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ELECTRICAL THICKNESS MEASUREMENT BY A SINGLE-HORN METHOD

by

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In order to correct the boresight error of a radome, it is necessary to start with a radome whose walls are uniform in electrical thickness over any given cross section taken perpendicular to the radome axis. It is a difficult problem to manufacture radomes of uniform electrical thickness; therefore, it is desirable to be able to measure the electrical thickness of the radome wall. This measurement may then be used in a control procedure in the manufacture or subsequent correction of the radome. The most common method of making this measurement is by means of a two-horn interferometer. This method is in general satisfactory; however, particularly for large radome of a high fineness ratio, the mechanical problems of maintaining the separation of two horns, one inside and one outside the radome, to close tolerance becomes very difficult. Thus, it would be desirable to obtain the electrical thickness of the radome wall by means of a reflection measurement using only a single horn placed outside the radome. Such an apparatus has been designed and constructed at Hughes Aircraft Company and is the subject of this paper.

The electrical thickness, ϕ, of a dielectric panel is defined by the equation

$$\phi = \frac{2\pi d}{\lambda} \sqrt{\epsilon} \tag{1}$$

at normal incidence. The reflection from the panel has minimum amplitude when $\phi = n\pi$. Then, if λ_m is the wavelength for minimum reflection, for $n = 1$,

$$\pi = \frac{2\pi d}{\lambda_m} \sqrt{\epsilon} \tag{2}$$

Dividing (1) by (2), we obtain

$$\phi = \frac{\lambda_m}{\lambda} \pi = \frac{f}{f_m} \pi \tag{3}$$

ϕ is the electrical thickness at the operating frequency or design frequency of the panel. If dielectric constant is desired, it may be computed from

$$\epsilon = \left(\frac{\lambda_m}{2\,d} \right)^2 = \left(\frac{C}{2\,f_m\,d} \right)^2 \qquad (4)$$

$$\text{I.P.D.} = \phi - \frac{2\pi d}{\lambda} \qquad (5)$$

Another term in common use is insertion phase delay, defined, for normal incidence by equation (5). The above is valid only in the far field of the horn, which is not strictly the case with the present apparatus.

A block diagram of the apparatus used to measure the reflection from the panel is shown in Figure 2. As may be seen, it is basically a reflectometer setup terminated in an E-plane rectangular horn. The frequency is swept by means of a tracking klystron, the frequency of which is varied with a hand crank. The reflection is measured with a directional coupler and crystal detector and is displayed on a recorder. The recorder table is servo-driven along with the klystron frequency. Thus, a graph with reflected power on the vertical axis and frequency on the horizontal axis is obtained.

The measurement of the frequency at which minimum reflection occurs is complicated by the fact that interactions between the horn and the dielectric panel occur, thus causing minima to appear at many frequencies. As shown by R. M. Redheffer, [1] this interaction is due to two causes. First, the reflection from the panel adds vectorially to the reflection at the mouth of the horn due to the mismatch of the horn to space. When these two reflections are out of phase, a minimum will occur, even though the reflection from the panel is not a minimum. This effect has been reduced by the design and construction of an extremely well-matched horn. The horn is flared to an E-plane aperture of approximately 1 1/2 inches. The transition from the waveguide to the horn is a curved section tangent to two walls of the waveguide, thus minimizing throat reflections. A ground plane 3 inches by 5 inches is located at the mouth of the horn. The remaining mismatch is minimized by the insertion of a teflon strip and a block of polyfoam in the mouth of the horn. The horn match is shown in Figure 3. A second cause of interaction is the backscattering of reflected energy by the horn and the resultant multiple reflections between the panel and the horn. This effect is naturally aggravated by the ground plane used for matching. However, probably due to rapid inverse - square attenuation of these multiple reflections, they have been found experimentally not to interfere with the measurements as did the interactions due to mismatch of the horn.

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1. R. M. Redheffer, "The Interaction of Microwave Antennas with Dielectric Sheets", M.I.T., Rad. Lab., Report R - 483 - 18

In order to test the operation of the equipment, three 12 inch by 6 inch panels of plexiglass ground to thicknesses of 0.437 inch, 0.414 inch, and 0.392 inch were made. Curves of reflection versus frequency are shown in Figures 4, 5, and 6. The dielectric constant of the plexiglass was then computed and compared with the dielectric constant as computed from a measurement made on a small sample of each sheet in a cavity dielectrometer. As may be seen, the measurements by any one method agree with each other within ± 2 percent. However, the reflectometer measurements are considerably lower in value than those made with the interferometer and cavity. It is felt that this is due to the fact that spherical rather then plane waves are incident on the panel, thus increasing the apparent angle of incidence. This effect becomes smaller as the dielectric constant is increased and the panel becomes thinner. A sheet of epoxy - Shell 1001 12 inches by 12 inches of thickness 0.278 inches was measured with the reflectometer as shown in Figure 7. Its dielectric constant was computed and compared with a measurement made on the panel with an interferometer. The measurements all agree to within 2 percent.

Many measurements were made on radomes, since this was the primary purpose of the instrument. A typical measurement is shown in Figure 8. This radome has previously been found to be electrically uniform with respect to rotation with the Hughes Aircraft Company boresighting equipment. The dielectric constant and electrical thickness at 9000 mcs. are shown and compared with results obtained from an interferometer. No change in electrical thickness with radome rotation was observed. Both measurements were taken at a point where the radome was about 5 inches in diameter. No effect due to the opposite wall of the radome was observed. A second radome, found to be asymmetrical with respect to rotation with the boresighting equipment, was measured. This radome has a variation in physical thickness with rotation of 0.004 inch in addition to a variation in dielectric constant of the wall. Electrical thickness and dielectric constant measurements at various rotational positions were computed and compared with measurements made on an interferometer. The electric thickness varies about 8^{o} from the thin to the thick portions of the dome.

All of the measurements were made at an optimum distance of 3/4 inch from the horn to the panel. Variations of ± 1/8 inch cause no appreciable shift in the frequency of minimum reflection. At distances much smaller than 3/4 inch, the reflection from the front interface of the panel becomes large with respect to that from the rear interface of the panel due to inverse - square attenuation, and the minimum almost disappears. At distances much larger than 3/4 inch the magnitude of the reflection from the panel picked up by the horn becomes too small for satisfactory measurement. The range of the tracking klystron and of the horn match is 8000 to 10,000 mcs; thus the instrument is limited to a range of ± 20 percent in dielectric constant or ± 20 degrees in electrical thickness if the panel or radome is designed to be a half-wave thick at normal incidence at the center frequency of 9000 mcs. Obstacles such as panel edges in the field of the horn do not seem to affect the readings of the reflectometer greatly. Panels as small as 6 inches by 6 inches give satisfactory results and it is felt that 3 inch by 3 inch panels will also be satisfactory, although this has not yet been tried. The measurements made by the reflectometer are consistently too low especially for panels of low dielectric constant. Thus the instrument in its present form must be calibrated for such measurements. However, the relative measurements at various points of a radome wall are sufficiently accurate and are still very useful. It may be possible to apply a theoretical correction to account for the fact that the panel is in the near field rather than the far field of the horn. It may also be possible to construct a lens in the mouth of the horn to produce more nearly plane waves at the panel.

The reflectometer is being modified for normalization with a ratio meter to eliminate errors due to variations in klystron output with frequency. For rapid measurement, the tracking klystron will be replaced by a traveling-wave tube electrically swept through the 8000 to 10,000 mcs. range several times a second. The reflection versus frequency may then be displayed on the face of an oscilloscope. An attempt is being made to construct a matched horn without the use of a ground plane.

It is felt that the present instrument is capable of a relative measurement of dielectric constant with an accuracy of ± 2 percent, electrical thickness with an accuracy of ± 1 percent, and a resolving power of one electrical degree.

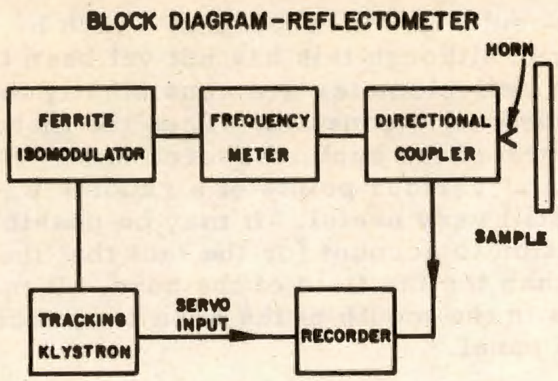

Figure 1

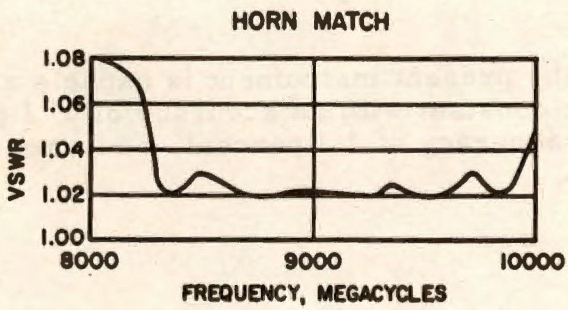

Figure 2

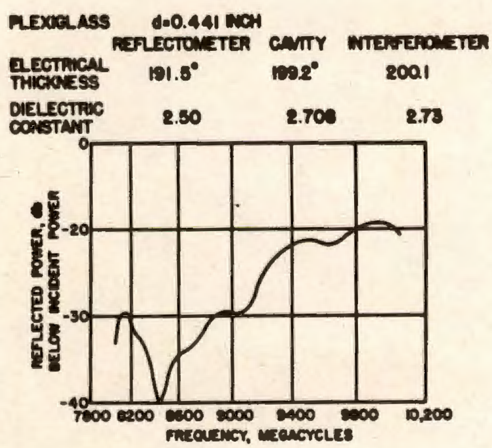

Figure 3

PLEXIGLASS d=0.417 INCH

	REFLECTOMETER	CAVITY	INTERFEROMETER
ELECTRICAL THICKNESS	179.9°	188.3°	189.0°
DIELECTRIC CONSTANT	2.47	2.705	2.72

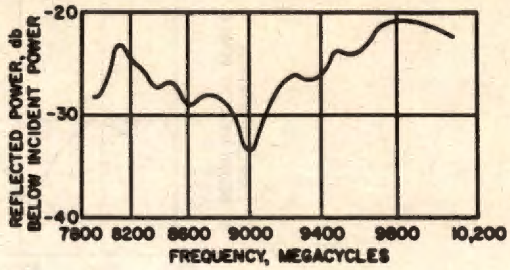

Figure 4

PLEXIGLASS d=0.399 INCH

	REFLECTOMETER	CAVITY	INTERFEROMETER
ELECTRICAL THICKNESS	174.4°	179.8°	182.2°
DIELECTRIC CONSTANT	2.52	2.696	2.77

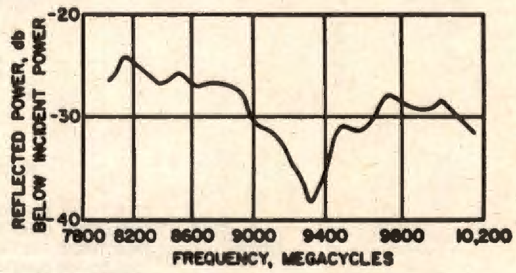

Figure 5

EPOXY-SHELL 1001 d=0.278 INCH

	REFLECTOMETER	INTERFEROMETER
ELECTRICAL THICKNESS	174.5°	176.3°
DIELECTRIC CONSTANT	5.23	5.33

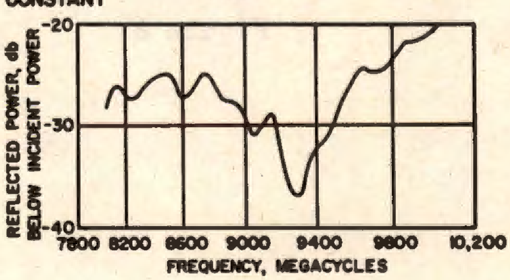

Figure 6

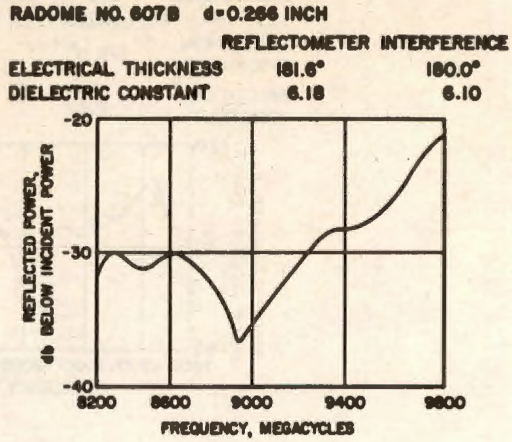

Figure 7

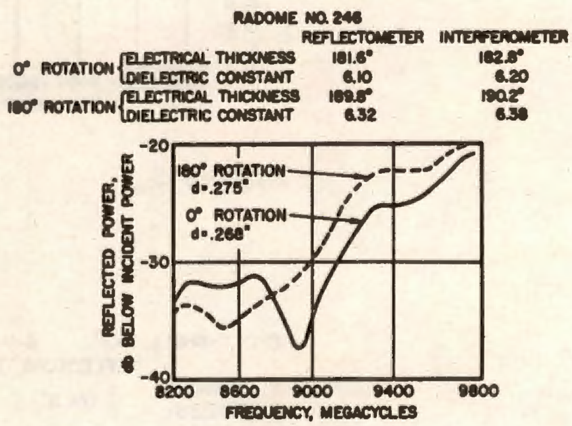

Figure 8