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Decibels and Their Uses

By the Engineering Department, Aerovox Corporation

BECAUSE of the large number of inquiries reaching us relative to use of the *transmission unit*, we devote this issue to a concise explanation of the unit and its applications.

The transmission unit is a useful tool. Its widespread adoption has enabled uniformity in the expression of identical ratios of different electrical units often in different circuits or systems. Present practice finds it convenient to express in *decibels* the gain or loss in amplifiers, antennas, and receivers; the extent of attenuation or transmission in wave filters and volume-level networks; the amount of signal rejectivity afforded by selective receiver circuits; etc. A working knowledge of the unit is now prerequisite to a number of measurement operations in radio and telephony.

The standard transmission unit is the decibel (abbreviated *db*) and is equal to one-tenth of a *bel*. Nominally, it supersedes the TU (transmission unit), although specifying exactly the same thing as the latter term. The bel, named in honor of Alexander Graham Bell, was adopted by an international convention of telephone engineers.

The decibel is a logarithmic expression of a ratio between two quantities. As a unit of measurement, it specifies no definite amount of current, voltage, power, or sound but represents merely a ratio between two magnitudes of either one. It is therefore a relative unit. Since the db is a logarithmic unit, successive gains or losses expressed by it may be added algebraically.

The db may express a ratio between two values of either current, voltage, power, or sound energy. It thus becomes possible to determine the db gain for a given amplifier from ratios that express either voltage, current, or power amplification. Gain is expressed as *plus* db; loss as *minus* db.

While the decibel may show gain or loss with respect to the power at some point in a system, it properly has no regard for the finite value of any reference power. However, it is accepted practice in some radio and telephone measurements to designate the power level of 0.006 watt (6 milliwatts) as *zero db* and to express any other value of power as a certain number of db above or below this reference level. Hence, the expressions "db up" and "db down", now in common parlance.

DETERMINATION

Ratios are common to everyday scientific ratings. They express relative superiority or inferiority, gains or losses in a concise and readily understandable manner. We state that a certain transformer permits a voltage step-up of 2 to 1, or that the response of a superheterodyne to signal and image is 200 to 1, and so on. Such simple ratios might easily be converted into convenient statements of db gain and db attenuation.

The ratio of two values of power, for example, P_1 and P_2 is represented as

$$(1) \qquad \frac{P_1}{P_2}$$

Or, the larger power is divided by the smaller. It is easily seen that the actual instantaneous magnitudes of P_1 and P_2 might extend over a wide range of values but would be of no concern

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to the quotient as long as they remained in the same proportion to each other.

The number of decibels represented by such a ratio is obtained by multiplying the logarithm of the indicated quotient by 10:

(2)
$$\text{no. db} = 10 \log_{10} \frac{P_1}{P_2}$$

Observe that the common logarithm of the quotient (ratio) is employed; i. e., the logarithm to the base 10. Hence the form, $\log_{10}$. From equation (2) the following rule may be stated:

(Rule A) The number of db is numerically equal to 10 times the common logarithm of a power ratio.

Voltage and current ratios may also be expressed in terms of decibels. If the two values of voltage, E_1 and E_2 are measured across the same or identical impedances, or if the two values of current (I_1 and I_2) are taken through the same or identical impedances:

(3)
$$\text{no. db} = 20 \log_{10} \frac{E_1}{E_2} = 20 \log_{10} \frac{I_1}{I_2}$$

Observe that in equations (3) the logarithm of the ratio is multiplied by 20 instead of 10. This is because power varies directly as the square of the voltage or the square of the current, and a logarithmic expression obtained in the manner of equation (2) needs to be multiplied again by 2, since doubling a logarithm is equivalent to squaring the number.

If, as is occasionally the case, the current or voltage values in the ratio are not associated with the same or identical impedances, our decibel computation must take into consideration the absolute magnitudes of the corresponding impedances and power factors of the impedances:

(4)
$$\text{no. db} = 20 \log_{10} \frac{E_1}{E_2} + 10 \log_{10} \frac{Z_2}{Z_1} + 10 \log_{10} \frac{f_1}{f_2}$$

and

(5)
$$\text{no. db} = 20 \log_{10} \frac{I_1}{I_2} + 10 \log_{10} \frac{Z_1}{Z_2} + 10 \log_{10} \frac{f_1}{f_2}$$

Z_1 and Z_2 are the impedances in which the voltages and currents operate, and f_1 and f_2 are the values of the corresponding power factors of the impedances.

From equations (3), (4), and (5) the following rules may be stated:

(Rule B) When a voltage or current ratio shows values associated with the same or identical impedances, the number of db is numerically equal to 20 times the common logarithm of the ratio.

(Rule C) When a voltage ratio shows values associated with unequal impedances, the number of db is numerically equal to a sum of three logarithmic expressions: 20 times the log of the voltage ratio plus 10 times the log of the INVERTED impedances ratio plus 10 times the log of the power factor ratio.

(Rule D) When a current ratio shows values associated with unequal impedances, the number of db is numerically equal to the sum of three logarithmic expressions: 20 times the log of the current ratio plus 10 times the log of the impedance ratio plus 10 times the log of the power factor ratio.

RELATIONSHIPS

By definition, the common logarithm of a number is the exponent denoting the power to which 10 must be raised to equal the given number. Thus, 3 is the common log of 1,000, since 10 must be raised to the third power to equal 1,000. 5 is the common log of 100,000; 6 of 1,000,000.

Column 2 of Chart I lists common logs corresponding to a few of the even-numbered ratios frequently encountered in radio work. The ratios are given in column 1. These logs are multiplied by 10 (in column 3) to give db for power ratios, and by 20 (in column 4) to give decibels for current or voltage ratios.

It is readily seen from the chart that a power ratio of 100 to 1 corresponds to 20 db, while a current or voltage ratio of the same magnitude corresponds to 40 db. A ratio of 1,000,000 is equivalent to 60 db for power, but 120 db for current or voltage. It is also seen that a power, voltage, or current ratio must be squared in order to double the number of decibels; and that increasing a power ratio to 10 times its original value is equivalent to adding 10 db, while the same increase in a current or voltage ratio is equivalent to adding *20* db.

It should be apparent to the reader that the same number of db may be obtained from each of a number of ratios with widely divergent numerator and denominator values, as long as the same proportion exists between the two terms. A clear understanding of this condition not only explains away the mystery of why an extremely low-powered system can show the same number of db gain as one of high power, but at the same time also places illustrative emphasis upon the relativity of the transmission unit.

CHART I

(1) RATIO	(2) LOG OF RATIO	(3) DB FOR POWER RATIO	(4) DB FOR CURRENT OR VOLTAGE RATIO
1	0	0	0
10	1	10	20
100	2	20	40
1000	3	30	60
10,000	4	40	80
100,000	5	50	100
1,000,000	6	60	120

Consider, for example, three a. f. amplifiers—one delivering 1 watt output with 0.1 milliwatt input; the second delivering 10 volts output for 100 millivolts input, both input and output circuits operating into 500 ohms impedance; and the third delivering 50 watts output for 5 milliwatts input. The gain in each case is 40 db.

Another familiar example deals with antenna gain. A certain efficient directive array might be found to deliver at a given location a field strength amounting to ten times the number of microvolts delivered there by a simple dipole antenna. It is seen that the gain for this *voltage* ratio of 10 is 20 db.

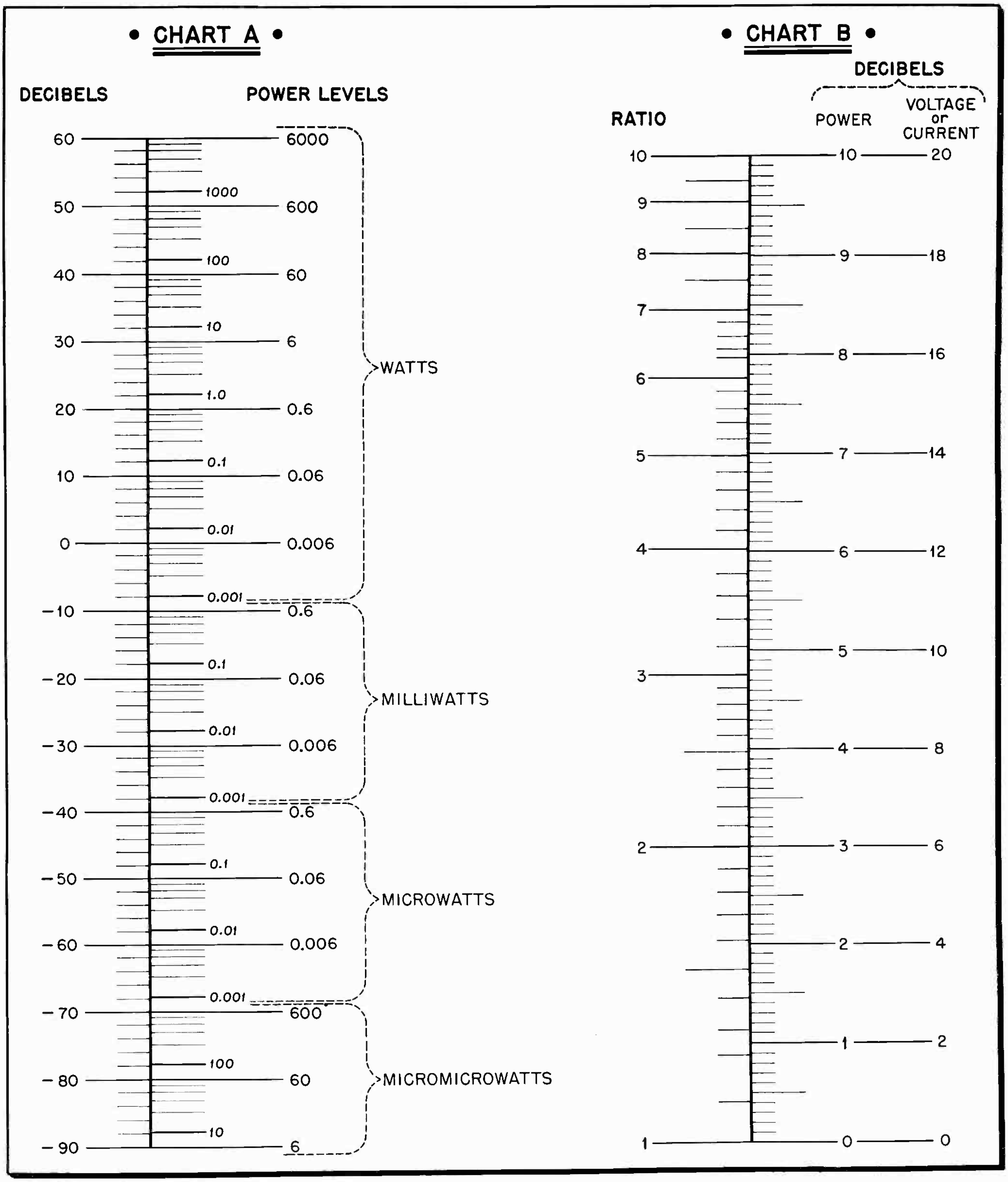
APPLICATIONS

1. *Amplifier Power Gain or Loss.* (a) Measure a.f. or r.f. input watts, (b) measure a.f. or r.f. output watts, (c) apply equation 2 and Rule A.
2. *Amplifier Voltage Gain or Loss. Input & Output Impedances Equal.* (a) Measure a.f. or r.f. input voltage, (b) measure a.f. or r.f. output voltage, (c) apply voltage equation 3 and Rule B.
3. *Amplifier Current Gain or Loss. Input & Output Impedances Equal.* (a) Measure a.f. or r.f. input current, (b) measure a.f. or r.f. output current, (c) apply current equation 3 and Rule B.
4. *Amplifier Current or Voltage Gain or Loss. Unequal Input & Output Impedances.* (a) Measure a.f. or r.f. input voltage or current, (b) measure a.f. or r.f. output voltage or current, (c) determine absolute values of input and output impedances, (d) determine absolute values of power factor for the two impedances, (e) apply voltage equation 4 and Rule C or current equation 5 and Rule D.

Note—Any of the foregoing amplifier characteristics may be taken for the entire amplifier (overall), a single stage (per stage) or any cascaded group of stages. A *plus db* rating indicates gain; *minus db*, loss.

5. *Directive Antenna Front-to-Back Gain.* (a) With antenna array pointed in direction opposite to receiving location, measure the signal voltage at a given location with suitable field-strength indicating apparatus, (b) record volts, millivolts, or microvolts response as E_2, (c) point antenna array directly toward the receiving location and record the increased field strength indication as E_1, (d) apply voltage equation 3 and Rule B.
6. *Amplifier Output Level, or A. F. Line Level.* This is stated by engineers and manufacturers as so many db, the number of decibels above or below 6 milliwatts (zero db) being assumed. Apply the equation:

(6)
$$P \text{ in watts} = .006 \times \text{antilog} \frac{db}{10}$$



This ready-reference chart is issued in this handy form as a supplement to the July 1941 issue of the Aerovox Research Worker. It may be mounted for use as a wall chart or other convenient means, as the reader prefers.

INSTRUCTIONS — OVER

Ready Reference Charts

For the reader's convenience, two charts have been made up from calculations involving equations (2), (3) and (6).

By referring to Chart A, the number of decibels corresponding to any power level between 6 micromicrowatts and 6 kilowatts may be found quickly, the necessity for performing equation (6) computations being eliminated in most practical instances. From Chart B, the number of decibels corresponding to any current, voltage, or power ratio may be quickly located.

Particular notice should be taken of the subdivisions in the power column of Chart A. These graduations are uniformly spaced (as regards numerical value) except that the lowermost subdivision in each power group has not the same value as each of the upper five in the group. For this reason, we have numbered the lowermost subdivision in each group. Thus, the numbered line, 10 micromicrowatts is only 4 micromicrowatts removed from the 6 micromicrowatt major division, while each other subdivision up to 60 micromicrowatts is exactly 10 microwatts higher than the previous one. Thus, we read, 10, 20, 30, 40, and 50 micromicrowatts between 6 and 60 micromicrowatts. Similarly, we read, 100, 200, 300, 400, and 500 microwatts in the next highest power group, between 60 and 600 micromicrowatts.

To illustrate the use of Chart A, locate the db output rating of a 6L6 amplifier, the audio output power of which is 60 watts. Opposite the 60-watt line in the power column will be found the 40 line in the decibel column. On the basis of 6 milliwatts as zero db, a power level of 60 watts is 40 db.

The power output of a high-quality microphone rated at —45 db may be found in the same manner. Read 0.2 microwatt directly opposite --45 db in Chart A.

A current, voltage, or power ratio is located in the ratio column of Chart B and the number of decibels read directly opposite in the power column or current-voltage column, depending upon the nature of the ratio. For example: a power ratio of 4 is seen to correspond to 6 db while a current or voltage ratio of the same value equals 12 db.

The use of Chart B can be extended beyond the current or voltage ratio of 10 by adding 20 db for each place the decimal point has been moved to the right to make the figures in the ratio column correspond to those in the ratio desired. For example: to find the db equivalent to a current or voltage ratio of 44, locate 4.4 in the ratio column of Chart B. Read the equivalent 12.8 db in the current-voltage db column. The decimal point was moved one place in 4.4 to convert it into the ratio, 44. Therefore, add 20 db to the result. 12.8 plus 20 equal 32.8 db.

The use of Chart B may similarly be extended beyond the power ratio of 10 by adding 10 db for each place the decimal point is moved to the right. For example: look up the power ratio 160 as 1.6 in the ratio column. This would correspond to 2 db. But the decimal point was shifted two places to change 1.6 to 160 and 10 db must be added for each place. The result, therefore, is 2 plus 20, or 22 db.

EQUATIONS

(2)
$$\text{no. db} = 10 \log_{10} \frac{P_1}{P_2}$$

(3)
$$\text{no. db} = 20 \log_{10} \frac{E_1}{E_2} = 20 \log_{10} \frac{I_1}{I_2}$$

(4)
$$\text{no. db} = 20 \log_{10} \frac{E_1}{E_2} + 10 \log_{10} \frac{Z_2}{Z_1} + 10 \log_{10} \frac{f_1}{f_2}$$

and

(5)
$$\text{no. db} = 20 \log_{10} \frac{I_1}{I_2} + 10 \log_{10} \frac{Z_1}{Z_2} + 10 \log_{10} \frac{f_1}{f_2}$$

Z_1 and Z_2 are the impedances in which the voltages and currents operate, and f_1 and f_2 are the values of the corresponding power factors of the impedances.

(6)
$$P \text{ in watts} = .006 \times \text{antilog} \frac{db}{10}$$

(7)
$$db = 8.686 \text{ nepers}$$

and

(8)
$$\text{nepers} = 0.1151 \text{ db}$$

CHART I

(1) RATIO	(2) LOG OF RATIO	(3) DB FOR POWER RATIO	(4) DB FOR CURRENT OR VOLTAGE RATIO
1	0	0	0
10	1	10	20
100	2	20	40
1000	3	30	60
10,000	4	40	80
100,000	5	50	100
1,000,000	6	60	120

(*See Charts A & B on other side*)

RULES

(Rule A) The number of db is numerically equal to 10 times the common logarithm of a power ratio.

(Rule B) When a voltage or current ratio shows values associated with the same or identical impedances, the number of db is numerically equal to 20 times the common logarithm of the ratio.

(Rule C) When a voltage ratio shows values associated with unequal impedances, the number of db is numerically equal to a sum of three logarithmic expressions: 20 times the log of the voltage ratio plus 10 times the log of the INVERTED impedances ratio plus 10 times the log of the power factor ratio.

(Rule D) When a current ratio shows values associated with unequal impedances, the number of db is numerically equal to the sum of three logarithmic expressions: 20 times the log of the current ratio plus 10 times the log of the impedance ratio plus 10 times the log of the power factor ratio.

The term db is the figure stated for the amplifier or line. An *antilog* is the figure or number which corresponds to a certain log. (Looking up an antilog in the log tables is the reverse of the process of looking up a log.)

7. *Microphone, Hum, Input Signal or Noise Level.* This is generally stated as so many negative db, or "db down," and like Example 6 refers to zero db as 6 milliwatts. Apply equation 6, changing the sign of the numerator, db to minus. If the numerator is not equally divisible by 10, it must be made so by adding the smallest number which will make it so, dividing both this sum and the added number by 10, and combining the quotients to give the log, db/10. Thus, —19 db would not be divisible by 10, but could be made so by adding 1. If both −20 and +1 are then divided by 10, the result is −10 plus +0.5. Combining the two gives −10.5 as the logarithm. The antilog of —10.5 is then multiplied by 0.006, as indicated by equation 6.

THE NEPER

If the Napierian logarithm, instead of the common (base 10) log is used in any of the equations given in this article, the units obtained from the calculations will not be decibels but *nepers*, which are employed in some types of engineering measurements, particularly in Europe.

The base of the Napierian logarithm is the number 2.71828, designated by the letter e. The Napierian logarithm of a number n is written $\log_e n$.

(7) $$\text{db} = 8.686 \text{ nepers}$$

and

(8) $$\text{nepers} = 0.1151 \text{ db}$$

USE OF THE SLIDE RULE

Problems involving decibels are easily solved on the slide rule, making use of the L logarithm scale. Converting a power ratio to decibels is accomplished by setting the indicator to the power ratio on the D scale and reading the number of db on the L scale. Example: the power ratio corresponding to 5 is 6.99 db. When the power ratio is higher than 10, divide by 10, 100 etc. until the quotient is less than 10. Find the corresponding db and add 10 decibels for each place the decimal point had to be moved in order to bring the ratio within the range 1-10. Example: What is the db gain corresponding to a power gain of 5530? Moving the decimal point three places to the left, we obtain 5.53. Set the indicator to 5.53 on the D scale and read 7.42 on L. Add 30 db to the result, which gives 37.42 db.

If the power ratio is less than 1, the CI and L scales should be employed. Finding the db gain corresponding to voltage ratios — if the impedances and power factors are the same in each case — proceed as described in the foregoing but multiply the result by 2.

The "log-log" slide rule offers an alternative method of finding decibels. Set the index on the slide to 10 on LL3. Opposite the power ratio on LL2 and LL3 find the gain in db on C. If the power ratio was greater than 10, all values found on C are between 10 and 100. If it was less than 10, the C scale may be read directly.

Finding decibels from the voltage ratio is accomplished by setting 2 on the C scale to 10 on LL3. Opposite the voltage ratio on LL2 or LL3, the db may be read on C. If the voltage or current ratio is between 1 and *pi*, the db gain is between 1 and 10. If the ratio exceeded 3.14, multiply the C indication by 10.

It is interesting to note that gain in nepers may be found by aligning the indices. Opposite the current or voltage ratio on LL2 and LL3, find nepers on C.

When converting power ratios less than 1 to decibels, set 1 (middle of B scale) to 0.10 on the LLO scale. DB loss is then found on B opposite the power ratio on LLO. For current or voltage ratios, set 2 on the B scale to 0.10 on the LLO scale and proceed as before.

To find the gain in db directly from two values of current, voltage, or power, set the larger of the two on C to the smaller on D. Opposite the index of C, find db on L.

READY-REFERENCE CHARTS

For the reader's convenience, two charts have been made up from calculations involving equations (2), (3), and (6).

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The power output of a high-quality microphone rated at —45 db may be found in the same manner. Read 0.2 microwatt directly opposite −45 db in Chart A.

A current, voltage, or power ratio is located in the ratio column of Chart B and the number of decibels read directly opposite in the power column or current-voltage column, depending upon the nature of the ratio. For example: a power ratio of 4 is seen to correspond to 6 db while a current or voltage ratio of the same value equals 12 db.

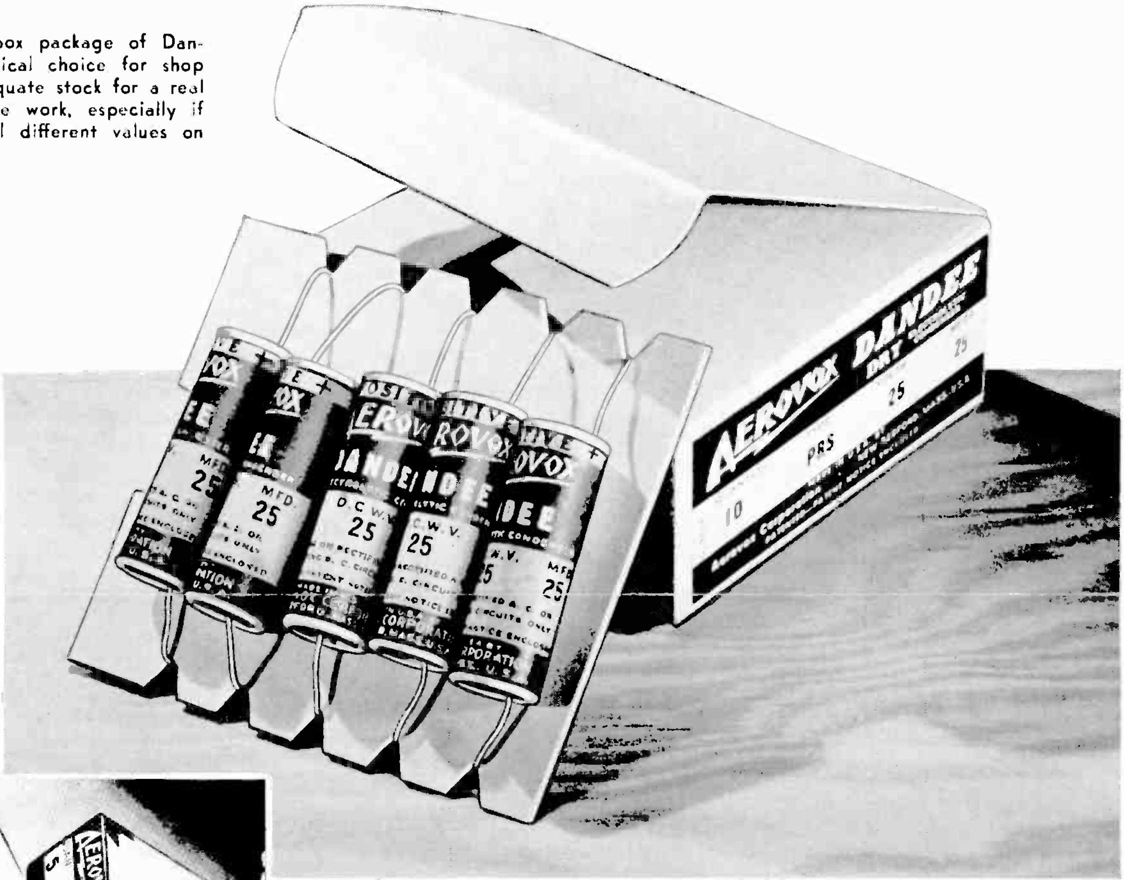
The use of Chart B can be extended beyond the current or voltage ratio of 10 by adding 20 db for each place the decimal point has been moved to the right to make the figures in the ratio column correspond to those in the ratio desired. For example: to find the db equivalent to a current or voltage ratio of 44, locate 4.4 in the ratio column of Chart B. Read the equivalent 12.8 db in the current-voltage db column. The decimal point was moved one place in 4.4 to convert it into the ratio, 44. Therefore, add 20 db to the result. 12.8 plus 20 equal 32.8 db.

The use of Chart B may similarly be extended beyond the power ratio of 10 by adding 10 db for each place the decimal point is moved to the right. For example: look up the power ratio 160 as 1.6 in the ratio column. This would correspond to 2 db. But the decimal point was shifted two places to change 1.6 to 160 and 10 db must be added for each place. The result, therefore, is 2 plus 20, or 22 db.

ERRATUM NOTICE

The bypass condenser C_1 in the transmitter circuit diagram, Fig. 1, in the March, 1941 issue of the Research Worker should be connected in parallel with the 6L6 cathode resistor, instead of in the manner shown.

● The ten-in-a-box package of Dandees is your logical choice for shop use. Insures adequate stock for a real volume of service work, especially if you carry several different values on hand.



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50 v. D.C.W.—10-10 mfd.
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