Crosstalk on Open-Wire Lines

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(Manuscript received September 29, 1955)

Crosstalk on open-wire lines results from cross-induction between the circuits due to the electric and magnetic fields surrounding the wires. The limitation of crosstalk couplings to tolerable magnitudes is achieved by systematically turning over or transposing the conductors that comprise the circuits. The fundamental theory underlying the engineering of such transposition arrangements was presented by A. G. Chapman in a paper entitled *Open-Wire Crosstalk* published in the Bell System Technical Journal in January and April, 1934.

There is now available a Monograph (No. 2520) supplementing Mr. Chapman's paper which reflects a considerable amount of experience resulting from the application of these techniques and provides a basis for the engineering of open-wire plant. The scope of the material is indicated by the following:

TRANSPOSITION PATTERNS

This describes the basic transposition types which define the number and locations of transpositions applied to the individual open-wire circuits.

TYPES OF CROSSTALK COUPLING

Crosstalk occurs both within incremental segments of line and between such segments. Furthermore, the coupling may result from cross-induction directly from a disturbing to a disturbed circuit or indirectly by way of an intervening tertiary circuit. On the disturbed circuit the crosstalk is propagated both toward the source of the original signal and toward the distant terminal. A knowledge of the relative importance of the various types of coupling is valuable in establishing certain time-saving approximations which facilitate the analysis of the total crosstalk picture.

TYPE UNBALANCE CROSSTALK

Crosstalk is measured in terms of a current ratio between the disturbing and disturbed circuits at the point of observation. Crosstalk between open-wire circuits is also generally computed in terms of a current ratio (cu) but it is also convenient to refer to it in terms of a coupling loss (db). The coupling in crosstalk units (cu) is the product of three terms: a coefficient dependent on wire configuration; a type unbalance dependent on transposition patterns; and frequency. The coefficient represents the coupling between relatively untransposed circuits of a specified length (1 mile) at a specific frequency (1 kc). The type unbalance is a measure of the inability to completely cancel out crosstalk by introducing transpositions because of interaction effects between the two halves of the exposure and because of propagation effects, primarily phase shift. Type unbalance is expressed in terms of a residual unbalance in miles and the frequency is expressed in kilocycles.

The coefficients applicable to lines built in accordance with certain standardized specifications are available in tabular form. When it is desired to obtain coefficients for other types of line, it is possible to compute approximate values which may be modified by correction factors to indicate the relationship between the computed values and measurements on carefully constructed lines.

Expressions for near-end type unbalance for certain simple types of exposures are developed and the formulas for all types of exposures are given. In addition, the values for near-end type unbalance are tabulated at 30° line angle intervals for lines where the propagation angle is 2,880° or less.

The principal component of far-end crosstalk between well transposed circuits results from compound couplings involving tertiary circuits. Again the expressions are developed for some of the exposures involving a few transpositions and the procedure for obtaining the formulas for any type of exposure is shown. Formulas are included for the types of exposures encountered in normal practice and the numerical values of far-end type unbalance are given at 30° intervals for line angles up to 2,880°.

SUMMATION OF CROSSTALK

The procedures referred to thus far evaluate the crosstalk occurring within a limited length of line known as a transposition section. In practice, however, a line is transposed as a series of sections. It is necessary, therefore, to determine how the crosstalk arising within the several sections and that arising from interactions between the sections tend to combine. In a series of like transposition sections there is a tendency for the crosstalk to increase systematically, sometimes reaching intolerable magnitudes. This tendency can be controlled to a degree by introducing transpositions at the junctions between the sections, thus cancelling out some of the major components of the crosstalk. Complete cancellation is impossible because of interaction and propagation effects.

ABSORPTION

Since very significant couplings exist by way of tertiary circuits, it is possible for crosstalk to reappear on the disturbing circuit and thus strengthen or attenuate the original signal. This gives rise to the appearance of high attenuation known as absorption peaks in the line loss characteristic at certain critical frequencies. The evaluation of such pair-to-self coupling requires the use of coefficients which differ from those between different pairs and these are given for standard configurations.

STRUCTURAL IRREGULARITIES

It is impracticable to maintain absolute uniformity in the spacing between wires and in the spacing of transpositions. Thus there are unavoidable variations in the couplings between pairs from one transposition interval to the next. This in turn reduces the effectiveness of the measures to control the systematic or type unbalance crosstalk and produces what is known as irregularity crosstalk. Since the occurrence of structural irregularities tends to follow a random distribution, it is possible to evaluate it statistically and procedures for doing so are included. In addition to this direct effect of structural irregularities, there is a component of crosstalk resulting from the combination of systematic and random unbalances. A method is developed for estimating the magnitude of this important component of crosstalk.

EXAMPLES

In order to demonstrate how the procedures and data are used in solving practical problems, there is included the development of a transposition system to satisfy certain assumed conditions. This is carried through to the selection of transposition types for one transposition section and the selection of suitable junction transpositions.

Additional examples of transposition engineering are given in the form of several transposition systems which have been widely used in the Bell System. These include:

Exposed Line — for voice frequency service.

C1 — for voice frequency and carrier service up to 30 kc.

J5 — for voice frequency and carrier operation up to 143 kc.

O1 — for voice frequency and compandored carrier operation up to 156 kc.

R1C — suitable for exchange lines with a limited number of carrier assignments.

Altogether, the theory, explanatory material, formulas and comprehensive data included in the Monograph make it possible to estimate open-wire crosstalk couplings and provide the necessary background for the development of new transposition systems.