistance has been removed from the instrument and must be supplied externally in order to provide a point where the impedance is the same in both direction, for the insertion of an adjustable attenuator. A portion of the series resistance is made adjustable as shown by the slide wire in the diagram. This is for the purpose of facilitating accurate adjustment of the sensitivity to compensate for small differences between instruments and any slight changes which may occur with time.

The maximum sensitivity possible with this, the simplest circuit, is +4 vu for indications at the 0 vu or 100 per cent mark when placed across 600-ohm line. The maximum sensitivity occurs, of course, when the loss in the adjustable attenuator is zero. The upper limit to the range of measurement is limited only by the amount of loss introduced by the adjustable attenuator, its power handling capacity and that of the two series resistors.

The volume indicator of *Fig. 4* can be bridged across circuits of other than 600 ohms, of course, but when this is done a correction factor must be applied in order to determine the true level. *Figure 5* shows the magnitude of the correction factor. It is to be noted that the basic volume indicator circuit (*Fig. 4*) has an input impedance of 7500 ohms and should not be bridged across circuits of appreciably higher than about one-tenth of this impedance if undue loading of the circuit is to be avoided. On the other hand, when used across circuits of less than the normal 600 ohm value, the sensitivity of the instrument is reduced, as indicated by *Fig. 5*.

*Figure 6* shows an arrangement in which, by adding a transformer, the sensitivity has been increased at the expense of decreasing the input impedance to a low value. The circuit is designed so that the impedance facing the instrument itself is the same as in the basic circuit (*Fig. 4*). Thus the correct dynamic characteristics are obtained. The input impedance, on the other hand, is low, hence the device cannot be bridged across a through line but must be used to terminate the circuit. In practice, approximately a 10 db increase in sensitivity may be obtained by this arrangement.

In high-fidelity audio systems the use of a 150-ohm circuit impedance is becoming common practice.<sup>6</sup> However, when the basic volume indicator circuit is used with 150-ohm circuits a loss in sensitivity of 6 db results. Therefore, on a 150-ohm circuit the instrument is ca-

<sup>6</sup> Monroe and Palmquist, *Proc. I.R.E.*, Vol. 36, No. 6, p. 786 (June 1948).

pable of reading levels only down to +10 vu. The loss in sensitivity in situations such as this can be avoided by utilizing a circuit similar to Fig. 6 except that the step-up ratio of the transformer is made only great enough to overcome its own losses and that which results from the existence of lower voltage (for a given volume level) on a circuit of lower impedance. In the particular instance cited a step-up ratio of slightly more than 1:2 would be necessary if the transformer were without losses and slightly greater than this in a practical case.

The input impedance of the volume indicator (7500 ohms in the basic circuit) will be reduced under these circumstances by a factor equal to the square of the turns ratio. This is not a serious disadvantage, however, since the impedance of the circuit being bridged has also been reduced by essentially this same factor. Therefore the ratio of the circuit impedance to the bridging impedance remains approximately the same. For the particular example cited, namely a 150-ohm circuit, practical volume indicator transformers, when terminated in a standard volume indicator, have input impedances of about 1700 ohms.

#### Transmission Level Practices

The volume levels that are used for the transmission of speech and program waves may be determined upon in a number of ways depending upon the communications service involved. For example, in a system employed for voice communication, where loss of naturalness of the speaker's voice is not a factor, the relative audio levels might be maintained as high as possible without loss of intelligence. Another criterion might be the transmission of voice and music at the same loudness. On this basis, using the standard volume indicator, voice would be peaked 2 or 3 db below music.<sup>1</sup> Still another possible basis for determining relative transmission level is the appearance of aural distortion caused by overloading of the particular facility involved. Determinations of this kind are usually made on an A-B test basis<sup>1</sup> and the results will depend to a large extent upon the shape of the overloading characteristic of the system involved. Transmission practices based upon this criterion ensure the maximum use of the facility concerned while avoiding detectable aural distortion. For this reason it has great appeal, from a purely technical standpoint, for high-fidelity broadcasting and sound recording applications. However, it does not take into consideration the listener's preferences.

Program transmission practices, where listening for pleasure is concerned, may well be determined on the basis of the average listener's wishes. A study<sup>7</sup> made with this criterion de-

veloped that on the average, listeners prefer to hear broadcast music and speech at about the same peak levels as read on a standard volume indicator. Furthermore, listeners like to hear broadcast music and speech at the same relative levels, regardless of the absolute sound level that is individually preferred.

The Columbia Broadcasting System is following this practice with considerable success. The measure of success in this instance being the almost complete absence of listener complaints concerning the relative loudness of speech and music. A few complaints continue to be received of course, but when specific cases are investigated it is almost always found that either (a) the recommended transmission practices were violated because of some special circumstance or (b) that the program originated on another network.

<sup>1</sup> Chinn, Gannett and Morris; *Proc. I.R.E.*, Vol. 28, No. 1, p. 9, Jan. 1940.

<sup>1</sup> *Loc. cit.*, pg. 4.

<sup>7</sup> Chinn and Eisenberg, *Proc. I.R.E.*, Vol. 35, No. 12, p. 1547 (Dec. 1947).