PRECISION AUTOMATED REFLECTOMETER USING AIR-LINE REFERENCES SPANS UHF THROUGH MILLIMETER RANGES

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Introduction

The precision swept frequency reflectometer[1] uses a precisely dimensioned coaxial air-line or waveguide of suitable length for the frequency resolution required as an in situ impedance reference. The unknown impedance at the far end of the above reference creates a rotating unknown reflection phasor at the near or measuring device end of the line during swept frequency measurement. A waveguide reflection measurement is described by Hollway and Somlo[2] and the coaxial arrangement by Lacy and Oldfield.[3]

In the previous papers, the resulting data is shown in sweep frequency form that includes a sinusoidal ripple related to the length of the standard air-line impedance reference. The data needs to be analyzed by the user. This paper represents the algorithms for digital data reduction by means of two methods: A) averaging over a weighted window, that is, wider in frequency span than a ripple cycle; and B) ripple amplitude extraction by a windowed discrete Fourier Transform. Reference calibration is initially performed and is included in the data reduction process.

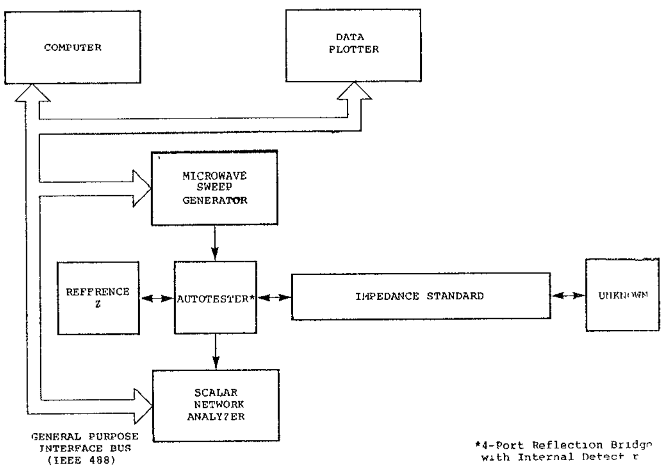
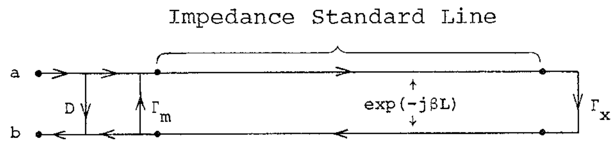


FIGURE 1. BLOCK DIAGRAM OF PRECISION AUTOMATED SWEPT REFLECTOMETER

General Description

Figure 1 shows the block diagram of the coaxial measurement system. For coaxial measurements with reflection bridges,[3] the reference port may be connected either to a precision termination (50 ohms) or to an offset termination (40.91 ohms for 20 dB return loss). Waveguide measurements use a directional coupler and a reference reflection[2] inserted between the coupler measurement port and the waveguide reference line. Appropriate programs for the two methods[3] of measurement, A) for error averaging and B) for ripple extraction, using the algorithms discussed below are used on the computer to conduct the digital data reduction. The computer controls the microwave sweeper network analyzer and graphics terminal via the IEEE 488 interface bus.



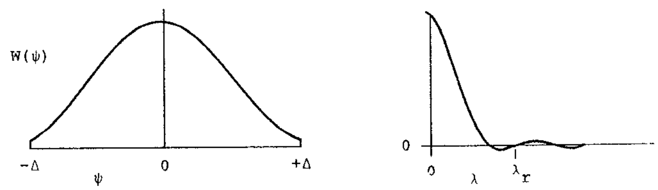
a. Reflectometer Flowgraph

$$\Gamma'_x = \frac{b}{a} = D + \frac{\Gamma_x \exp(-j2\beta L)}{1 - \Gamma_m \Gamma_x \exp(-j2\beta L)}$$

b. Measurement Equation

FIGURE 2. PRECISION REFLECTOMETER

Figure 2 shows the minimum form reflectometer flowgraph and the corresponding equations. The reflection bridge with its characteristic impedance (50 ohms) as reference termination will be typified with a directivity and test port match that are identified in the equation of Figure 2. When these error values are smaller than reflection coefficient to be measured at the end of the standard reference line, the error phasors will rotate during the frequency sweep with respect to the unknown phasor.



Window

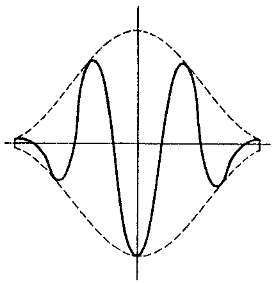
Cepstrum of Window

$$X_o(\omega) = \int_{-\Delta}^{\Delta} X(\omega + \psi)\, W(\psi)\, d\psi$$

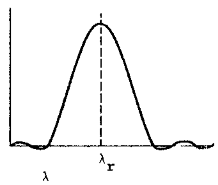
FIGURE 3. METHOD A - ERROR AVERAGING

The errors can be virtually eliminated by a low pass digital filter in the form of a select window as shown in Figure 3, whose cepstral response is also shown. Thus, the raw data X is given a weighted average, by the window function W over several cycles of the characteristic interference cycle, determined by length of the reference impedance line. This removes the error phasors rotating with respect to the desired unknown reflection phasor. This Method A, error averaging, is used for unknown reflection magnitudes that are greater than the magnitude of directivity for the reflection bridge.

Method B requires the precise extraction of the characteristic ripple amplitude. The window must have a minimal spectral width with respect to the frequency scan. Within the window, a discrete Fourier Transform is taken to precisely extract the desired amplitude. The window shape applied to the frequency scan data is shown in Figure 4 on the left. Accompanying that is the cepstrum (frequency analog involved with the Fourier Transform of the data series representing frequency scan). The windowed transform must virtually eliminate any average value (corresponding to zero frequency of the cepstrum), accommodate phase variations of the unknown and suppress data irregularities.



Real Part of $W(\psi)\ \exp(j\lambda_r\psi)$



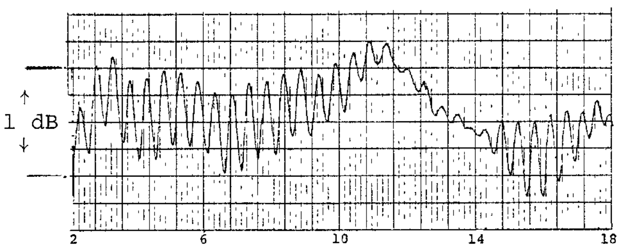
Cepstrum for Ripple Extraction [λ_r - Ripple Occurrence in Swept Frequency Trace]

$$\left|X_r(\omega)\right| = \left|\int_{-\Delta}^{\Delta} X(\omega+\psi)\ W(\psi)\ \exp(j\lambda_r\psi)\,d\psi\right|$$

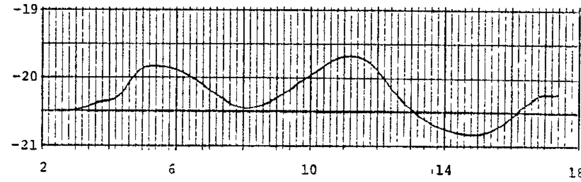
FIGURE 4. METHOD B - RIPPLE AMPLITUDE EXTRACTION

Measurement Data

Figure 5 shows the use of Method A, error averaging, in the measurement of an offset termination with nominal return loss of 20 dB. The ripple variations on the trace of 5a shows the effect of the bridge directivity on the measurement. After the digital processing, the true value determined by the average is shown in 5b. The periodicity is due to distributed reactive compensation within the termination.



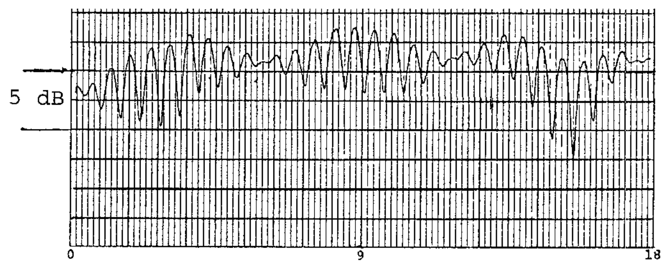
a. Raw Sweep Reflection Data



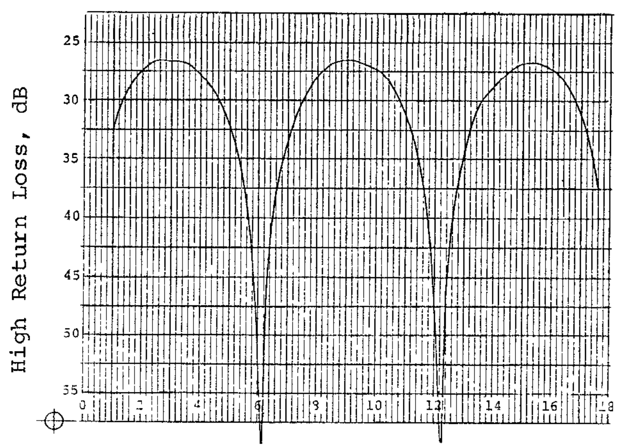
b. Processed Data With Error Averaging Applied

FIGURE 5. MEASUREMENT OF A 20 dB RETURN LOSS TERMINATION

Figures 6 and 7 show two applications of the ripple magnitude extraction method. In 6a and 6b the device under measurement is a one inch length of low impedance coaxial line followed by a 50 ohm termination. Physical impedance[4] references are thus obtained at odd multiples of a quarter wave length for the low impedance section. The raw data is given in 6a and the processed data is 6b.



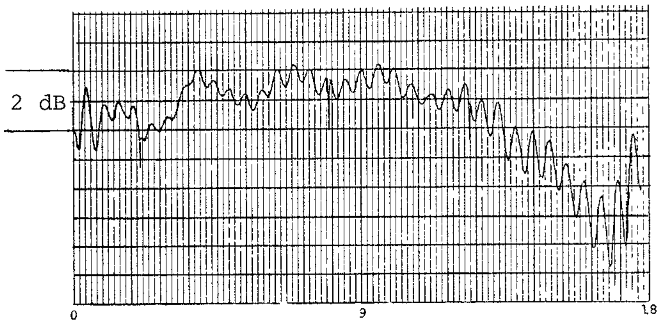
a. 1 inch Section of Low Impedance Line--Raw Data



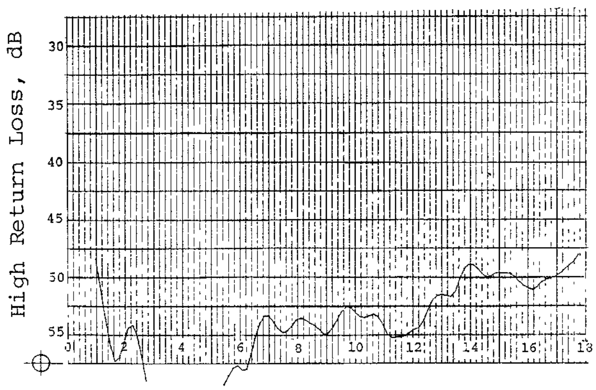
b. Processed Data for a.

FIGURE 6. CALCULABLE PHYSICAL IMPEDANCE REFERENCE

Figures 7a and 7b show the measurement of a beadless precision 50 ohm termination. The bridge has a 20 dB offset termination in the measurement configuration of Figure 1. The raw data is given in 7a, and the processed resultant is shown in Figure 7b.



a. Raw Sweep Data for 50 Ohm LPC-7 Termination Taken with 30 dB Return Loss Bridge Reference



b. Processed Return Loss Data Using Ripple Amplitude Extraction Algorithm

FIGURE 6. PRECISION TERMINATION DATA

Other related measurement tasks include: a) the measurement of the source match of oscillators or amplifiers under active conditions, and b) the detailed frequency response of the directivity for reflection bridges and directional couplers.

Results will also be presented for waveguide reflection measurement in the 26.5 to 40 GHz band.

Conclusion

The limiting intrinsic accuracy factor of the precision reflectometer is the "in place" physical air-line impedance reference. This may be easily inspected and gauged. The length of the reference line will determine the frequency resolution. The measurement system calibration depends on the physical line impedance plus a reference level determined by placing a short at the measurement port in Figure 1 and taking an "error averaged" frequency run.

The number of r.f. components involved is minimal, but this involves no sacrifice of measurement accuracy and strongly supports reliability. All of the system is commercially available to be supplemented with computer programs for the algorithms above presented.

References

1. Hollway, D.L. and P.I. Somlo, "Origin of High-Resolution, Swept-Frequency Reflectometry," Microwave Journal, August 1973.

2. Hollway, D.L. and P.I. Somlo, "A High-Resolution Swept-Frequency Reflectometer," IEEE Trans MTT, April 1969.

3. Lacy, P. and W. Oldfield, "A Precision Swept Reflectometer," Microwave Journal, April 1973.

4. Beatty, R.W., "Calculated and Measured S_{11}, S_{21}, and Group Delay for Simple Types of Coaxial and Rectangular Wave-guide 2-Port Standards," NBS Technical Note 657, December 1974