Measurement of Telephone Noise and Power Wave Shape *

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IN studies of the inductive coordination of power and telephone systems from the noise standpoint, a knowledge of the magnitudes of the harmonic currents and voltages on the power circuits and of the harmonic components of the telephone circuit noise is necessary. It is also necessary that there be available a means of rating and summing up these individual components to give an overall indication of their effects on a person using a telephone connected to one of the exposed circuits. This paper discusses methods which have been developed for making such overall measurements.

The effect on a listener of a given amount of noise on a telephone circuit is a complex one, and it is not practicable in the day-by-day maintenance of telephone circuits to measure separately all the factors involved. Rather, it is necessary to make some overall measurement of the circuit noise which may be related to its effect on telephone transmission. It is, of course, desirable that the measuring devices used should measure different circuit noises as equal when they produce equal interfering effects on telephone transmission.

Two methods of measuring telephone circuit noise are at present in use in the Bell System. One of these methods is subjective, that is, uses the human hearing mechanism as a part of the measuring apparatus. This method consists of comparing, in a telephone receiver, the noise to be measured with a noise generated by means of a standard buzzer. The observer adjusts the magnitude of the buzzer noise by means of a calibrated potentiometer until, in his judgment, it is as disturbing as the noise to be measured.

The objective method of noise measurement which has been made available within the last few years employs an electrical network for weighting the various single frequency components of a noise as closely as practicable in accordance with their interfering effects on telephone transmission, and a calibrated amplifier to raise the energy level of the weighted components sufficiently to operate an electric meter. The chief operating advantages of the objective method are the repro-

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ducibility of the results and the ease and speed of making measurements. Its disadvantage lies in the difficulty in determining the complex nature of the human hearing mechanism and simulating its characteristics sufficiently well in objective apparatus.

One of the important steps in the development of the objective noise meters has been the determination of the relative interfering effects of different single frequency tones. Two types of tests have been used for this purpose, (*a*) judgment tests and (*b*) articulation tests.

Judgment tests usually are set up so that the observer may compare directly two noises in the presence of speech heard over a representative telephone circuit. The magnitude of one of the noises is adjusted until it is judged to be as disturbing as the second noise. The magnitudes which the observer judges to be equally disturbing can be measured and in the case of single frequency tones, the relative weighting which should be applied to the two frequencies may thus be determined.

An articulation test consists essentially in calling a number of meaningless monosyllables over a circuit to a group of observers, each of whom records the sounds that he hears. The percentage of sounds correctly received is termed the "per cent articulation" for the particular condition tested. On a given circuit, two different noises which produce the same loss in articulation would usually be considered as equally interfering. As before, in the case of two different single frequency noises, measurements may be used to determine the relative weightings to be applied to the two frequencies.

In 1919, the results of judgment and articulation tests on the relative interfering effects of different single frequency tones were published in a paper by H. S. Osborne.[1] Since that time, several other sets of tests of this character have been made in order to check the values previously obtained and to extend the frequency range covered. From the results of all these tests [2] and a recognition of the trend toward more uniform frequency response in telephone message channels, a single curve of relative interfering effects of different single-frequency tones in a telephone receiver has been derived. This is shown in Fig. 1, the curve being labeled " receiver currents." By combining with this curve the frequency characteristic of a representative transmission path between the toll circuit terminals and the

[1] "Review of Work of the Subcommittee on Wave Shape Standard of the Standards Committee," H. S. Osborne, *A. I. E. E. Transactions*, Vol. 38, Part 1, 1919.

[2] The articulation and judgment tests mentioned here also contributed largely to the selection, by the C. C. I. F. (international advisory committee on telephony), of a curve of relative interfering effects of single-frequency tones expressed in terms of voltage across the receiver, which it has recommended as a basis for noise measurement on international circuits. The weighting given in curve A of Fig. 1, when expressed in similar terms is in conformity with the weighting recommended by the C. C. I. F.

telephone subscriber's receiver, a second curve indicating the relative interfering effects of different single-frequency currents in the telephone line has been derived. This is also shown in Fig. 1. These two curves have been incorporated in the indicating noise meters for use in measuring noise in the subscriber's receiver and noise at the terminals of a toll circuit, respectively.

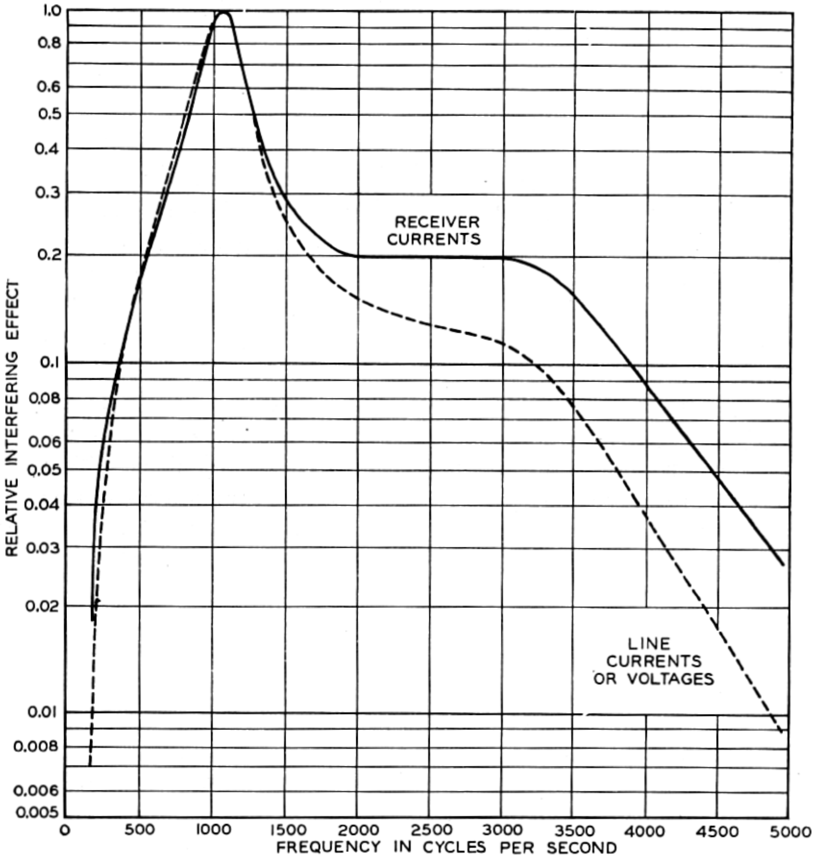


Fig. 1—Relative interfering effects of telephone circuit noise currents.

A second important factor considered was the manner in which various single-frequency noises combine in the human ear. The rule of combination adopted was that by which each single frequency contributed to the total meter reading in proportion to its weighted power. (This is the equivalent of the familiar root-sum-square rule for summing up currents or voltages,) In addition to the requirements for weighting and rule of combination, it was thought desirable to employ an indicating instrument in which the change of reading was about as rapid as the change in appreciation of loudness in human hearing. From published results and confirming tests it was determined that on the average, the indicating instrument should reach a full deflection for sounds lasting .2 second or longer.

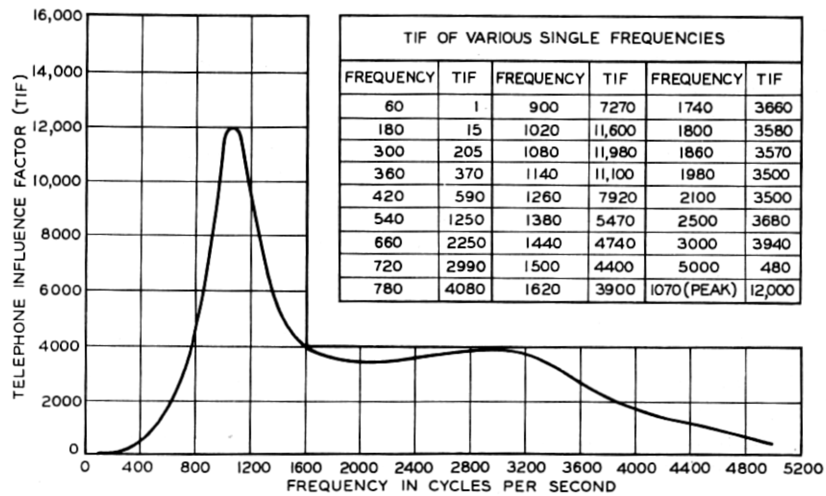
Under these general specifications, several models of circuit noise meters were built and two series of tests were made to determine their adequacy for measuring circuit noise. These tests were made under the auspices of the Joint Subcommittee on Development and Research of the Edison Electric Institute and the Bell System. The first was a rather extensive series of articulation tests on open-wire toll circuit noise. Since none of the toll circuit noises tested contained components of importance above 2,000 cycles, a series of judgment tests was carried out on representative noise of the type arising by induction in telephone circuits exposed to a-c. lines supplying rectifiers and on various high-frequency noises derived therefrom.

The articulation tests showed that when toll circuit noises of various types produced equal losses in articulation under the given set of telephone conditions, they were measured as substantially equal by both the objective and subjective methods of measuring. The objective method gave a slightly better correlation than did the subjective method even though the average of 18 individual observers was used in the latter. While the correlations were not as close with the high-frequency noises as in the case of the more common types of toll circuit noise, on the average the noise meter rated the rectifier noises at least as well as did the ear balance method, the latter using 10 observers.

A device called the "Telephone Interference Factor Meter" for measuring or rating the wave shape of power system currents and voltages in terms of their influence on exposed telephone circuits was described in the Osborne paper of 1919, referred to above. With this instrument, an indication was obtained of the total harmonic content of a given voltage wave, the individual components present being weighted approximately in proportion to their relative interfering effects.

The data obtained from the more recent studies of relative interfering effects described above have made possible a revision of the method of measuring T.I.F., in which the basic principle has been retained but in which the frequency weighting characteristic has been revised somewhat and its range extended to about 5,000 cycles. In connection with this revision, the name has been changed to "Telephone Influence Factor."

The Telephone Influence Factor (T.I.F.) of a voltage or current wave is the ratio of the square root of the sum of the squares of the weighted effective values of all the sine wave components (including, in alternating current waves, both fundamental and harmonics) to the effective value of the wave. The weightings decided upon to be applied to the individual components are as shown in Fig. 2.



TIF OF VARIOUS SINGLE FREQUENCIES					
FREQUENCY	TIF	FREQUENCY	TIF	FREQUENCY	TIF
60	1	900	7270	1740	3660
180	15	1020	11,600	1800	3580
300	205	1080	11,980	1860	3570
360	370	1140	11,100	1980	3500
420	590	1260	7920	2100	3500
540	1250	1380	5470	2500	3680
660	2250	1440	4740	3000	3940
720	2990	1500	4400	5000	480
780	4080	1620	3900	1070 (PEAK)	12,000

Fig. 2—Frequency weighting characteristic for TIF measurements.

In deriving the revised frequency weighting characteristic, the following factors representing distortion occurring in the various media intervening between the power circuit current or voltage and the telephone subscriber's ear were considered.

1. Relative interfering effects of single-frequency components in the receiver of a subscriber's telephone set.
2. Distortion occurring between the terminals of the circuit in which the noise is induced and the subscriber's receiver.
3. Variation in coupling between power and telephone circuits with frequency.
4. Variation of effects of telephone circuit unbalances with frequency.

Data on Items 1 and 2 above were combined to derive the line weighting characteristic of the telephone circuit noise meters indicated by the "line currents" curve of Fig. 1. It was, therefore, possible to use this curve directly to represent the combination of these two factors. A factor directly proportional to frequency was adopted to represent inductive coupling between power and telephone circuits (Item 3), the work of the Joint Subcommittee on Development and Research having indicated that, in general, coupling may be so represented. After studying data available on Item 4, it was concluded that no type of frequency weighting could be adopted which would satisfactorily represent all types of telephone circuit unbalances. Thus T.I.F. as measured by the method described here is a correct index to the influence of a power circuit voltage or current only for those cases where unbalances are independent of frequency. This is usually the case on open-wire toll circuits and open-wire exchange circuits employing bridged ringers. In other cases some empirical modification may be necessary.

Since a large amount of data has been obtained with the old T.I.F. meter, it was considered desirable, if practicable, to adjust the scale of the revised set so that readings made by this method would, in general, be approximately the same as readings obtained by the old meter. In this connection calculations using the old and new weightings were made on a large number of machines and circuits of various types on which harmonic analyses were available. These calculations were supplemented by a considerable number of comparative measurements in the factory and in the field, using meters employing the old and new weightings. These calculations and tests indicated that in the average case, reasonably satisfactory correlation between the readings made by the two meters would result if a peak value of 12,000 were assigned to the new weighting characteristic, as shown in Fig. 2.

Several experimental models of T.I.F. measuring sets were made employing the new weighting characteristic and these have given very satisfactory results. The adoption of the rule that coupling is to be considered proportional to frequency also makes it possible to use a circuit noise meter and a small amount of auxiliary apparatus to form a T.I.F. meter.

The development of the revised method of measuring T.I.F. has also been conducted under the auspices of the Joint Subcommittee on Development and Research of the Edison Electric Institute and the Bell Telephone System.