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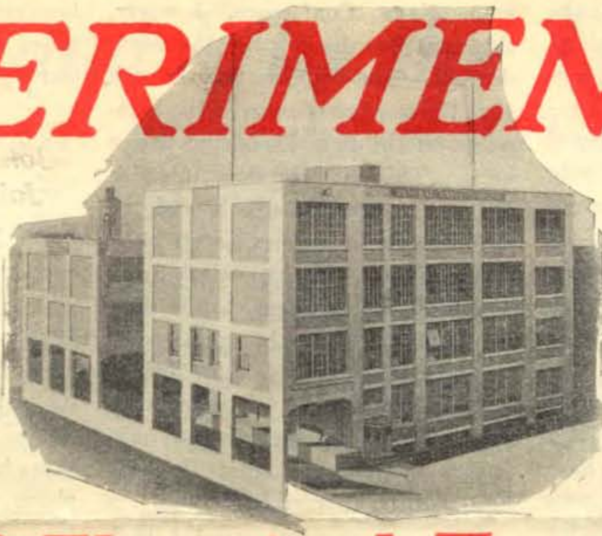

Units of Electrical Transmission

By J. W. HORTON, Chief Engineer

The communication engineer, although he deals generally with very small amounts of energy, is frequently concerned with ratios of energy having enormous magnitudes. The ratios between the rates of energy flow in different parts of a communication system, if expressed numerically, may be quite as impressive as the figures used by the power engineer. As an example the power delivered by an ordinary telephone transmitter is of the order of 0.01 watt. This may be used to control the output of a 100-kilowatt radio transmitter, in which case the ratio of the powers at the two ends of the system is ten million. Again it is quite possible for the energy delivered to its loud-speaker by a modern radio receiver to exceed the energy delivered by the antenna by one hundred million to one.

Because of the relations between the quantities involved the communication engineer finds it desirable in describing the efficiency of his apparatus to adopt a method differing markedly from that used by the power engineer. Until recently this method was to compare the performance of any piece of apparatus to that length of standard telephone cable which changed the amount of power delivered by the same ratio.

In making this comparison two factors must be taken into account, first the energy dissipation — or attenuation — within the apparatus, and second, the ability of the apparatus to receive and deliver energy across the junctions between it and associated circuits. To describe the performance of any apparatus, therefore, it is customary to consider the power which would be received by a given load circuit from a given generator circuit when they are connected directly together and the power received when the apparatus in question is included between them.

In the case of a length of standard cable it was assumed that the generator and receiver circuits were both long lengths of similar cable so that the only loss due to introducing the reference length was the dissipation within the reference length. Under these conditions the actual loss in a real cable when the current flowing has a frequency of 800 cycles per second is given by the expression:

$$P_1/P_2 = e^{0.218L} \qquad (1)$$

where e is the base of Napierian logarithms and L is the length of the cable in miles. From this the number of miles of standard cable which, when connected into a long length of similar cable, changes the amount of power received by the ratio P_1/P_2 is:

$$L = 4.587 \log e\ P_1/P_2 \qquad (2)$$

From the change in received power occurring when any piece of apparatus is introduced between given generator and receiver circuits the attenuation, or gain, of the apparatus expressed in equivalent miles of standard cable is given by the above formula.

One consequence of expressing performance in this way is that the over-all value for a system is computed by adding together the values expressing the performance of the several parts. This differs from the practice of the power engineer who multiplies together the percentage efficiencies of his components.

The above method of expressing the transmission efficiency of a piece of apparatus as some function of the logarithm of a power ratio has two decided advantages for the communication engineer. In the first place it fits in conveniently with his transmission formulæ, of which (1) given above is a typical example. In the second place it is most convenient when used in connection with the sensation of loudness, which also follows a logarithmic law. This latter fact can be demonstrated by determining the amounts of energy required to give a series of sounds differing by apparently equal intensity intervals. If these amounts of energy are compared it will be found that successive values bear a fixed ratio to one another.

In spite of its convenient logarithmic character the "mile of standard cable" or "800-cycle mile" has certain disadvantages. First, it is associated with an arbitrarily selected physical cable and is significant only for currents having a frequency of 800 cycles. Second, it requires, when used in mathematical computations, the use of an arbitrary constant based on the physical cable. Because of these disadvantages an effort has been made to standardize a new unit which will be of greater simplicity. Several such units have been proposed. In Europe a unit known as βl has been employed for some time. Here the number of units is given directly by the natural logarithm of the current ratio. In America the unit which has come into general use is such that the number of units is ten times the logarithm to the base 10 of the power ratio. That is,

$$N = 10 \log \frac{P_1}{P_2} = 20 \log \frac{I_1}{I_2}.$$

The European method is probably more convenient from the standpoint of mathematical computations. However, the use of one additional conversion factor is undoubtedly less confusing to the mathematicians than would be the use of natural logarithms to the relatively larger number of practical engineers. An immediate advantage of using the logarithm to the base 10 appears when it is recognized that the number of transmission units may be computed from the power ratio by the means of an ordinary slide rule or may be looked up in the nearest table of logarithms.

The use of the various units and their relative merits have been discussed at International Communications Conferences and it has been agreed that both shall be retained. The unit based on the logarithm to the base ten of the power ratio has for some time been known as the transmission unit (TU) for want of a more definite title. At the last meeting of the International Communications Conference, however, this unit has been given the name decibell. The nominal unit is such that the number of units is the logarithm to the base 10 of the power ratio. This has been done in order that the two units—the βl and the Bell—should be approximately alike in magnitude. The so-called practical unit will, however, be the decibell, which, since the number of units is 10 times the logarithm of the current ratio, is obviously one-tenth the size of the nominal unit. It has been decreed that the new unit shall be abbreviated as "db".

It was originally intended that transmission units should be used in referring to the performance of apparatus, that is, to the gain or to the loss resulting when the apparatus was employed. Since, however, the unit is based on power ratios it is only natural that it has come to be used for expressing amounts of power. This is most frequently done by selecting, arbitrarily, some amount of power as a "reference level" and describing other amounts of power as being so many transmission units above or below this reference level. It must be emphasized that a power level expressed in this way can have no significance unless the reference power is specified. There may be as many reference points as there are systems for electrical communication. In telephone lines for example the standard output of a repeater is spoken of as "zero level" and the rate of energy flow at other parts of the system is thus referred to this level. In high quality broadcast transmission a power level of 0.006 watts has been arbitrarily chosen as zero level. Thus when we say that an amplifier is capable of delivering a "plus 10 db level" we mean that it is capable of delivering 0.06 watts. The use of transmission units in describing power levels emphasizes the advantage of using a logarithmic unit in connection with such phenomena as hearing which itself follows a logarithmic law. The practice should, however, not be carried to the point where the reference power level is lost sight of.

Johns Hopkins Graduate Joins Engineering Staff

On December 1 we welcomed to our engineering staff Arthur E. Thiessen, a graduate of the Class of 1926 of Johns Hopkins University. Mr. Thiessen's undergraduate thesis was on the subject of magnetic alloys. For the past two and a half years he has been with the Bell Telephone Laboratories in New York City, working largely on apparatus for high speed cables.

As is true with most of our engineering staff, Mr. Thiessen is a former amateur. Pre-war amateurs on the Pacific Coast will undoubtedly recall Mr. Thiessen's spark transmitter at Portland, Oregon.

Dr. Hull Returns to Boonton

Since his return from Europe, where he attended the U. R. S. I. Conference, Dr. Lewis M. Hull has assumed the direction of the technical work of the Aircraft Radio Division of Radio Frequency Laboratories. He is, therefore, now making his headquarters at Boonton, New Jersey. Dr. Hull will be associated with our Engineering Department only in a consulting capacity. His work and interests have been principally in the line of radio-frequency measurements. One of his contributions along these lines is the Type 403 Standard-Signal Generator.

TELEVISION

We have received many inquiries as to whether we were contemplating putting out any television apparatus. The answer has been uniformly "No". The reason? Read "The Old Man's" article on this subject on page 24 of the January issue of "Q. S. T." This is one of the best summaries of the subject we have yet seen.

How and Why the Talkies

By HORATIO W. LAMSON, Engineering Department

Part Two

In the December issue of the EXPERIMENTER we outlined the general problems of the talking movies and discussed in some detail the wax disc method of recording and reproducing synchronized sound. We now propose to consider the optical method whereby a photographic record, corresponding to the fluctuating sound impulses, is obtained upon a film in the studio and subsequently reproduced as sound in the theater.

There are two fundamental forms which such a film record may take. The one most commonly employed has a constant transverse width and an intensity or "density" which varies from point to point along the film in accordance with the frequency and amplitude fluctuations of the corresponding sound waves. Such a record is shaded in appearance and similar in character to a photograph of a heavily banded light spectrum. It may be obtained by varying the intensity of the light source, either directly or indirectly, or by changing the effective width of the narrow slit opening through which the film is exposed. In either case the density across the record is constant at any given point along the film, giving thus the characteristic banded effect.

On the other hand, in the second type of record, a constant source of illumination is employed, while the electrical impulses corresponding to the sound waves operate a mechanism that serves to vary the relative amount of the transverse slit which is illuminated at any given instant. This produces a black-and-white non-shaded record having a fine saw-tooth appearance.

There are three distinct methods of optical recording which may be described here, all of which are fundamentally adapted to produce a banded type of record.

The first makes use of the neon or similar type of glow lamp which is so well known in the art of television. The intensity of the light emitted by such a lamp can be varied rapidly and easily by a fluctuating voltage applied to it. If, now, our film is driven uniformly along behind a narrow transverse slit which is illuminated on the opposite side by such a lamp, we have the means of producing a banded film record corresponding to the variations of the sound waves picked up by the studio microphones.

The second method utilizes a constant source of light and employs an ingenious device known as a "light-valve." This consists of two parallel duraluminum tapes each six mils wide and three mils thick. These are so placed in the optical system that, when at rest, they form an effective slit which, viewed against the source of light, presents an opening two mils wide by one quarter of an inch long. By means of a high grade optical system an image of this slit in the light valve is thrown onto the the film in the form of a transverse line of light one-eighth of an inch long and, normally, only one mil wide.

The two duraluminum tapes form an electrical loop circuit and they are so located in a steady magnetic field that, when a pulsating current is passed through them, they move in opposite directions. In this manner the effective gap opening between the tapes, and, hence, the width of the image line on the film, is varied according to the frequency and amplitude of the electrical impulses. Such a modulation of the light gives, of course, the characteristic banded record on the moving film. We note that in this case the time during which each spot on the film is exposed to a constant light source varies, while in the other two methods described each spot on the film record is illuminated for the same time interval by a modulated light intensity.

It is found desirable in practice to adjust the tension on the tapes until they have a natural frequency of about 7000 cycles per second. Under this condition a 100 per cent. modulation of the light, i.e., opening the valve slit to a maximum of four mils and just closing it completely requires about ten milliwatts of power at the lower audio frequencies and about 0.1 milliwatt at the natural frequency of the tapes.

A third method of optical recording utilizes an interesting device known as the Kerr cell. A beam of light of constant intensity is passed first through a Nicol's prism which polarizes the beam in a particular plane. It is then passed through a narrow gap between two electrodes and subsequently through a second Nicol's prism set at 45 degrees to the first. The gap between the electrodes in the Kerr cell is filled with nitro-benzol, a liquid which has the property of rotating the plane of polarized light passing through it when subjected to an electrostatic field to a degree proportional to the impressed voltage. Obviously, then, a modulation of the effective intensity of the light source may be produced by applying an alternating potential to the electrodes, so that, if we employ a fixed transverse slit against the film, a banded record will result. The separation of the electrodes and the length of the light path between them determine the voltage necessary to produce 100 per cent. modulation, i.e., variation between full transmission and total extinction of the light. As in the case of the neon lamp, the degree of modulation of the Kerr cell is essentially independent of frequency, but in the Kerr cell the degree of modulation is proportional to a cosine function of the amplitude which, obviously, limits the usefulness of this device.

In all three methods of optical recording the nominal effective time of exposure is about 1/18,000 second, corresponding to the nominal film speed of ninety feet per minute. This means that modulation of the record at a frequency of 18,000 cycles or higher would be nil with an increasingly better modulation as we go below 18,000 cycles. In the workable audio range, however, the modulation is satisfactory, or can be made so by the use of equalizers.

The technique of studio recording follows along the general lines previously described. The responses of the several studio microphones, properly mixed, are amplified sufficiently to operate whichever type of recording device is used. In general two separate film records are made, one for the sound and one for the photography. This permits a different technique of development for the two films, which is very desirable. Synchronization is accomplished by an interlocking electrical drive system, which contains mechanical filters in the drive of the sound film to maintain a constant and uniform rate of travel past the exposure slit.

It is customary in both disc or photographic recording to make two identical sound records and subsequently to choose the better for printing the released positive films or preparing the playing records. The optical sound record, as printed on the films sent out to the theaters, takes the form of a strip about one-eighth of an inch wide along one side of the picture. The picture and the sound strip are printed separately on the positive film, the space occupied by one being shielded from the light while printing the other.

Great care must be taken in selecting both the p sitive and negative raw film stock to be used in sound picture work. Any irregularities in the transparency of the film or emulsion will, of course, generate unwelcome "background" noises in the final reproduction. While the eye can barely detect a two per cent. change in film density sudden irregularities of only one-tenth of one per cent. will give rise to an audible background noise.

In reproducing the optical sound record in the theater we employ another device used in the art of television, namely, the photo-electric cell. When subjected to a steady polarizing voltage the photo-electric cell allows a current to flow through it which is proportional to the intensity of light falling upon the cell. A narrow transverse slit is interposed between the cell and a constant source of light. This slit extends across the portion of the film carrying the sound record so that the intensity of the light passing at any instant into the photo-electric cell depends either upon the relative density of the banded film back of the slit or upon the width of the "cut-off" portion of the saw-tooth film record at the point in question.

Thus if the film is drawn uniformly at the original speed across the slit we will obtain a pulsating current in the photo-electric cell circuit which will be a reproduction of the current in the studio microphones.

When projecting a motion picture the film is advanced intermittently at the rate of sixteen "frames" per second, each frame being stationary for the brief instant during which light is passing through it to the screen. Obviously, then, the synchronized picture and sound record can not be adjacent on the film. In practice they are spaced about fifteen inches apart along the film, thereby allowing for a "loop" to take up the intermittent slack between them. Mechanical filters are used in the drive to insure an extreme uniformity of motion past the photo-electric cell slit.

The electrical impulses obtained from the photo-electric cell are extremely small in amplitude. A two-stage resistance-coupled amplifier is ordinarily necessary to bring them up to an energy level comparable with that obtained directly from the electromagnetic pickup used in the disc method of reproducing. On account of the high impedance of the photo-electric cell circuit, it is desirable to build this amplifier into the same container which holds the photo-electric cell. The output of this amplifier, at low impedance, is then carried to the fader and, from this point on, the same speech amplifying system used with the disc method is employed, likewise the same technique of fader operation, monitoring, and control of the output panel.

A large proportion of the theaters in which synchronized sound installations have been made are equipped with machines designed for projecting either the disc or the film type of record. They can, therefore, utilize the standardized product of all producers.

A few statistics may be of interest in closing. A number of concerns are now developing and placing on the market equipment for recording and reproducing sound pictures. Among them are: the Electrical Research Products, Inc., a subsidiary of the Western Electric Company, who use both the disc record (Vitaphone) and the film record (Movietone); the R. C. A. Photophone (a film record); and the General Talking Pictures Corporation (De Forest Phonofilm), likewise a film record.

Among the producers using the E. R. P. I. system are:

1. Paramount Famous Players Lasky Corp.
2. Metro-Goldwyn-Mayer, Inc.
3. Warner Brothers.
4. Fox-Case.
5. First National.
6. Universal.
7. Christie Comedies.
8. Victor.

The following producers are licensed under the R. C. A. Photophone system:

1. F. B. O.
2. Tiffany-Stahl.
3. Pathe.
4. Mack Sennett.
5. Educational.

In conclusion we wish to acknowledge our indebtedness to the Bell Laboratories Record for certain data used in this article.