DU MONT

VOL. 7, NO. 3

MAY - JUNE, 1945

OSCILLOGRAPHER

TRANSMISSION LINE MEASUREMENTS

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Among the expanding uses of the cathode-ray oscillograph there is one so new and interesting that it compels immediate attention—the study of transmission line phenomena. A rapid, accurate and visual means of study is provided and in contrast to previous methods, permanent records may be made by photographic means.

The Du Mont Type 248 cathode-ray oscillograph is particularly suited to such measurements because it incorporates many special features which eliminate the need for auxiliary equipment. The features which apply specifically to transmission line studies are the internal trigger pulse generator, driven sweep and beam modulation amplifier.

The internal trigger pulse generator furnishes an output signal of either positive or negative polarity consisting of one-half microsecond pulses of approximately 100 volts peak amplitude, the repetition rate being variable between 200 and 3,000 pulses per second. It is this pulse which serves as an indicator of the transmission line properties.

A clear representation of transmission line characteristics is made possible by the exclusive driven sweep feature of the Type 248. The sweep operates so that repeated pulses fall on top of each other leaving a section of the sweep clear for the presentation of reflections.

The beam modulation amplifier provides a means of impressing time demarcations on the pattern for quantitive or calibration purposes. This amplifier is used in conjunction with an external signal or with the internal timing oscillator. The signal is applied through the amplifier to the grid of the modulating electrode of the cathode-ray tube, and can be made to blank out the beam, resulting in accurate markers along the trace under observation. The timing oscillator provides marker signals at intervals of 1, 10, or 100 microseconds, and is keyed by the driven sweep circuit.

THEORY

Assume that a pulse is travelling along an ideal, loss-free transmission line with a velocity V equal to the velocity of propagation of light in free space. At the end of an interval of time $T=L/V$, where L is the length of the line, the pulse will travel the length of the line and impinge upon the load resistor R_L. If R_L is equal to the characteristic impedance Z_O of the loss-free line, the energy of the pulse will be completely absorbed by R_L and no reflection will take place. If, however, the line is not terminated in its characteristic impedance ($R_L \neq Z_O$), there will be a reflection of the incident pulse. The magnitude and phase of this reflected pulse with respect to the initial pulse will depend upon the relation of R_L to Z_O according to the equation

$$e_r = e_i \, (R_L - Z_O) \, / \, (R_L + Z_O) \qquad (1)$$

where e_r and e_i are the voltages of the reflected and incident pulses respectively.

It is apparent that if R_L is greater than Z_O the polarity of the reflected pulse will be the same as the incident pulse. If, however, R_L is less than Z_O, the polarity of the reflected pulse will be the reverse of the incident pulse. In the limiting cases, when the line is short circuited, R_L is zero and $e_r = - e_i$; and when the line is open circuited, R_L is infinite and $e_r = e_i$.

If a reflection takes place at the receiving end (R_L), the reflected wave will travel back along the line to the sending end in the time $T = L/V$. Once again we will have either complete absorption or partial reflection, depending on the relation of the sending end impedance (Z_s) to the characteristic impedance (Z_O). If Z_s is equal to Z_o we will have complete absorption, but if it is not we will have a reflection, the magnitude and phase of which will be determined by equation (1) (substituting Z_s for R_L).

It must be remembered that the instantaneous voltage at either end is always the sum of the incident pulse voltage and the reflected pulse voltage; therefore

$$e_L = e_i + e_r \quad \text{or}$$

$$e_L = e_i \frac{2R_L}{R_L + Z_o} \qquad (2)$$

at the receiving end and

$$e_s = e_r \frac{2Z_s}{Z_s + Z_o} \qquad (3)$$

at the sending end.

In equation (3) e_r is the voltage of the pulse reflected from the receiving end which is incident with respect to the sending end.

A review of equations (2) and (3) reveals that the polarity of the resultant pulse is the same as that of the incident pulse irrespective of the magnitude of the terminating impedances, and has a value ranging from zero to 2e, depending upon the relative magnitude of the terminating impedance and the characteristic impedance.

It is now evident that when both the receiving and sending ends are terminated in impedances other than the characteristic impedance many successive reflections will take place on the line until the total energy of the pulse is dissipated in the terminating impedances. In actual cases, the pulse is also attenuated by the line as it travels back and forth.

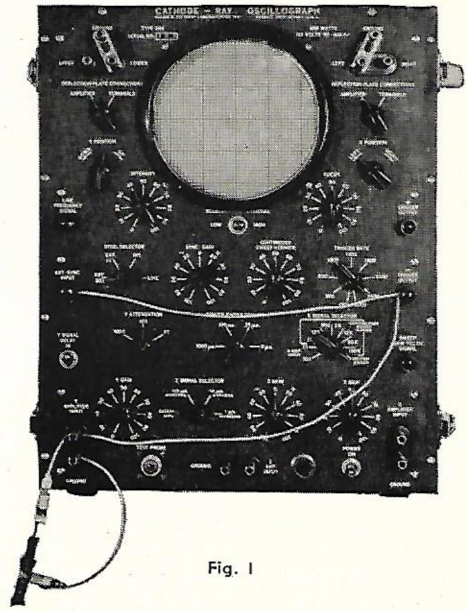

Fig. I

METHOD

To utilize the Type 248 cathode-ray oscillograph in transmission line studies the connections must be made as shown on figure 1. The negative trigger output is used to synchronize the oscillograph driven sweep and also to supply the pulse to be observed. The negative trigger output is used so that a large pulse will merely cut off the first amplifier stage, and not drive the grid positive. As the pulse is fed to the transmission line at the vertical amplifier input terminal, and there is no external sending end termination, the Y-axis amplifier input impedance is the sending end terminating impedance. R_L, the receiving end terminating impedance is selected so that the characteristic impedance of the transmission line is within its range.

Figure 2 is a photograph of the pattern produced when the receiving end impedance is equal to the characteristic impedance. Note that only the original pulse is visible, since no reflections have taken place. In order to determine the unknown characteristic impedance of any transmission line it is merely necessary to connect the line as shown in figure 1 and vary the receiving end impedance until a pattern identical with figure 2 is obtained. This adjustment is critical, since any slight variation from the characteristic impedance will produce a reflected pulse which will be visible on the oscillograph screen.

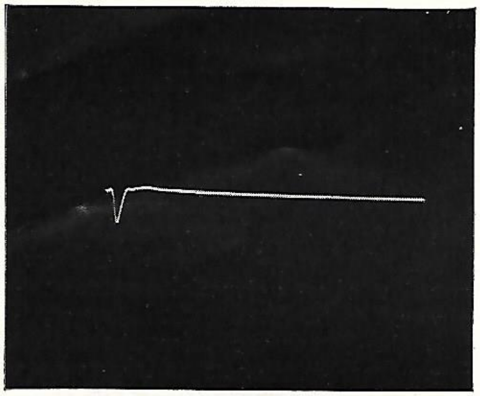

Fig. 2

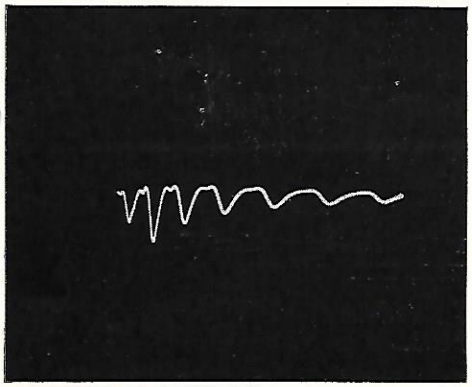

Fig. 3

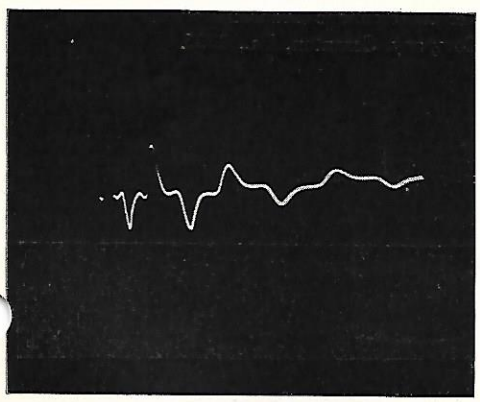

Fig. 4

Figures 3 and 4 illustrate patterns which result when the terminating impedance is not equal to the characteristic impedance. In the case of Figure 3, R_L is greater than Z_o. In Figure 4, Z_o is greater than R_L. In both cases the terminating impedance at the sending end is the oscillograph Y-axis amplifier input impedance, in parallel with the pulse generator output impedance. The characteristic impedance of the line is approximately 50 ohms, making the sending end impedance much larger than the characteristic impedance. Note that the second pulse on both photographs is almost twice the amplitude of the first. This is a result of the terminating impedance at the sending end being much greater than the characteristic impedance. Substituting in equation (3)

$$\frac{Z_s}{Z_s + Z_o} = 1 \text{ (approximately)}$$

therefore

$$e_s = 2e_r$$

With the patterns shown in figures 3 and 4, most of the important properties of transmission lines can readily be determined. Utilizing the beam modulation feature of the Type 248, we can impress a time scale on the pattern. The transmission time along the line may be determined by measuring the distance between the centers of the first and second pulses. This measurement is made by counting the time markers between the two points.

Once the transmission time is known,

the velocity of propogation can be calculated since

$$V = \frac{L}{T} \qquad (4)$$

where V is the velocity of propagation, L is the length of the line and T is the transmission time along the line (one way).

In addition to determining the presence of a discontinuity on a transmission line, we can now locate it. Any such discontinuity along a line will create a reflection which will appear on the screen of the cathode-ray oscillograph as a foreign pulse. The transmission time to the discontinuity may be determined as explained previously; and so, with the velocity of propogation known, equation (4) may be used, solving for L, the distance to the discontinuity. We can also forecast the type of fault by observing the polarity of the reflection.

The cathode-ray oscillograph is also very useful in continuous monitoring of transmission lines to detect and locate faults immediately after their occurrence.

A photograph of the normal pulse conditions on a particular line may be taken and any new discontinuity can readily be detected by placing the negative of the photograph over the oscillograph screen.

The study of transmission line characteristics is just one of the many special applications of the new Du Mont Type 248 cathode-ray oscillograph which are made possible by the incorporation of many special features uncommon to the usual cathode-ray oscillograph. These special features do not in any way restrict its usefulness as a general purpose laboratory instrument or as a production test instrument. Further information on the Type 248 cathode-ray oscillograph may be had upon request.

Bibliography:

(1) Ware, L. A. and Reed, H. R. "Communication Circuits", John Wiley & Sons, Inc., New York, 1942.

(2) Everitt, W. L., "Communication Engineering", McGraw-Hill Book Company, Inc., New York, 1932.

(3) Bewley, L. V., "Travelling Waves on Transmission Systems", John Wiley & Sons, Inc., New York, 1933.

(4) Norris, F. W. & Bingham, L. A., "Introductory Study of Electrical Characteristics of Power & Telephone Transmission Lines", International Textbook Company, Scranton, Pa., 1936.