HIGHLY SENSITIVE MEASUREMENTS WITH A LENS-FOCUSSED REFLECTOMETER

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A lens-focussed microwave reflectometer is described which offers exceptional sensitivity and very wide bandwidth. The system produces a well confined spot focus and, with the prescribed calibration procedure, gives effective directivity approaching 70 dB. Precision of ±1 dB is demonstrated for measurements, in X-band, at the -50 dB level.

INTRODUCTION

In this presentation, a technique is described for measuring very small reflections from a scattering body in free space. The sensitivity which is achieved far exceeds the sensitivity which is normally obtained in a vector measurement employing a microwave network analyzer. The focussing lens can provide very tight beam confinement to separately resolve closely spaced scatterers. Applications include measurement of material properties and scanned imaging of weakly scattering objects. The design of the lens is frequency independent making it useful over a wide range of frequencies. Lenses can be fabricated from a suitable low-loss dielectric such as teflon or rexolite and the design of the lenses is straightforward [1].

For a lens aperture which is much larger than the wavelength, the radiated field can be described quite accurately as a single, fundamental Gaussian mode. At the focal distance, the beam produces a plane wavefront. Because the calibration and measurements are performed in or very near the focal plane of the lens, good accuracy can be obtained with the assumption of TEM propagation and the analysis of the measurement system can be treated as a transmission line problem. A detailed description of Gaussian beam propagation is, therefore, not essential to the analysis and can be found elsewhere [2].

APPARATUS

For the apparatus described in this paper and shown in figure 1, a bi-convex lens was assembled from two plano-convex dielectric lenses placed back-to-back. One lens surface forms a plane wavefront from a spherical wave at the feedpoint and the second lens surface refocuses the plane wave at the beam waist which determines the measurement plane 18 inches from the front surface of the lens. Lenses were machined from cast acrylic (PMMA). The phase center of a small standard gain horn is placed at the focal point, 12 inches from the rear surface of the lens to serve as the feed.

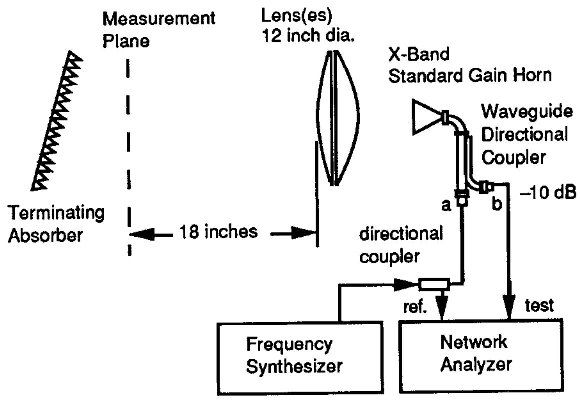

Figure 1. Block diagram of the X-band, lens-focussed reflectometer setup.

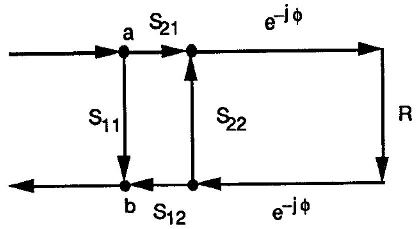

Figure 2. Signal flow graph representation of the reflectometer.

CALIBRATION PROCEDURE

Figure 2 is a signal flow graph representation of the reflectometer as a two-port connected to an unknown termination. By use of a vector network analyzer, the output of the directional coupler at port b is referenced to the input at port a which allows the measurement to be treated as a one-port S_{11} measurement.

By application of the non-touching loop rule [3] to the flow graph of fig. 2, the measured reflection coefficient, Γ, is given, in terms of the unknown terminating reflection coefficient, R, by the following relation.

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$$\Gamma = \frac{b}{a} = \frac{S_{11}(1 - S_{22} R e^{-j2\phi}) + S_{21} S_{12} R e^{-j2\phi}}{1 - S_{22} R e^{-j2\phi}} \quad (1)$$

For economy of notation, relabel the parameters from equation (1) according to

$$A = S_{11}, \quad B = S_{21} S_{12} e^{-j2\phi}, \quad C = S_{22} e^{-j2\phi},$$

to give the following, simplified expression of equation (1).

$$\Gamma = \frac{A(1 - CR) + BR}{1 - CR} \quad (2)$$

The unknown calibration coefficients A, B, and C, are determined from measurements made with a short-circuit, an offset short-circuit and a matched load. The calibration coefficients thus obtained are given by

$$A = \Gamma_L \quad (3)$$

$$B = \frac{(\Gamma_L - \Gamma_o)(\Gamma_L - \Gamma_1)(1 - e^{-j2\delta})}{\Gamma_o - \Gamma_1} \quad (4)$$

$$C = \frac{(\Gamma_L - \Gamma_o) - (\Gamma_L - \Gamma_1) e^{-j2\delta}}{\Gamma_o - \Gamma_1} \quad (5)$$

where Γ_o is measured (complex) reflection coefficient of the reference short, Γ_1 is the measured reflection from a short offset a distance δ from the reference plane toward the generator, and Γ_L is the measured reflection with a matched termination.

Inverting equation (2) gives the actual value of the reflection coefficient of the device under test in terms of the measured reflection and the calibration coefficients.

$$R = \frac{\Gamma - A}{C\Gamma - AC + B} \quad (6)$$

The short-circuit calibration is performed by use of a metal plate placed normal to the microwave beam at the beam waist or the focal distance of the lens. The offset short measurement was obtained using the same metal plate as for the reference short, displaced from the reference plane about a quarter of a wavelength at mid-band by machined metal spacers. For the matched load calibration, a two-foot square of two-inch wedged absorbing material was placed several inches beyond the measurement plane. Subsequent measurements of a test object are made with the terminating absorber at the same position as for the calibration.

MEASURED RESULTS

As an example of the type of measurement which can be made with the reflectometer, measurements were made of the reflection coefficient, at normal incidence, of 3M Corp. type 6700 bonding film. According to the manufacturer's specifications, the material has a relative dielectric constant of 2.35 ± .10. The measured average thickness of the sample was .0014 inch.

Figure 3 displays the results obtained for the measurements. Each data point gives the reflectivity of the film sample obtained from the mean of the measured amplitude and phase of the reflection at each frequency. The error bars represent the range of the reflectivity which falls within the limits of one standard deviation of the measured amplitude and phase of the raw film data. These error bars extend over a range of less than ±1 dB for almost all of the results. The solid lines which are plotted on figure 3 give the upper and lower values of the reflectivity of the film sample which were calculated using the upper and lower limits of the dielectric constant specified by the manufacturer.

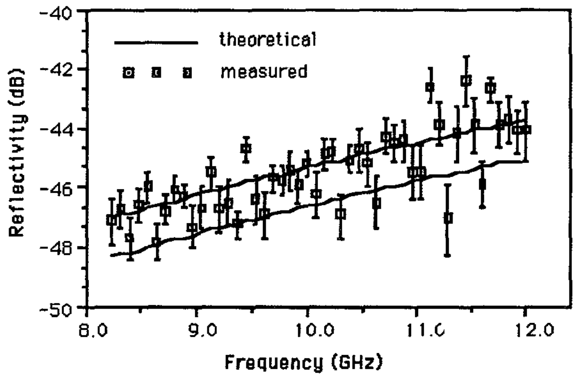

Figure 3. Plot of measured and calculated reflectivity of 3M Corp. type 6700 bonding film.

For frequencies below 8.2 GHz, the lens aperture is apparently too small to support the fundamental Gaussian mode at the longer wavelengths. The loss of accuracy at frequencies near 11.5 GHz is due to a measurement "fade" caused by interference between various reflections in the system which reduce the measurable effect of the reflection from the sample. This problem could be remedied by repositioning the feed slightly or by moving the reference plane of the measurement.

REFERENCES

[1] Henry Jasik, *Antenna Engineering Handbook..* New York: McGraw-Hill, 1961.

[2] H. Kogelnik and T. Li, "Laser beams and resonators," *Proc. IEEE*, vol. 54, pp. 1322-1329, 1966.

[3] J. K. Hunton, "Analysis of microwave measurement techniques by means of signal flow graphs," *IRE Trans. MTT*, vol. 8, pp. 206-212, 1960.