THE MEASUREMENT OF PHASE DELAY on DIELECTRICS AT MICROWAVE FREQUENCIES

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For the past several years, Airborne Fire Control Radars have been improved considerably and have become a necessary part of USAF aircraft.

To utilize the full potential of the Weapon Systems, the radome has to be designed, built, checked and corrected in vast quantities. In an attempt to meet this demand, large scale construction of facilities has begun.

Interferometers, boresight measuring equipments, transmission and reflection test ranges and dielectric measuring equipments have been and are being constructed in an attempt to design and produce the required radomes.

Even at best, the testing, evaluation and correction of fire control radomes are time consuming and costly. One of the many attempts to reduce the cost and time involved has been directed to the improvement of test equipment.

Wright-Field looking for a simple go or no-go gage for production testing had in mind a single horn, induction or perhaps a capacitive type device to detect the electrical phase variation in all types of radome walls. This device had to be small, easily carried, accurate and simple to use. The main objective was to be able to use this device on all shapes and sizes of radomes regardless of the material used in its basic construction.

A device was conceived, by the Radome Branch, Wright Air Development Center, whereby the reflection coefficient could be used to determine the equivalent electrical thickness of a radome under investigation, with a single horn at normal incidence.

One of the prospective advantages of this new instrument lies in the fact that it not only indicates a rejected radome but can tell the operator where and to what extent, either positive or negative, the radome is out of tolerance "electrically". Another advantage lies in its simplicity of design and operation which reduces testing time and cost.

Figure one (1) shows the basic diagram. A Klystron is used to supply energy at a 1000cps modulated X band frequency. The forward sensing directional coupler (D_1) is used to detect the forward energy from the Klystron. The other directional coupler (D_2) is used to detect reflected energy from a sample when placed at the antenna aperture. A precision constant phase attenuator (A) is placed in the forward sensing arm of directional coupler (D1), and a constant amplitude phase shifter (ϕ) is placed in the reflected energy arm of (D_2). Energy is fed from (A) and (ϕ) to the hybrid arms of a magic tee. A crystal detector on one of the coplaner arms of the magic tee is connected directly to a V.T.V.M. The other coplaner arm is terminated by the use of an E-H tuner and a resistance load.

By adjusting the attenuator in the forward energy arm, it is possible to obtain the exact magnitude of forward energy to balance the reflected energy at the magic tee thereby giving a null. Further, by adjusting the phase shifter, either automatically or manually, it is possible to get a very sharp null in amplitude and in phase. The calibrating of this device is accomplished by a metal panel placed at the antenna aperture.

THEORY

Electrical thickness, effective dielectric constant and phase delay and their variations can be determined by measuring the reflection coefficient of a dielectric test panel, or radome. In obtaining the reflection coefficient, a known reference is required against which the signal reflected from a panel can be compared. When a metal calibration panel is used, the reflection is 100% and the phase reversal is π .

If $|P|^2$ is the power reflected from the radome panel, comparing this with the 100% metal panel reflection means that the $|P|^2$ is $|R|^2$, the absolute value of the complex reflection coefficient of the radome panel. If P' is the measured phase indication of the signal returned from the panel, using 0° as a calibration point, which was obtained by use of the metal panel, then $\pi + P' = R'$ will be the argument of the reflection coefficient of the radome panel.

The electrical thickness, effective dielectric constant, and phase delay, and their variations can all be computed from R and R'. A solid wall, at normal incidence for the lossless case

$$R' = \frac{3\pi}{2} + T' \quad (1)$$

where T' is the argument of the complex transmission coefficient. Since phase delay is expressed as,

$$\psi = T' - \frac{2\pi d}{2} \quad (2)$$

where d is panel thickness and λ the wavelength, we have

$$\psi = R' - \frac{3\pi}{2} - \frac{2\pi d}{\lambda} \quad (3)$$

Thus we have expressed phase delay in terms of measurable quantities. Since,

$$R' = -\frac{3\pi}{2} - \arctan \frac{1 + r^2}{1 - r^2} \tan \phi \quad (4)$$

where $r = \frac{1-\sqrt{\epsilon}}{1+\sqrt{\epsilon}}$

and $\phi = \frac{2\pi d}{\lambda}\sqrt{\epsilon}$ (electrical thickness)

then $|R|^2 = 1-|T|^2 = \frac{4r^2 \sin^2\phi}{(1-r^2)^2 + 4r^2\sin^2\phi}$ (5)

now we have two equations expressing the measured R' and $|R|^2$ in terms of and ϕ. These two equations can be solved simultaneously to give ϕ in terms of R' and $|R|^2$. Since dielectric constant is

$$\epsilon = \frac{\phi^2\lambda^2}{4\pi^2 d^2} = \left(\frac{1-r}{1+r}\right)^2 \quad (6)$$

we have the dielectric constant in terms of known quantities. Similarly the equivalent formulas for the more complex cases such as sandwiches and lossy radome walls can be devised utilizing normal incidence.

The Dalmo-Victor Company was awarded the development Contract AF33(616) -3092 to completely develop such an instrument. The final instrument will feature automatic null seeking, recording, be small and light weight, and will be exceptionally easy to operate. It is expected that the accuracy will be ± 1 electrical degree. Delivery should be withing the next few months.

CONCLUSION

If such a device as this meets all expectations, fabrication of fire control radomes including monopulse can be checked accurately and quickly. This device is not expected to replace all the other large equipments, but certainly will expedite the production testing, correcting and final approval of guidance type radomes.

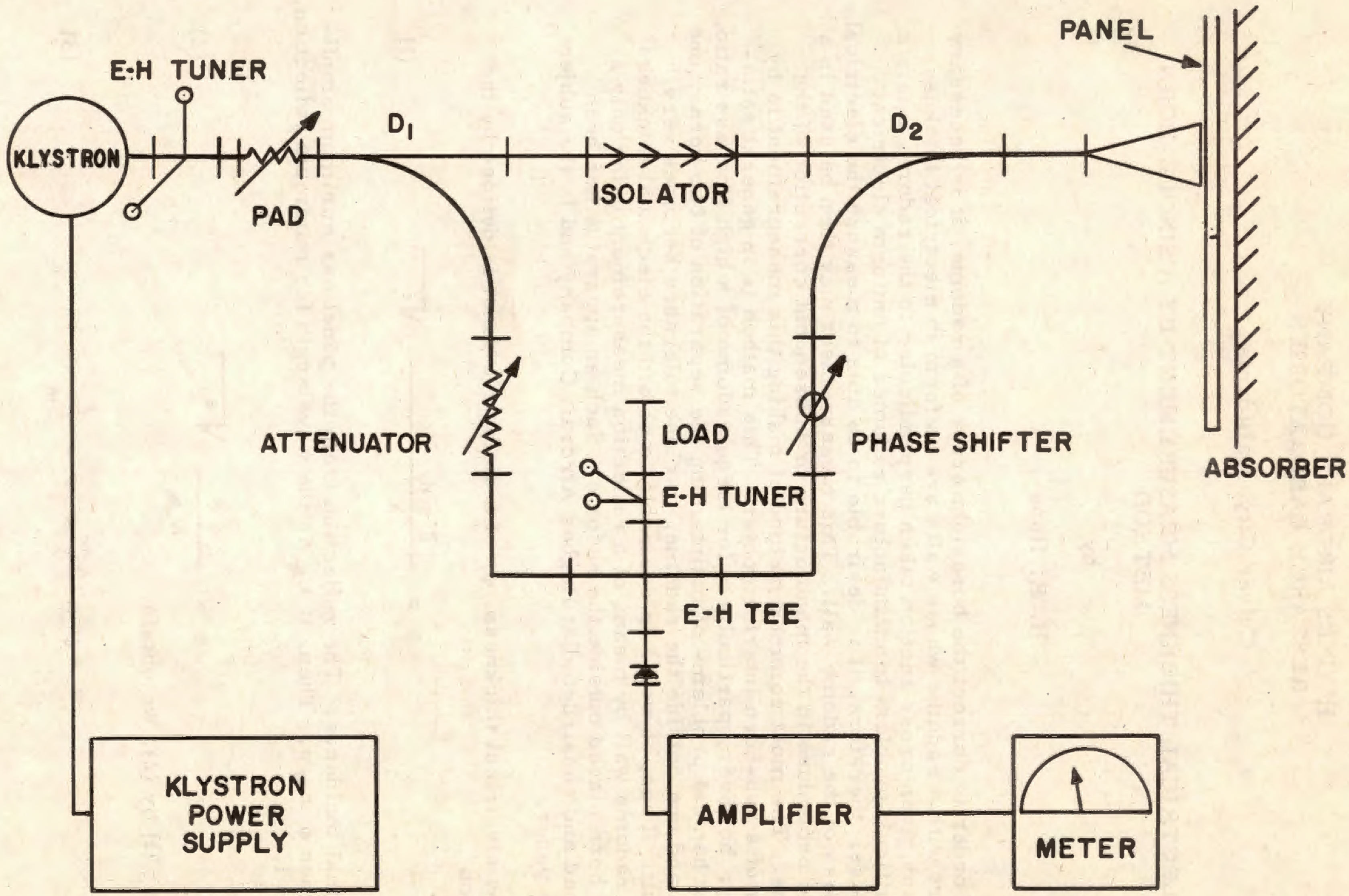

FIG. 1 ELECTRICAL THICKNESS GAGE