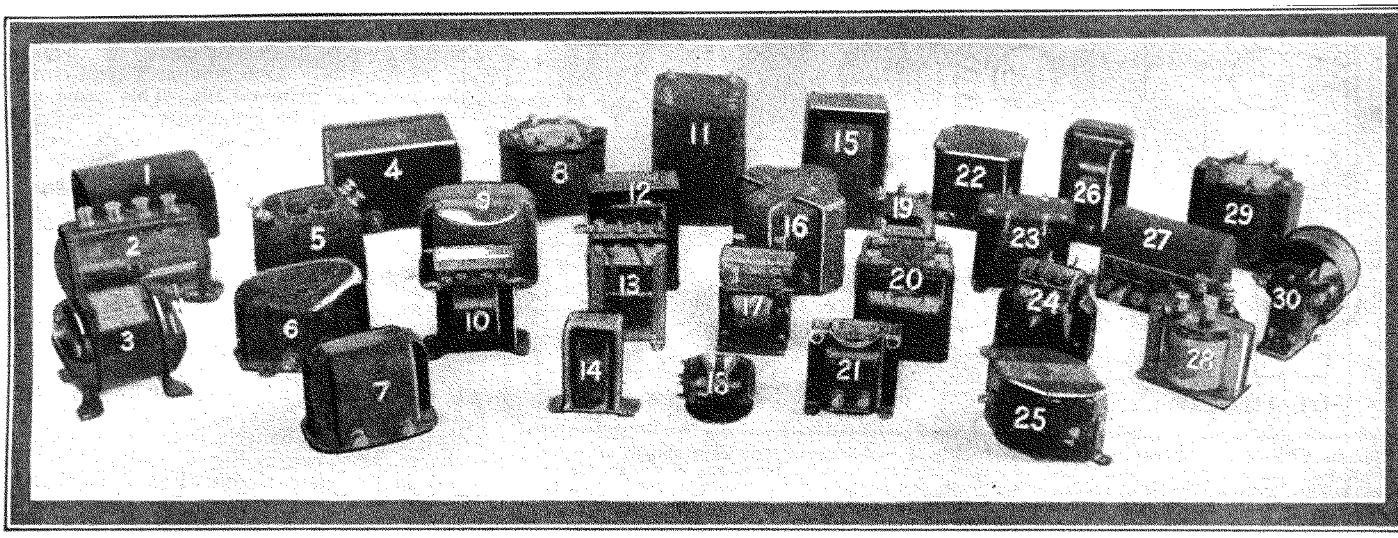
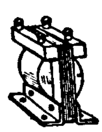


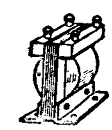
A group of the commercially-manufactured A.F. amplifier transformers which are being studied in the RADIO NEWS laboratories: 1, Como (push-pull); 2, General Radio (English); 3, Karas; 4, Jefferson; 5, Modern Symphony; 6, Precise; 7, Perry; 8, Wagner; 9, Acme; 10, Quality; 11, Marlefier; 12, Thordarson; 14, Thompson-Levering; 16, Erla; 17, Supertran; 18, Hedgehog; 20, Samson; 21, Dongan; 22, Amertran; 23, Kellogg; 24, All-American; 25, Bremer-Tully; 26, General Radio (American); 27, Como (variable ratio); 28, Foster; 29, Magic; 30, Hart & Hegeman.

How Should Transformer Curves Be Plotted?

By SYLVAN HARRIS



The question of the best scale to use, when drawing the "characteristic curve" of an audio-frequency amplifier on a diagram, has been given much attention recently by writers and experimenters. As often happens, the radio laymen have not yet been given full information. Mr. Harris treats the matter thoroughly and completely below, presenting some ideas which will be new to the fraternity.



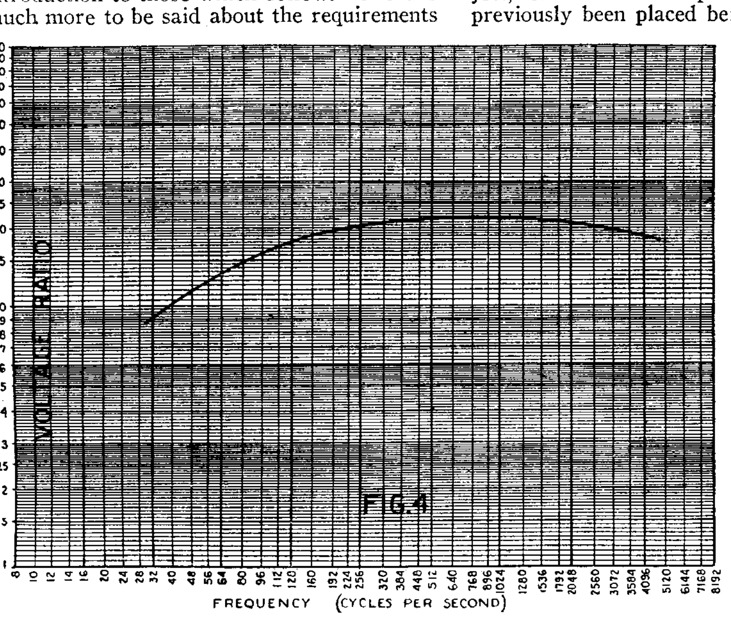
THE first article in this series on Audio-Frequency-Amplifier Transformers, which appeared in the June issue of RADIO NEWS, contained a short outline of the requisites and functions of transformers, coupled with an explanation of the frequencies which they must be designed to amplify. It was shown how necessary it is, for satisfactory reproduction, that the factor or ratio of amplification should be constant over the entire range—in other words that neither high nor low tones should be exaggerated or suppressed—because radio programs, musical ones especially, are composed of very complicated sound waves; and unequal amplification produces a distortion of the reproduced sounds, which alters their quality.

The reader of this and subsequent articles should not fail to refer to the previous discussion, if he has not already familiarized himself with its contents; as it is a necessary introduction to those which follow. There is much more to be said about the requirements for good amplifiers; but sufficient proof has been given already of the value of "characteristic" curves, in the design and choice of transformers. Parenthetically, much which has been said of transformers is of equal value in the consideration of other amplifier-coupling devices, such as impedance and resistances, etc.

There was also given, in the previous issue (June) referred to, a short article describing the method used in the RADIO NEWS Laboratories for the purpose of testing amplifiers and determining their characteristics. That article was written for the technically-informed reader; but the series of which the present one is a part is intended for the general public.

We come now to the question "How shall the characteristics be represented, so that the transformers and their properties may be most easily studied and compared?"

This article, in its dealing with this subject, is not mere repetition of what has previously been placed before the radio public; but presents ideas which have hitherto received the attention of only a few engineers and technical writers.



Here is an example of the manner in which Mr. Harris says that amplifier characteristics should be plotted. A special "logarithmic scale" is used for the horizontal distances, giving each octave an equal space—that between the heavy vertical lines. The vertical scale, that of voltage step-up, is logarithmic also, but on a different scale based on a study of the sensation of loudness, as explained elsewhere. The resulting curve shows most intelligently the effect on the ear of the tones emerging from the phones or speaker when the A.F. currents of the frequencies causing them have passed through this amplifier.

HOW DIAGRAMS ARE MADE

When it is desired to illustrate the ratios existing between two or more variable quantities, so that the eye can comprehend them at a glance, a "graph" is made, by plotting the quantities on cross-section paper. The latter, commonly called graph paper, is ruled in various styles, of which the simplest is made by ruling parallel lines, vertical and horizontal, spaced equally apart. This style of ruling is shown in Fig. 1, on which is drawn a sample "frequency-voltage-characteristic curve" of an amplifier-transformer.

In all styles of graph paper, the distances measured on the vertical lines are called *ordinates;* and the distances measured on the horizontal lines are called *abscissas*. The latter is derived from a Latin word signifying "cut off."

Generally speaking, the ordinates and abscissas are called "co-ordinates"; although this term is more accurately applied to the location of particular points. The co-ordinates, for instance, of the point A in Fig. 1 are 1100 (cycles per second) and 22.2 (voltage-amplification ratio.) The term "voltage ratio" is used throughout these articles in preference to "amplification."

Where the ordinates and abscissas are equally spaced (for equal numbers) and are at right angles to each other, they are called *Cartesian* co-ordinates, after the inventor of the system, the French mathematician, Rene Descartes—in Latin, Cartesius.

Returning to Fig. 1, it will be noted that both ordinates and abscissas are plotted in simple arithmetical progression, without giving any thought to the relation which the numbers bear to physiological sensations. But, in dealing with amplifiers used in radio receivers, we must not lose sight of the paramount fact that their action is connected intimately with the conversion of electrical impulses into sound waves. Therefore, if we are to consider the whole matter from a physiological standpoint, we should use the sense of sight to convey to our minds ideas corresponding to those impressed upon it by the sense of hearing.

WHY OTHER SYSTEMS ARE USED

Other writers, in attempting to accomplish this purpose, have employed various systems of co-ordinates, well known and often used by mathematicians, but little known to the average reader. The interesting fact is that so far no writers of popular radio articles have gone far enough to finish the job; and it is the purpose of this article to do so, if possible.

It will be noted in Fig. 1, which shows the characteristic curve of a fairly good transformer, that the ratio of output voltage to input voltage is zero at zero frequency, and rises very rapidly as the frequency increases; until it attains its maximum at about 600 cycles, and from that point falls off gradually as the frequency increases. The lower-frequency range of a transformer is very important in reproducing music. As illustrated in the first article of this series, the frequency range of the instruments of an orchestra is from about 32 cycles to about 4,000, without taking into consideration the overtones of the higher notes, which, although weak, have some effect in determining the quality of reproduction. This range is that of the *fundamental* tones of the piano, while the organ has an even greater range.

Again consulting Fig. 1, the lower part of the curve is found rather closely squeezed together, with regard to the acoustic considerations. A tone having a frequency of 1,100 cycles is rather high; referring to the piano, we find it a little more than two octaves above middle C. It is apparent that the lower portion of the curve is extremely important: a curve as steep as that in the low-frequency region of Fig. 1 is difficult to read, and certainly not accurate. Furthermore, it does not tell us what we want to know.

WHY THE "LOGARITHMIC" SCALE

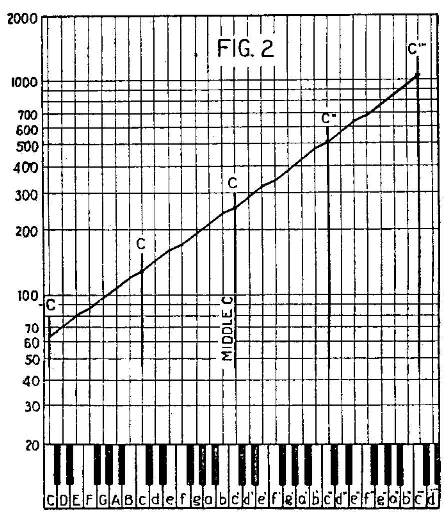
In Fig. 2 is the key to the solution of our problems. In this chart is shown part of the piano keyboard as the *"axis of abscissas,"* and above it, as *ordinates,* are plotted the numerical frequencies of the various notes. It will be seen that the Cartesian system of uniform spacing is not used in the vertical scale of ordinates or frequencies. The reason for this is a little difficult to explain in non-technical language, but we will do our best.

Suppose we consider middle C on the piano keyboard, indicated in the diagram as c'. The next octave above this, or c" has a frequency twice that of c'. In other words, although the distance along the axis of abscissas (horizontal) increases in equal amounts as we go from C to c', from c' to C", from c" to c"', in each case the frequency is doubled; because the frequency is multiplied by two, from each octave to the next.

Thus, let f indicate the frequency of any note at which we start, and the octaves will be f, 2f, 4f, 8f and so on. This is a *geometrical* progression in powers of 2; and if we plot it on a *logarithmic* scale, which is the vertical scale of Fig. 2, a straight line results. This is the case in the diagram, except for the arbitrary manner in which the piano keyboard is laid out. Incidentally, it may be said that the piano's musical scale is about as unscientific a thing as one can imagine. There are many approximations, and many slightly inharmonious chords and dissonances which result from them. However, so accustomed are we to this that we do not notice it, especially in orchestral music. The effect, however, is often noticeable in group singing without an accompaniment.

The "curve" of Fig. 2, therefore, is not exactly a straight line; there are kinks in it, due to the half-tones in the scale of the piano. However, the principle is correct, even if the pianoforte is not; so that we can use the logarithmic scale for our frequencies in plotting the frequency-voltage characteristics of transformers or other A.F. coupling devices. Note that we are proceeding step by step in this discussion.

In Fig. 3 we have the same characteristic as that in Fig. 1, but now we have used the *"common or Briggs* logarithmic" scale for the abscissas. The Briggs scale uses the number 10 as its *base;* in other words, each block in Fig. 3, going horizontally, has values in it which are the values of the preceding block multiplied by 10. Note how the curve



The piano scale is awkwardly arranged for our purposes; for its line of frequencies is not straight, but kinked by the presence of half or semi-tones. The line between points an octave apart, however, is straight, and we begin here, with our discussion.

is spread out in the lower-frequency range. This portion of the curve is beginning to show its true importance by its visual appearance.

EVEN DIVISIONS FOR OCTAVES

Having satisfied ourselves that a logarithmic scale is required, we have now to determine what kind of logarithmic scale to use. The one shown in Fig. 3 is *"to the base* 10." We have seen above that the musical octaves advance by a power of 2; it seems therefore, that 10 is the wrong base to use.

The human ear perceives octaves by extremely similar physiological sensations; each of the various notes in the scale of each octave is an octave of similar notes in other octaves, furnishing other likewise similar physiological sensations. There is good reason, therefore, why each octave should be

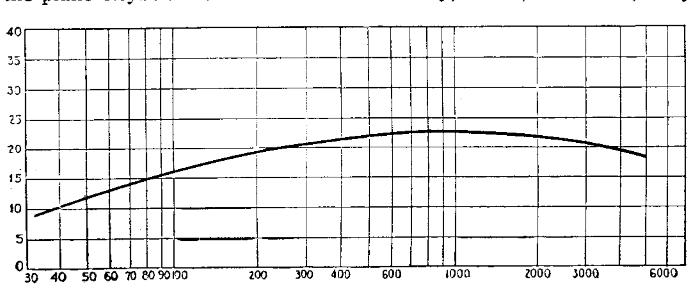
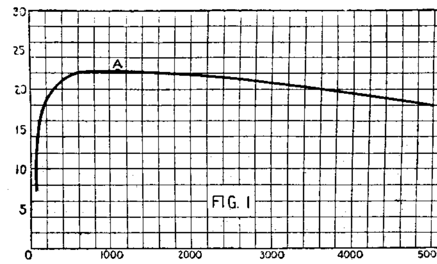


FIG 3

This is the curve of the same transformer characteristics shown in Fig. 1, but it is here plotted on a paper ruled to a "common logarithmic" scale for its horizontal measurements. It will be seen how it opens up at the lower frequencies. Even more informative results are obtained by using the special scale, shown in Fig. 4 on the opposite page.



This is the curve of a transformer (the same as in Fig. 3 and 4) plotted in the ordinary manner, with an equally-spaced scale. See how nearly vertical the curve is at the low frequencies.

represented graphically in exactly the same fashion as any other octave. For this reason the writer has constructed a graph in which the frequency scale has been plotted logarithmically to the base 2. This is shown in Fig. 4, and it will be seen that each heavy vertical line represents one of the c's of the musical scale. The distance between adjacent heavy vertical lines represents an octave, each exactly similar to all the others. All the various notes in the octaves are not shown, as this would require a complicated scale, on account of the half-tones or semi-tones. The octaves are divided sufficiently, however, to enable us to plot the characteristics satisfactorily.

This plan is not original with the writer; it has been used before by Dr. Harvey Fletcher in his papers on the "Physical Measurements of Audition," presented in the *Bell System Technical Journal,* October, 1923, and July, 1925.

We have not quite finished with our system of plotting the curves. We have yet to consider how the physiological sensation of *loudness* depends upon the voltage ratio which we are plotting. In radio, as well as in the telephone business, according to the words of Dr. Fletcher, "the commodity being delivered to the customers is reproduced speech. One of the most important qualities of this speech is its loudness, so it is very reasonable to use a *sensation scale* to define the volume of speech delivered."

The problem is to decide what scale of sensation to use. The reader will begin to understand the nature of the problem when he asks himself "What do we mean when we say that one sound is twice as loud as another?" If we ask a similar question regarding the pitch of the sound, we can give an answer readily, because we have the octaves to use as mileposts. In the matter of loudness, however, we have no such simple criterion; so the choice of a scale of loudness must necessarily be somewhat arbitrary.

THE TELEPHONE SCALE OF LOUDNESS

However, the telephone companies have adopted a logarithmic unit for measuring the efficiency of their transmission apparatus; and the matter of chief interest in the latter, as with a radio set, is the effect upon the loudness of the speech reproduced at the receiving end. As a matter of convenience, tied up with certain intricate transmission-line calculations, they have adopted a scale such that the loudness difference is plotted as a *function of the common logarithm of the intensity ratio.*

This choice of scale is practically independent of the electron tube and the telephone receiver used in the last stage of audio-frequency amplification in a radio set; for, barring certain elements of distortion, the pressure on the diaphragm is proportional to the plate current in the unit: and this again is proportional to the voltage on the grid of the same tube.

In Fig. 4, therefore, we have what the writer believes to be the best method of representing graphically the frequency-voltage ratio characteristic of a transformer. So

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How Should Transformer Curves Be Plotted?

(*Continued from page* 53)

far as the designer of the transformer, or the expert mathematician, is concerned, it makes little difference what scale is used. But, in order to give the average reader a better idea of the effect of a transformer on the current impulses flowing through it, this scale will be found helpful and useful; for it will enable him better to imagine the changes in sound which will be caused at the output of his radio receiver by employing the transformer whose curve is shown in diagram form. In other words, the scale employed gives a curve whose height above the horizontal scale at any given pitch is most nearly proportional to the effect on the ear of the reproduced tone.

In our next article we will consider in detail some of the requirements to be met, from the *practical* standpoint, by transformers and other audio coupling devices.