SWEPT LONG LINE DETECTOR NETWORK ANALYZER

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Abstract:

A network analyzer is described which provides the measurement of both magnitude and phase of S_{11} and S_{21}. The RF components of the system are resistors, video detectors, and long lines, giving wide bandwidth.

Summary:

The long line technique for measuring VSWR[1] is well known. The voltage on a transmission line having a mismatched termination is shown in FIG. 1. V_I is the incident wave, V_R, the reflected wave and V_T, the vector sum. In the plane of a short circuit $V_R = V_I$ and $\Theta = 0$. When the point at which the voltage is observed is separated from the short circuit by a long length of transmission line ℓ then Θ is given by

$$\Theta = 4\pi\ell/\lambda$$

and the attenuation of the long line causes

$$V_R < V_I$$

When the termination is other than a short circuit then the phase of the termination ϕ will be any value not necessarily zero and the general expression of Θ will be

$$\Theta = 4\pi\ell/\lambda + \phi$$

As frequency is swept V_R will trace out a circle as shown in FIG. 1 (assuming V_R is invarient with frequency). The law of cosines gives the total voltage V_T at this point.

$$V_T^2 = V_I^2 + V_R^2 - 2V_IV_R \cos\Theta$$

When a detector is used that is square law over the region of voltage swing of V_T then the rectified current is given by

$$I = kV_T^2 = k(V_I^2 + V_R^2 - 2V_IV_R \cos\Theta),$$

if the incident wave is constant while the circle is being traced out and

$$I = kV_I^2 (1 + |\Gamma|^2 - 2|\Gamma| \cos\Theta)$$

in which $|\Gamma| = V_R/V_I$. If $|\Gamma|$ is independent of frequency then the AC component of I is proportional to $|\Gamma|$. As $|\Gamma|$ becomes smaller the required square law dynamic range of the detector becomes even smaller so that no severe requirements are being placed on the detector.

The attenuation of a long line changes with frequency and would make data difficult to evaluate if only one long line were used. Therefore the sweeper output is split by a resistive power divider and put into two identical long lines with matched detectors. The second long line has a reference termination on it and the rectified AC from its detector is used to obtain the reflection coefficient $|\Gamma|$ directly in the manner customary for network analyzers by forming the ratio of both rectified AC's. The AGC voltage for the sweep generator is obtained from an AGC detector which is connected to the common node of the resistive power splitter.

Since two long lines are being used it is also possible to obtain the phase of the unknown termination by comparing the zero crossings of the AC out of the detectors. Since both lines are the same lengths their zero crossings will be different only by the differences in their ϕ. When the reference has $\phi = 0$ then the difference will be the phase of the unknown. This phase is read out very simply by having the positive going zero crossing of the reference detector turn on a bistable circuit and the positive going crossing of the unknown detector turn it off. The average output voltage of the bistable vibrator is directly proportional to ϕ.

In order to measure S_{21} the circuit is rearranged so that there are two paths to each square law detector, one by way of a resistive path and one by way of the long line and device being measured. Magnitude and phase are sensed the same as for S_{11} comparing the output of the square law detector having a reference attenuator in place of the unknown.

Both S_{11} and S_{21} measurements can be made in the network analyzer without removing the unknown and without RF switching. The RF circuit for the swept long line detector network analyzer is shown in FIG. 2. As with other network analyzers low multiple path errors are obtained by increasing generator-to-detector loss. Typical multiple path errors for the swept long line detector network analyzer are shown in FIG 3. The phase errors are given for $|S_{11}| = 1$ and $|S_{21}| = 0.1$. Phase errors for other values of $|S_{11}|$ and magnitude errors can be calculated using Garver, et. al.[2] and in no case can exceed that permitted by the quality of the output connectors. S_{21} errors can be calculated using phasor diagrams.[2]

The swept long line detector network analyzer has advantages in that it is extremely wideband, because no bandwidth limiting coupling elements are required. It is accurate in that high quality lines can be used for the long lines giving accurate S_{11} measurements. It is inexpensive to make in that the resistive network can be fabricated on one substrate with very few processes.

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It has disadvantages in that measurements at single frequencies or of rapidly changing S parameters are difficult to make. The frequency resolution of S parameter detail is determined by the length of the long line. Longer lines give finer detail. 10 MHz intervals are given by 10 meter lines. Measurements can be made at single frequencies by using the circuit in a balanced bridge mode.

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1 L. Libby, "Frequency Scanning VHF Impedance Meter", Electronics, June 1948, p. 94.

2 R. Garver, D. Bergfried, S. Raff, and B. Weinschel, "Errors in S_{11} Measurements due to the Residual SWR of the Measuring Equipment," IEEE Trans. on Microwave Theory and Techniques, vol. MTT-20, Jan. 1972, pp. 61-69.

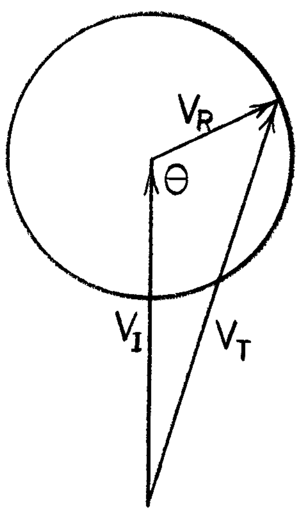

Figure 1 Voltage Addition at Detector for S_{11} Measurement

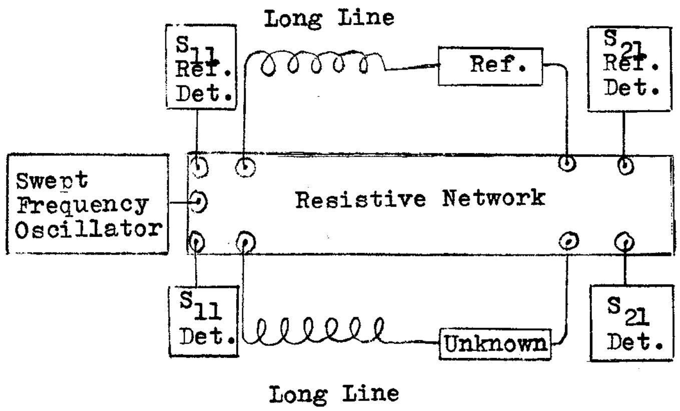

Figure 2 RF Circuit for Swept Long Line Detector Network Analyser

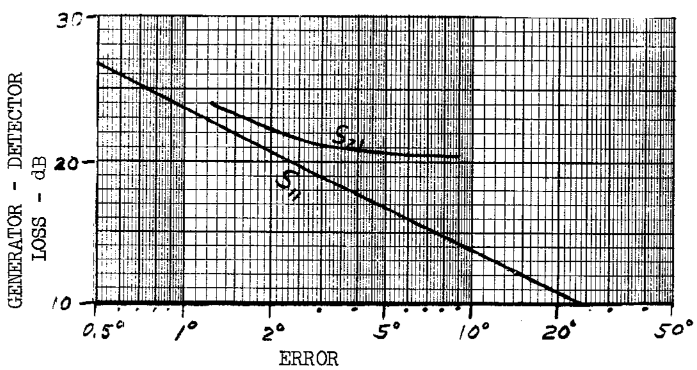

Figure 3 Typical Multiple Path Errors