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Wide Band Transmission Over Balanced Circuits *

By A. B. CLARK

In a recent paper [1] amplifiers capable of handling frequency band widths of the order of 1,000 kc. or more are described, together with terminal apparatus for effectively utilizing these wide bands for telephone, telegraph and television purposes. The paper confines itself to the coaxial line structure for transmitting these wide frequency ranges but points out that broad-band transmission is also applicable to balanced conductor systems. The present paper discusses briefly some of the possibilities of the more familiar balanced circuits, circuits more or less as they now exist in the present plant being first considered, following which are circuits obtained by new construction. Wide-band transmission over balanced circuits offers interesting possibilities both for circuits in the present plant and for new construction.

A HIGH degree of *electrical balance* [2] has been for a long time a fundamental requirement of telephone transmission lines. This has been required not only to prevent interference entering into telephone circuits from other types of electrical circuits but also to prevent mutual interference between the closely adjacent telephone circuits on open-wire lines or in cables.

In the central offices, to be sure, unbalance in apparatus has been frequently employed for simplicity and convenience. In toll circuits, however, such office unbalance has been electrically separated from the outside plant by the use of repeating coils or otherwise. In local circuits the high standard of balance required for toll circuits has not generally been necessary since the exposures to interfering fields are less severe and the range of speech levels is much smaller. However, when local circuits are connected to toll circuits the unbalances are kept electrically separated from the toll circuits by the use of repeating coils. In recent years the tendency to the use of higher frequencies in com-

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[1] "Systems for Wide-Band Transmission Over Coaxial Lines" by L. Espenschied and M. E. Strieby, *Elec. Engg.*, October, 1934; *Bell Sys. Tech. Jour.*, October, 1934.

[2] As used here, the term *electrical balance* refers to the two sides of a telephone circuit. To secure such balance, the aim has been to construct the go and return conductors of each circuit of the same gauge and material and to locate them symmetrically with respect to earth and to surrounding conductors. The aim has also been to apply to each circuit terminal apparatus symmetrical with respect to its series impedances and shunt admittances to ground.

munication circuits, the increase in the strength of interfering fields and the development of highly efficient amplifiers has led to constantly more exacting requirements in electrical balance of telephone circuits.

The development of multichannel systems by carrier methods employing constantly increasing frequency ranges has placed particularly exacting requirements on such electrical balance. In a recent paper, "Carrier in Cable,"[3] are described the balancing methods which have been developed to permit the use of an increased frequency range in such cables. The recently published paper, "Systems for Wide Band Transmission Over Coaxial Lines"[1] points out the possibilities and possible requirements for very much wider frequency ranges. In that paper, coaxial lines are proposed which are particularly interesting in that they abandon electrical balance altogether and depend entirely on metallic shielding.

For such wide frequency range transmission, very interesting and important questions are raised, first as to the extent to which such wide bands can be placed on existing types of structure which are based on balance and, second, as to whether new construction designed particularly for such wide bands should depend on balance or shielding alone or a combination of the two. It is the purpose of this present paper to discuss these questions.

As noted in the Espenschied-Strieby paper, the apparatus described for broad-band transmission on concentric structures would also serve for other types of line structures. There would, of course, be problems in either balancing the apparatus or isolating its unbalances from the line structure. For the purposes of the present paper it is assumed that there will be no important reaction from the apparatus standpoint on this consideration of line balance and shielding.

Existing Cables

The attenuation of pairs in existing cables has a characteristic with respect to frequency generally similar to that of coaxial conductors but is, naturally, considerably higher because of the smaller physical dimensions and higher dielectric losses of the cable pair. For example, at a million cycles an ordinary 19-guage cable pair has an attenuation of about 18 db per mile, an ordinary 16-gauge pair about 14 db per mile, while a small-sized coaxial structure has an attenuation of about 6 db per mile. This means more repeaters for the cable pairs, three times as many for 19-gauge and a little more than twice as many for 16-gauge. Also, it means more difficulty in maintaining stability of transmission,

[3] A. B. Clark and B. W. Kendall, *Elec. Engg.*, July, 1933; *Bell Sys. Tech. Jour.*, July, 1933.

including overcoming of the variations due to the effect of temperature changes.

Stable and highly linear repeater gain can be produced so readily now-a-days, thanks to the negative feedback amplifier invented by Mr. H. S. Black,[4] that the idea of such high attenuations is no longer appalling even though on 16-gauge pairs it means repeaters spaced only about four miles apart. Overcoming the transmission variations due to temperature with automatic regulators introduces no fundamentally new problems, but, of course, the complexity and precision of regulation must be considerably higher due to the considerably larger variations.

Crosstalk, of course, must be given special consideration. First of all, it is necessary to restrict transmission of a given high-frequency band to only one direction in a single cable; the other direction must be supplied by another cable [3] or other separate transmission medium.

Considering transmission in one direction only, if only one pair in a cable is set aside for high-frequency transmission of, say, a million-cycle band, most, but not all, of the crosstalk difficulty can be avoided. However, the fact must be reckoned with that if one pair in a cable is singled out and an amplifier is applied having 60 db or more gain at a point intermediate between voice-frequency repeater stations, the amplifier will have a strong tendency to sing due to crosstalk between the pairs connected to the input and output and the other pairs in the cable. If two cables are available, this difficulty can be avoided by jumping from one cable to another every time the high-frequency amplification is introduced. If two cables are not available, overcoming the difficulty may call for the insertion of high-frequency choking devices in some or all of the low-frequency cable conductors at points where high-frequency amplification is introduced.

Considering now crosstalk between two circuits in a cable transmitting in the same direction, assuming the amplifier difficulty to have been overcome, tests have been made on various cables in the field from which these conclusions have been drawn. For telephone message purposes it is probably uneconomical to apply million-cycle frequency ranges to more than a single pair in an existing cable. However, with television, the crosstalk requirements are much less exacting. This is because the range of intensities necessary for a good television image is much less than is needed to accommodate message telephone subscribers and, therefore, a considerably larger ratio of extraneous current to maximum signal current can be tolerated. Tests indicate that two or more television channels, each a million

[4] "Stabilized Feedback Amplifiers," H. S. Black, *Elec. Engg.*, January, 1934; *Bell Sys. Tech. Jour.*, January, 1934.

cycles wide (possibly wider), can be transmitted over separate properly arranged pairs in the same direction in a single existing cable without serious disturbance due to crosstalk.

With respect to noise in existing cables, the matter of principal concern is noise produced in telephone offices by apparatus working on other circuits, since the natural shielding afforded by the cable sheath largely eliminates noise from outside sources. Two methods are available for control of the noise produced in telephone offices: (1) Introduction of high-frequency choking devices in all wires not assigned to carrier service at the points where the cables enter offices in which noise is produced; (2) Attack on noise at points where it is produced by introduction of spark-killers and individual high-frequency choking devices. The lenient noise-to-signal ratio requirement for television mentioned above makes high-frequency television application much easier than message telephone.

While a million-cycle frequency range over more than one pair in an existing cable seems unlikely for telephone message purposes, there are interesting possibilities in the use of lower maximum frequencies. For example, it seems likely that twelve same-directional telephone channels may be obtained from each one of a large fraction of the pairs in existing toll cables and that the crosstalk between the pairs may be kept within proper bounds by simple balancing methods previously described.[3]

Open Wire

With open wire, conditions are just about the reverse of those with cable. A mile of open wire has an attenuation of only about 1 db at a million cycles as compared to 6 db for the small-sized coaxial. However, overcoming crosstalk between different pairs of wires on a pole line presents very formidable problems while avoiding interference from and to radio systems may be even more formidable.

The attenuation of open-wire pairs has been checked up to several million cycles and it has been found that it behaves as expected. When there is little crosstalk from the high-frequency band to other wires in the lead the attenuation-frequency characteristic is smooth; when there is severe crosstalk, the characteristic is bumpy. For a given length of circuit the attenuation is small compared with that of the small-sized coaxial, and the variation due to changing weather conditions is also small—about one-third that of the coaxial. It is interesting to note, however, that the percentage change in attenuation for the coaxial is less than half that for the open-wire line. While it is, of course, evident that the open-wire transmission variations depend in part on changes in the series resistance of the wires due to changing temperature and in part to changes in leakage and capacitance due to varying weather conditions, automatic transmission regulating systems similar in general principles to those already developed for other purposes should be adequate to maintain the required stability.

Crosstalk between different circuits becomes so severe at high frequencies that special transposition treatment or respacing of the wires becomes necessary. Minimizing interference from and to radio systems calls for a high degree of balance which may or may not dictate changes in the wire configuration. Here again it is necessary to distinguish between the requirements for television and for message telephone. Tests indicate that, in view of the more lenient television requirements, several million-cycle television channels can be transmitted over different pairs of a single open-wire line without serious disturbance and that to do this it will not be necessary to make radical changes in present wire configurations.

New Cables

For new construction, if television is not considered, effective carrier telephone systems may be set up by various methods. One might be a very broad-band method, a good example of which is given in the Espenschied-Strieby paper.[1] Another might be a much narrower band method using conductors similar to those in an ordinary cable. In the one case many telephone channels are obtained from a single pair by dividing up a frequency range, say one million cycles wide, into somewhat more than 200 channels. In the other case only 20 odd channels are obtained per pair of wires and use is made of 10 pairs of wires to obtain the same total number. It is too early to say which of these plans might be best under various practical conditions.

To meet future television needs, it may be necessary to provide for transmission of continuous frequency bands a million cycles in width or wider. It is interesting to compare the coaxial with balanced pairs surrounded by individual shields for such transmission.

For 6 db loss per mile at a million cycles, it works out that a solid copper coaxial unit with the rubber disc insulation described in the Espenschied-Strieby paper [1] has an internal diameter (inside of shield) of about 0.25 inch. For the same attenuation a pair of wires, each the same size as the central wire in the coaxial unit (70 mils diameter), insulated with rubber discs and with a copper shield, will have an inside diameter under the shield of about 0.4 inch. For outside conductors or shields made of lead the inside diameters become about 0.4 inch for the coaxial and 0.5 inch for the balanced pair. Therefore, if the thickness of the outer conductor is determined by mechanical considerations rather than outside interference, the coaxial is smaller and cheaper. As the frequency is made higher, the shielding from outside interference afforded by the surrounding cylinder increases, so that at very high frequencies mechanical considerations alone control and the coaxial is clearly cheaper than the balanced shielded pair.

In the frequency range up to about a million cycles, however, interference from outside sources, including natural static and radio, must be considered in determining the thickness of the surrounding cylinder and the cost comparison is not so clear. It will be evident that as regards shielding, the balanced pair is at a large advantage because the two sides of the circuit are designed to be electrically similar. By proper care in manufacture this balance can readily be made sufficient to insure adequate shielding with a surrounding lead tube of thickness determined solely by mechanical considerations.

With a coaxial structure, however, it appears likely that to keep interference within proper bounds, a simple lead tube must be made considerably thicker than required by mechanical considerations, so that such a structure would probably be more expensive than a lead shielded pair. However, by adding other materials an adequately shielded coaxial unit can be constructed which will have a considerably thinner outside wall.

For example, there is described in the Espenschied-Strieby paper [1] a coaxial unit in which the inside diameter is minimized by first using copper tapes, the thickness of wall is minimized by adding thin iron tapes and the whole is made waterproof by a thin surrounding lead tube. This results in a unit of smaller inside and outside diameters than those of a lead tube surrounding a balanced pair of like attenuation. Since, however, the wall of the coaxial is thicker and the structure more complicated, the costs of the two units are estimated to be not greatly different when they are designed for the frequency range up to a million cycles. A minor advantage for the balanced pair remains, however, in that, whatever may be the top frequency, there is no limitation as to the lowest frequency permissible for interference reasons.

In the above discussion of new cable construction the amplifiers and transmission regulators required have not been mentioned. If similar conducting and insulating materials are used, shielded balanced pairs and coaxials have similar transmission-frequency characteristics. The variations with temperature are also similar. The factors which limit the overall amplifications are also the same. There is only one important point of difference between the amplifiers required for the two systems. This is the necessity for input and output transformers to be balanced to ground with the balanced pairs. The excellence of balance required, of course, depends on the extent to which balance is relied on to reduce the required thickness of sheath. In view of the fact that very thin sheaths are impracticable for mechanical reasons it appears probable that only very modest requirements as to balance need be imposed on the design of these transformers.

To provide several circuits in new cables for meeting wide-band television needs, another method may be considered, that is, to provide balanced pairs considerably larger in size than ordinary pairs and with the rubber disc form of construction, or other form giving low dielectric losses, but with no shields at all around the individual pairs. Shielding from outside disturbances would be adequately provided by the outside lead sheath of the cable. Crosstalk between different pairs would be the principal concern. If all of the high-frequency pairs were to be used for television transmission, the crosstalk requirements, as already mentioned, would not be severe, so that by careful design the crosstalk could readily be kept within proper bounds—of course, restricting transmission of all wide-frequency bands to a single direction within a single sheath. Such high-frequency balanced pairs might prove suitable for telephone message circuits also. If not, the high-frequency pairs would be restricted to television only, and other pairs, worked at lower frequencies, would be provided for telephone message service.

Summary

It appears feasible under certain conditions to transmit continuous frequency ranges of 1,000,000 cycles or more over conductors in the existing telephone plant. This may some day prove very important, particularly if the art of television develops to the point of calling for such wide frequency range circuits to carry television impulses around the country as sound programs are now carried.

For new construction, the balanced type of circuit, as well as the unbalanced coaxial circuit, offers many interesting possibilities.