TESTING MICROWAVE TRANSMISSION LINES

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Abstract

Direct RF measurement techniques are discussed in terms of their application to testing of long microwave transmission lines such as those used in heavily loaded microwave relay systems or high power radar systems. The return loss profile, a measure of transmission line quality, is introduced. Test results presented include data obtained by means of measurement techniques which permit in-service determination of the transmission line operating characteristics.

Introduction

The quality of the microwave transmission line between the transmitter/receiver equipment and the antenna becomes more important as communications systems become more heavily loaded or as higher power levels are used in radar systems. Imperfections in coaxial and waveguide transmission lines which produce reflections result in echo distortion in a communications system and breakdown (arcing) in a high power radar system.

In a communications system, the object of the measurements is to determine that the intermodulation noise performance requirement is being satisfied. Any impedance discontinuity in a transmission line will cause part of the signal to be reflected, resulting in an echo. Thus, the signal is comprised of two components, the desired primary transmission path signal and the unwanted secondary path signal. These signals arrive displaced in time from each other and result in intermodulation noise.

Microwave link transmission line testing poses unique problems because only one port is normally available for testing. Thus, the properties of the line are often inferred from reflection data. The length of the typical microwave transmission line makes it inadequate to consider the line as a single-port or two-port device which can be characterized by a single return loss specification. It is desirable to generate a measure of return loss as a function of distance along the transmission line, which is the Return Loss Profile.

The methods of testing transmission lines discussed here are direct RF measurement techniques. Distinction is made between techniques which provide a composite picture of all reflections (standing wave techniques) and methods which measure both the magnitude and location of faults. Further distinction is made on those measurement techniques which permit "in-service" determination of the transmission line operating characteristic.

Measurement Techniques

A generalized representation of a test system is shown in Figure 1. Six specific methods of transmission line testing considered are: (1) Time-Domain Reflectometry, (2) Pulsed Time-Domain Reflectometry, (3) FM/CW with fixed IF, (4) FM/CW with variable IF, (5) Frequency-Domain Interferometer (Ripple), and (6) Swept VSWR. Comparison between time domain and frequency domain techniques provides a means to better understand the FM/CW technique.

Several of the measurement techniques are well documented in the literature. Ginzton has a thorough treatment of the measurement of impedance including VSWR.[1] A frequency-domain interferometer (ripple testing) is described in a Singer application note.[2] Time-domain reflectometry is discussed in a Hewlett-Packard application note.[3] Shoemaker discusses the advantages of pulsed TDR and presents test results.[4]

The frequency domain analogy to the pulsed TDR technique is the FM/CW technique. In FM/CW, the time or measure of distance to a target is obtained by using a continuous wave source that undergoes frequency modulation. Ismail presented a basic description of the technique in 1955 and illustrated its use as an aircraft altimeter.[5] The FM/CW technique has enjoyed renewed study with the availability of computers to make the transformation from one domain to another, Stinehelfer[6] will discuss this later in this session. Instrumentation uses of the technique are discussed with variations by Hollway and Somlo as a locating reflectometer.[7] Richter has done interesting radar work with a radar sounder.[8] More recently, Robinson has described the results of his work measuring discontinuities in a dielectric.[9] The work represented by these efforts deals with either an operational system or device testing. We utilized the FM/CW technique at Scientific-Atlanta in order to produce the Fault Locator. In this case, the operating parameters are optimized to test long, hundreds of wavelengths, transmission lines.[10] A brief description of the principle is presented in the Appendix.

Comparison of Techniques

Comparison of the six measurement techniques leads quickly to the establishment of two classes, in terms of the operating frequency and type distance information that is available. TDR, swept frequency VSWR, and ripple testing require that the initially recorded data be processed extensively in order to obtain a Return Loss Profile (RLP). Measurement systems based on either the pulsed TDR or FM/CW techniques are able to produce an RLP directly.

In all cases it is important to recall that most of the transmission line being studied is assumed to be or known to be low-loss uniform line. Altschuler discussed the measurement of the inaccessible terminal.[11] Useful practical information is available as a result of special conditions while the general case may not yield unique solutions. Techniques which produce magnitude and location data directly are useful because you stop looking or start questioning the data down the line from a significant change in the assumed low-loss uniform transmission line.

Return Loss Profiles shown by Figure 2, were measured in 6-GHz waveguide at three frequencies using the Scientific-Atlanta Fault Locator. Major discontinuities are evident at distances of 42, 105, and 205 feet.

The pulsed TDR requires a relatively large bandwidth detection system while FM/CW techniques require significantly smaller bandwidth detection systems since they lend themselves to superheterodyne operation. Thus, in order to achieve a given return loss level dynamic range, the pulsed TDR will require that more power be used. The minimum detectable signal or return is a function of the average power, but the actual radiated power will be in terms of the peak power as determined by the selected duty factor of the pulsed TDR.

The desired data presentation varies with the application. The pulsed TDR signal detection system is easily handled with an oscilloscope where the data is typically a display of relative voltage versus distance. The FM/CW systems are slower and typically use either a storage scope or an X-Y recorder. The display of the return loss level directly in dB is available with FM/CW systems since the addition of a logging circuit to a superheterodyne system is not difficult.

The distance display accuracy in a pulsed TDR is primarily a function of the pulse timing circuit accuracy and it is to the first order independent of the distance being measured. The distance display in the FM/CW systems is directly related to the tuning linearity of the RF source. Thus, at short ranges, the FM/CW distance readout is better than the distance accuracy on the pulsed TDR, while at longer ranges, the pulsed TDR readout will be better.

Resolution of multiple discontinuities or, in radar terminology, range resolution is a complex subject. Heuristically, the distance resolution in a pulsed TDR is limited by the pulse width because two discontinuities must be separated by at least one pulse width before individual pulse responses can be returned without mutual interference. Thus, the range resolution becomes smaller (better) as the pulse width is made shorter. The required frequency spectrum increases as the pulse width is made shorter. The narrower pulse width also means that the bandwidth of the detector must be increased to be able to respond to this shorter pulse which in turn implies that more peak RF power must be used in order to maintain a given return loss level dynamic range.

The analogous function for the FM/CW case is a modified sin x/x function. Two discontinuities must be separated by some distance sufficient to produce two separate return responses.

In the case of pulsed TDR, the transmitted pulse width establishes the range resolution and the required frequency spectrum while the frequency deviation in the FM/CW case establishes the width of the return response function and hence the range resolution. The pulsed TDR and FM/CW systems are believed to be equivalent systems from the standpoint of range resolution and spectrum utilization. Pulse shaping or response shaping techniques are applied with equal effectiveness to the pulsed TDR and FM/CW systems respectively.

Conclusions

Long microwave transmission lines may be tested by a variety of instruments which are based on either time or frequency domain techniques. Direct readout of return loss level in dB as a function of distance has been realized in an instrument based on the FM/CW technique. It is possible to use a low power FM/CW system to do maintenance work on active, operating communications systems. Even though some knowledge of the character of the line is required, the data obtained is immediately useful in real test situations.

REFERENCES

1. Ginzton, E. L., Microwave Measurements, Chapter 5, McGraw-Hill, New York, 1957.

2. __________, "Frequency Domain Reflectometry Measurement of Cable Lengths and Faults", Application Data Bulletin 9500-1, Singer Instrumentation, Palo Alto.

3. __________, "Cable Testing with Time Domain Reflectometry", Application Note 67, Hewlett-Packard Co., Palo Alto, 1965.

4. Shoemaker, W. B., Jr., "Nanosecond R-F Pulses for Waveguide Fault-Finding", Thesis presented to Naval Postgraduate School, Monterey, 1968.

5. Ismail, M. A-E.W., "A Study of the Double Modulated F.M. Radar", Thesis presented to Swiss Federal Institute of Technology, Zurich, 1955.

6. Stinehelfer, H. E., "Time Domain Oscillographic Network Analysis Using Frequency-Domain Data", 1974 IEEE G-MTT International Microwave Symposium.

7. Hollway, D. L. and P. I. Somlo, "Microwave Locating Reflectometer," Electronics Letters,

Vol. 5, Oct. 1969, pp 468-469.

8. Richter, J. H., "High Resolution Tropospheric Radar Sounding", Radio Science, Vol. 4, No. 12, Dec. 1969, pp 1261-1268.

9. Robinson, L. A., W. B. Weir, and L. Young, "Location and Recognition of Discontinuities in Dielectric Media Using Synthetic RF Pulses" Proceedings IEEE Vol. 62, No. 1, Jan. 1974, pp 36-44.

10. ____________ "Series 1691 Fault Locator", Application/Data Sheet, Scientific-Atlanta, Atlanta, Oct. 1971.

11. Altschuler, H. M., "Methods of Measuring Inaccessible Arbitrary Microwave Two-Ports", Thesis presented to Polytechnic Institute of Brooklyn, New York, 1963.

APPENDIX

In FM/CW, as the name implies, the timing or distance to a target is obtained through a frequency modulation technique. The frequency of the oscillator increases linearity with time, as shown by the solid line of Figure 3.

In a measurement system, a portion of the signal reaching an impedance discontinuities will be reflected back toward the oscillator, see Figure 1. These reflected signals will have the same modulation as the oscillator but will be delayed in time by the round trip propagation time between the oscillator and point of reflection. A reflected signal as illustrated by the dashed line of Figure 3 will be present at a time, t_d, later that is determined by

$$t_d = \frac{2d}{v}$$

where d = distance to point of reflection
v = velocity of propagation

If this reflected signal is heterodyned with a sample of the undelayed oscillator output, a difference frequency signal, f_d, will be generated.

$$f_d = t_d \left(\frac{\Delta F}{\Delta T}\right)$$

where $\frac{\Delta F}{\Delta T}$ = rate of change of oscillator frequency.

Or,

$$f_d = 2 \left(\frac{\Delta F}{\Delta T}\right) \frac{d}{v}$$

Thus, the distance to an impedance discontinuity is directly related to the difference frequency and inversely related to the rate of change of the source frequency. All aspects of the modulation must be considered in a working system; and such a discussion is beyond the scope of this review.

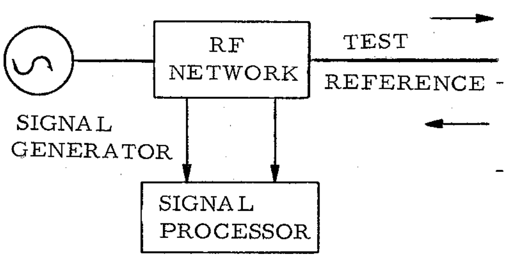

FIGURE 1
GENERAL TEST SYSTEM

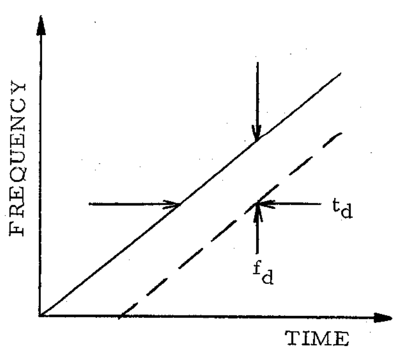

FIGURE 3
BASIC FM TECHNIQUE

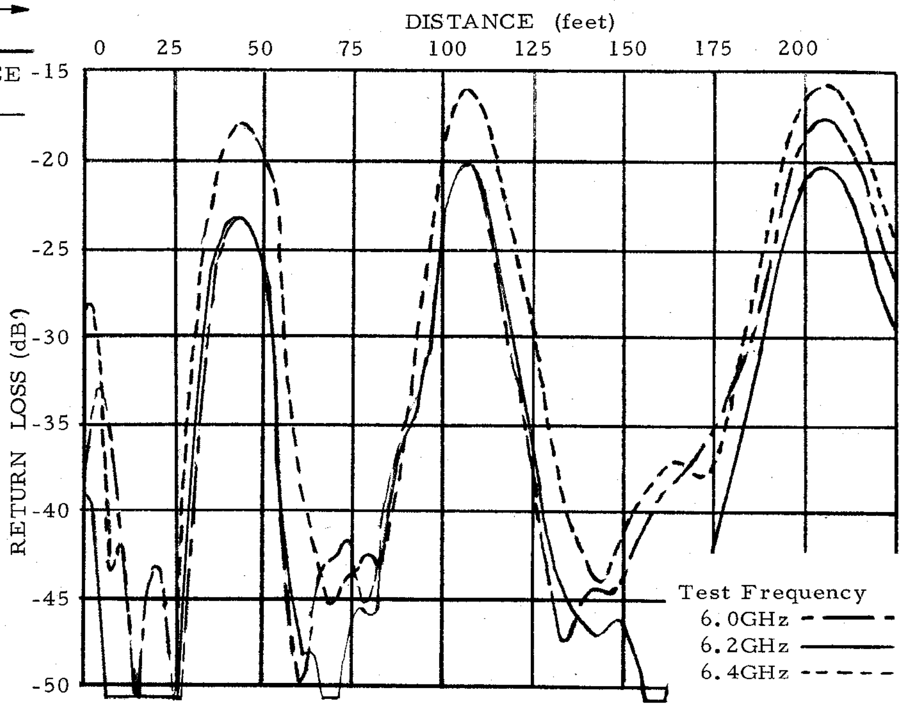

FIGURE 2
RETURN LOSS PROFILE