NEW METHOD FOR MEASURING LAGGING IN ELECTROMAGNETIC DELAY LINES

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The wide application of electromagnetic delay lines in computing equipment components has made it necessary to develop a new method for measuring the delay time of signals. Moreover, it has become necessary to specify more clearly the term "signal delay."

Current and voltages arise at the output of a line quadripole with lumped constants simultaneously with the application of an emf to its input, but the output of the signal occurs with a certain delay which depends on the number of sections and on the parameters of the circuit (strictly speaking, the signal is being distorted). The delay in the signal can be expressed by means of frequency or time characteristics of the line quadripole.

There exist in literature different approaches to the evaluation of the signal delay, on which are based pulse or phase methods for its measurement.

In [1] delay is defined as the time required to attain a definite part of the maximum signal output after it has passed through the line quadripole.

In [2] it is shown that the line system can be characterized by the delay time which represents the displacement of the mean value of the signal in the process of its building up:

\[ t_{d1} = \int_0^t t \cdot \psi (t) \, dt = \frac{a = \int_0^{a=\infty} a(t) \, da(t)}{a(\infty) - a(0)}, \]

where \( a(t) = \frac{A(t)}{A(\infty)} \) is a normalized transfer function of the system; \( \psi(t) = d'(t) \) is a normalized pulse reaction of the system.

The authors of this paper consider the mean value as the point from which to reckon the pulse rise time, and measure the signal delay as the time interval between the leading edge of the input signal and the leading edge center of the output signal.

Some authors [3, 4] suggest for determining the signal deformation the use of a more general power criterion which amounts to evaluating the general deviation of the signal shape at the output of the quadripole from the shape at its input by the value of its total quadratic error. Thus, it is shown for instance in [4] that in its transmission through

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Fig. 1. 1) Nonlinear amplifier; 2) relaxation network; 3) feedback network; 4) delay network; 5) tested delay line.

Fig. 2. Delay line under test, \( \tau_K \).

To the frequency meter

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the line system the videopulse acquires a shift in time and a distortion of its shape. As a measure of its distortion they take the following expression:

\[ \eta(t_{dl}, \lambda) = \int_0^\infty [\lambda \cdot e(t) - u(t - t_{dl})]^2 dt, \]

where \( u(t) \) is the signal envelope at the input of the system; \( e(t) \) is the signal envelope at the output of the system.

Parameters \( t_{dl} \) and \( \lambda \) are found from the minimum conditions of function \( \eta(t_{dl}, \lambda) \). If the input signal has a finite duration \( r \) and a square shape with an amplitude \( u_0 \), the value of \( t_{dl} \) is determined by equation:

\[ \frac{d}{dt_{dl}} t_{dl} + \int_{t_{dl}}^{t_{dl} + \pi} u_0 \cdot e(t) dt = u_0 [e(t_{dl} + \pi) - e(t_{dl})] = 0 \]

On the basis of pulse evaluations of the delay time pulse methods have been developed for measuring the retardation of signals in delay lines whose error at present amounts to 1-5%. Moreover, the error increases sharply for small delays.

Phase methods provide greater accuracy in determining delays. In this case signal delays are determined as the retardation time of one harmonic component of the input signal, namely as the phase delay \[ t_{dl} = \frac{\varphi(\omega)}{\omega} \] for \( \omega = u_0 \), or as a slope in the phase characteristic, namely a group delay, \[ t_{dlg} = \frac{d\varphi(\omega)}{d\omega}. \]

The group delay is evaluated by measuring the phase relationship of the low-frequency modulating signal superimposed on the high-frequency carrier before and after its transmission through the quadripole under investigation. The error in evaluating delay by the phase method depends on the error in measuring the phase difference of low-frequency envelopes, which is not less than 1-3%. Moreover, errors of 1% are attained by excessively complicated measuring circuits.

We suggest a new measuring method by means of which the signal delay in a line quadripole is determined as

\[ t_{dl} = \frac{\varphi(\omega)}{\omega} \]

This method simplifies delay measurements, since they are reduced to evaluating the frequency of the oscillator which has a single-valued relation to \( t_{dl} \).

The above method was first suggested by the author in his dissertation of 1954.

The block schematic of the measuring stage is shown in Fig. 1. The equation which represents the behavior of the circuit is of the form:

\[ \dot{u}(t) - K(u) \cdot \dot{u}(t - t_{dl}) + \frac{1}{T} u(t) = 0, \]

where \( u(t) = e(t) \) for \( 0 \leq t < t_{dl} \); \( u(t) = 0 \) for \( t < 0 \); \( K(u) = K_4(u) \cdot K_2; K_2(u) \) is the gain of the nonlinear amplifier; \( K_4 \) is the transfer constant of the feedback circuit; \( T \) is the time constant of the relaxation unit.

The electrical model of the measuring stage represented by (1) is shown in Fig. 2. The "nonlinear amplifier" of the block schematic in Fig. 1 consists in this circuit of tube \( T_1 \) with load \( R_a \); the "relaxation network" consists of coupling capacitance \( C_g \) and the input resistance of the delay line. The "feedback network" and the "delay network" consist of the delay line under test. The output of the amplifier is connected to the input of the delay line, and the output of the latter to the input of the amplifier, i.e., to the grid of tube \( T_1 \).

In order to simplify the problem let us assume that the anode load \( R_a \) and the grid leak \( R_g \) are equal to the characteristic impedance of the tested lined. The dc operation of the tube can be determined from the required gain \( K(u) > 1 \). The value of capacitor \( C_g \) should be made sufficiently large to meet condition \( T > t_{dl} \).

The circuit shown in Fig. 2 (taking into account the dispersion in the delay line and "stray delays") will then become self-oscillatory at a frequency: