BORESIGHT PREDICTION TECHNIQUE

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This paper covers a simple procedure by which the boresight error characteristics of figure-of-revolution radomes can be easily estimated. The method to be outlined will permit a rapid evaluation of the general configuration and magnitude of the boresight error characteristics of such radomes, without recourse to elaborate computational procedures.

Major efforts during the past few years have been directed at improving methods for predicting the boresight errors caused by radomes. As more refinements have been introduced, the computational procedures have increased in complexity. Some of the latest, and perhaps most elaborate, techniques require high-speed computers, with very large data-handling and storage capacities (such as the IBM 704), if the computations are to be carried out economically. Adequate computational facilities may not always be available, and it is not always possible to devote the necessary time to programming, which is quite complex.

For the purpose of this discussion, the boresight error will be defined as the tilt in average phase front induced by the radome wall, as illustrated in Figure 1. Actually, in a conically scanning system, boresight is defined as the angular shift of the cross-over, which to a first and generally fairly good approximation is the same as the beam refraction in the offset plane caused by the radome at the particular offset (or look) angle in question. The radome wall structure will be assumed to have fairly uniform transmission over the range of incidence angles encountered between the rays from the dish and the normals to the radome wall, so that pattern distortion due to poor transmission can be ignored. A collimated beam will be postulated with a plane phase front normal to the rays emanating from the dish as shown in Figure 1. During passage through the radome wall, the rays will undergo varying amounts of insertion phase (defined as phase retardation in excess of that incurred in travelling through an equal thickness of air at the given angle of incidence). The slope of a line drawn as a best fit through the various amounts of insertion phase undergone by the different rays, with respect to the phase front of the undistorted beam,

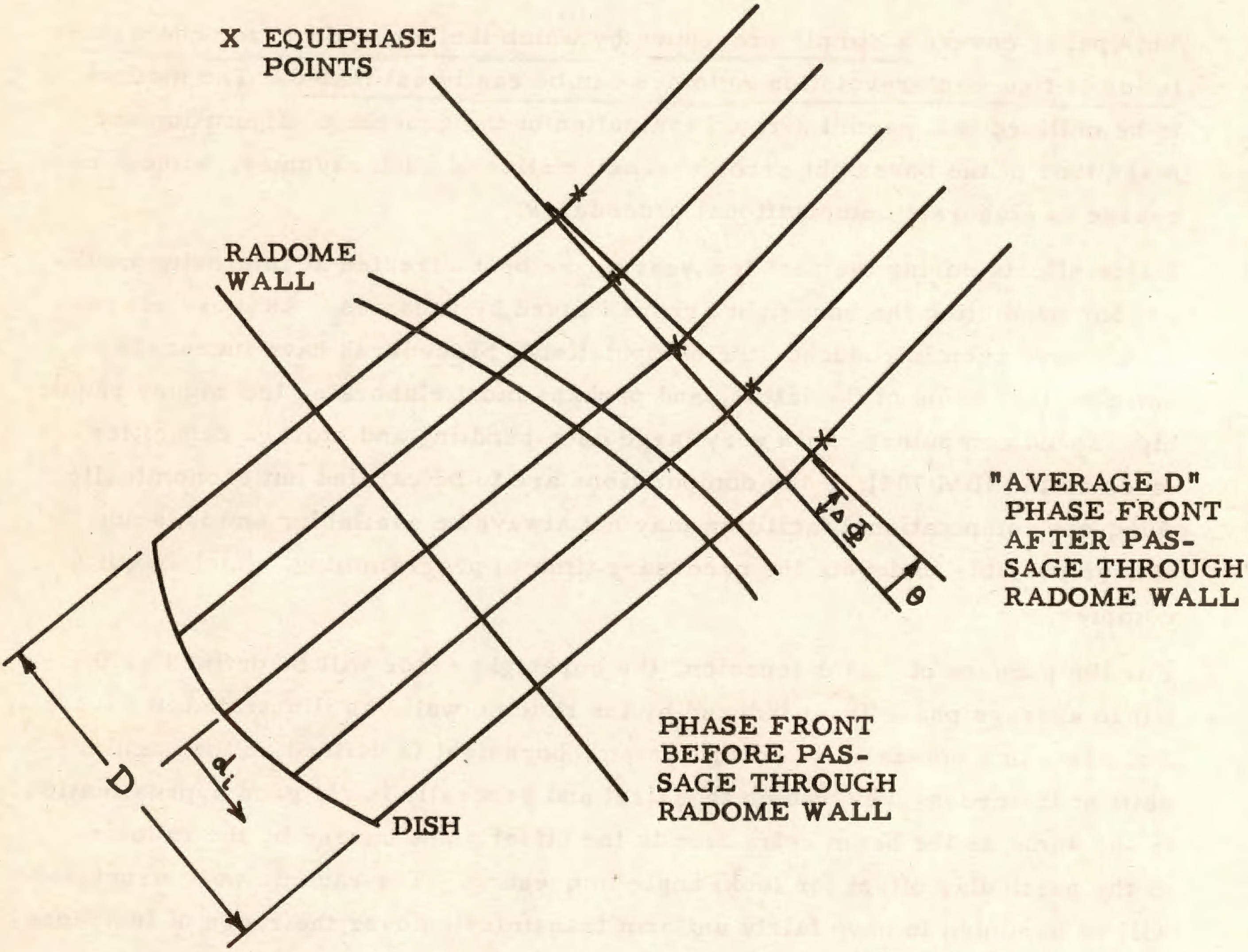

Figure 1 - Equivalent Effect of Radome Wall Structure on Beam

will define the boresight error. In Figure 1 the boresight error in radians will be defined as:

$$\theta \cong \frac{\Delta\Phi}{D.} = \frac{\Sigma w_i \Phi_i d_i - \dfrac{(\Sigma w_i \Phi_i)(\Sigma w_i d_i)}{w_i}}{\Sigma w_i {d_i}^2 - \dfrac{(\Sigma w_i d_i)^2}{w_i}} ,$$

where w_i = weighting factor for the i-th ray,

Φ_i = insertion phase undergone by the i-th ray,

d_i = distance in electrical degrees of the i-th ray from the central ray.

Only rays lying in the offset plane passing through the radome axis are assumed to contribute to the boresight error. Finally, it will be assumed that the radome is substantially a figure-of-revolution, that the antenna beam is symmetrical, and that the dish and radome are at least 10λ in diameter.

In Figure 1 five rays are shown emanating from the dish: the central ray, the 3-db down rays, and the edge rays. The central ray does not contribute to the slope of the new phase front, providing the other rays are symmetrically located with respect to it. With four rays, satisfactory results have been achieved for wall structures which may vary gradually in thickness. Sharp narrow discontinuities in the form of ring compensators result in less reliable results. Presumably better predictions can be achieved with a larger number of rays, but since the intent is to achieve a rapid survey of the characteristics, the increase in labor would defeat the purpose. On the other hand, it will be shown that tolerable results can be achieved with only the two edge rays.

Each ray is treated as if it were a plane wave impinging on an infinite plane sheet having the identical wall construction as that existing at the intersection between the ray and the radome wall, and at the same angle of incidence. Although the expressions for the insertion phase introduced by multiple-layer walls are quite lengthy and complex, it is possible to determine the insertion phase rapidly by applying Smith Chart techniques to the transmission line analogy of the multi-layered wall. O. J. Snow showed some years ago that this could be done to establish the transmission characteristics of multi-layered flat panels.(1) More recently Dr. H. F. Mathis, at Goodyear Aircraft Corporation, has shown that this technique can be extended to determine the insertion phase characteristics of such panels.(2) The graphical construction requires only four straight lines and one arc of circle per layer and a few simple calculations, which can be readily carried out with the aid of a slide-rule. The insertion phase of a single ray passing through a three-layer sandwich can be computed in about twenty minutes, without the benefit of any specially prepared charts. However, if a large number of points are going to be considered it is expeditious to prepare curves or tables of normalized impedance and propagation functions for the various layers over the range of incidence angles to be encountered.

After the insertion phase undergone by each ray has been computed, the slope of the phase front is established by calculating the slope of the best fit straight line passing through the varying amounts of phase retardation. A refinement can be introduced by weighting the contributions of the various rays according to the energy distribution across the dish. If only the two edge rays are used, the slope of the straight line passing through the insertion phase undergone by these two rays is used. In all these cases, it is implied that, to a first approximation, the insertion phase varies uniformly across the beam.

The degree of success that can be achieved with this method will be illustrated in the following examples, in which the predicted boresight errors of a radome, with this technique, are compared with the measured results. The calculations were carried out at five offset angles for four and for two rays. Figure 2 shows the results obtained for perpendicular polarization. The solid line is the measured boresight error characteristic; the dashed curve is based on four rays with weighting for energy distribution; the dotted curve is for four rays using uniform weighting; and the dash-dotted curve is based on the two ray prediction. In general there is good agreement between the over-all envelopes of the predicted and measured curves. At maximum error, the predictions do not exceed the measured results by more than 50%. As might be expected, the two-ray approximation shows less correlation with the measured results than do the more elaborate calculations. Figure 3 shows somewhat similar results for parallel polarization. In general, less correlation has been found for parallel polarization. The greater variations between predicted and measured values are believed to be due to the fact that contributions from off-axis regions are neglected. These same discrepancies have been noted before in more elaborate

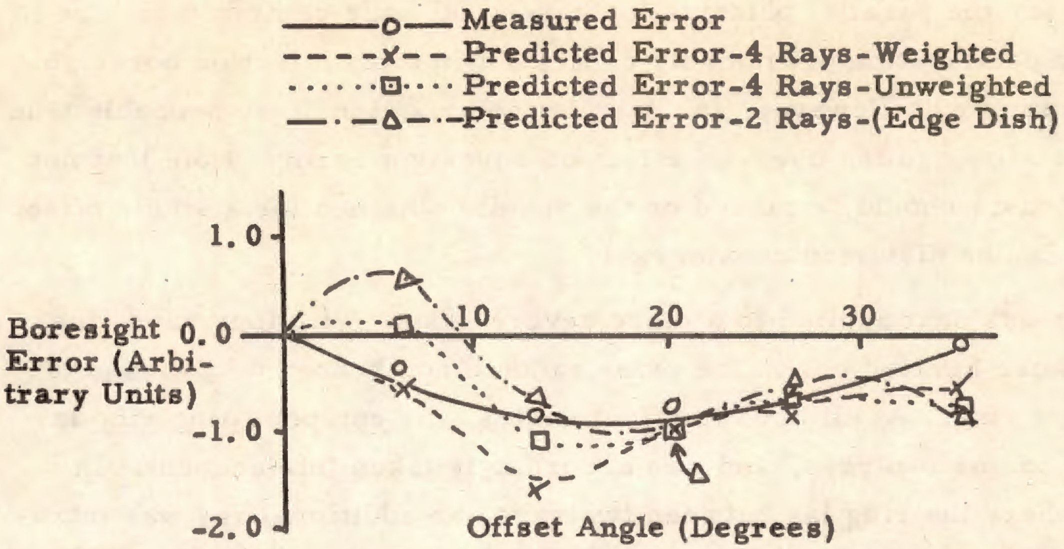

Figure 2 - Measured and Predicted Errors of Uncompensated Radome - Perpendicular Polarization

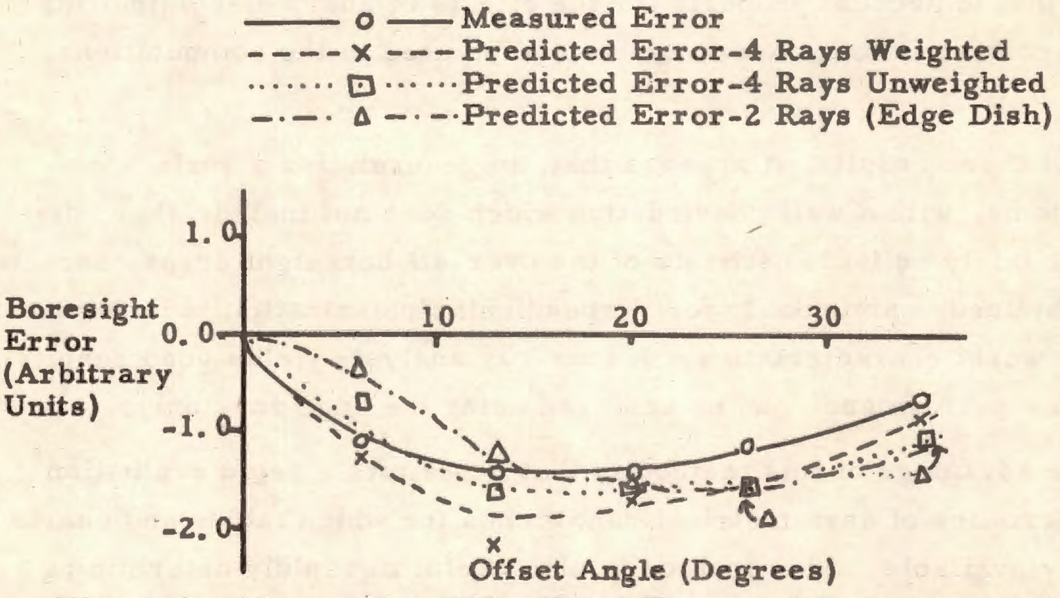

Figure 3 - Measured and Predicted Errors of Uncompensated Radome - Parallel Polarization

computations for the parallel polarization case. Off-axis contributions due to perpendicular polarization presumably cancel out in their effect on boresight because of symmetry. However, for parallel polarization, they probably tend to add and contribute to the over-all effect on boresight error. Note that not too much emphasis should be placed on the results obtained for a single offset angle, which can be distorted considerably.

The technique was next applied to a more severe case. With four rays, the calculations were carried out on the same radome compensated by means of a compensating ring. At all but two offset angles, the compensating ring lay in the path of one or two rays, and was accordingly taken into account. In those cases where the ring lay between two rays, an additional ray was introduced through the ring to make some allowance for its effect, and the effect of the central ray was also taken into account. As shown in Figure 4 for perpendicular polarization, the compensating effect is somewhat evident but the correlation between the predicted and measured results is not so good, as was found previously. In the case of parallel polarization, Figure 5, the lack of agreement is even worse, but the compensating effect is still present. It is believed that to account properly for the effects of sharp discontinuities such as these compensators, more rays should be used in the computational process.

On the basis of these results, it appears that, in general, for a surface of revolution radome, with a wall construction which does not include sharp discontinuities, a fairly reliable estimate of the over-all boresight error characteristic can be obtained, particularly for perpendicular polarization, which generally has the worst characteristics. A four-ray analysis yields good results, and a creditable performance can be achieved using the edge rays only.

One particular advantage of this method is that it permits a rapid evaluation of the characteristics of asymmetrical sandwiches for which tables and charts are not usually available. This method is also useful in rapidly determining the relative effects of wall tapers and other variations in construction. Of particular interest is the fact that in carrying out the graphical analysis, it is possible to acquire an understanding of the manner in which changes in wall structure parameters affect the behaviour of the beam.

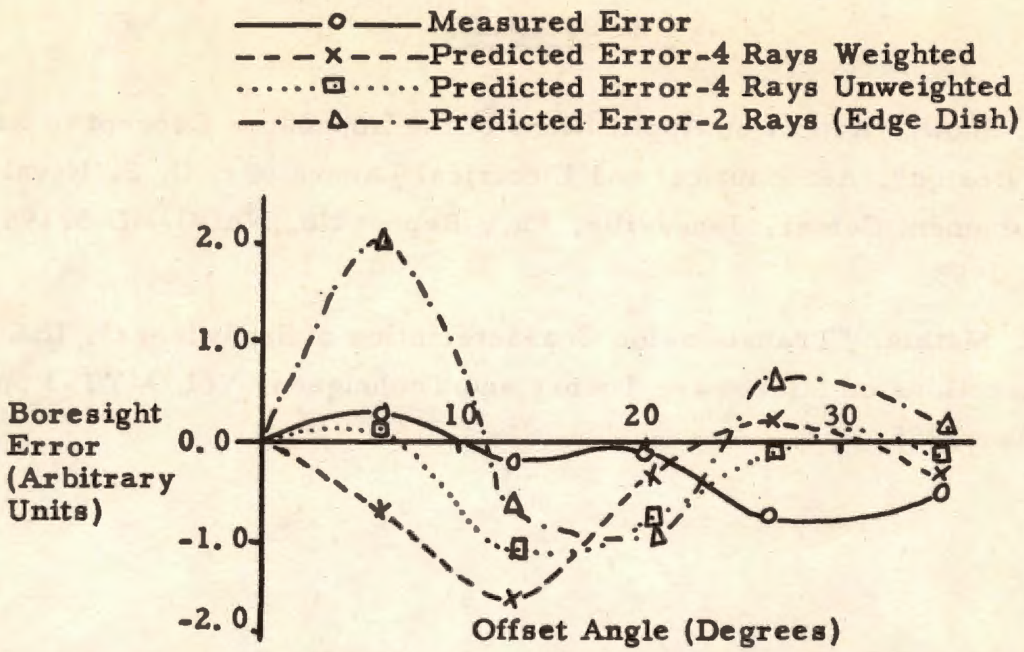

Figure 4 - Measured and Predicted Errors of Compensated Radome - Perpendicular Polarization

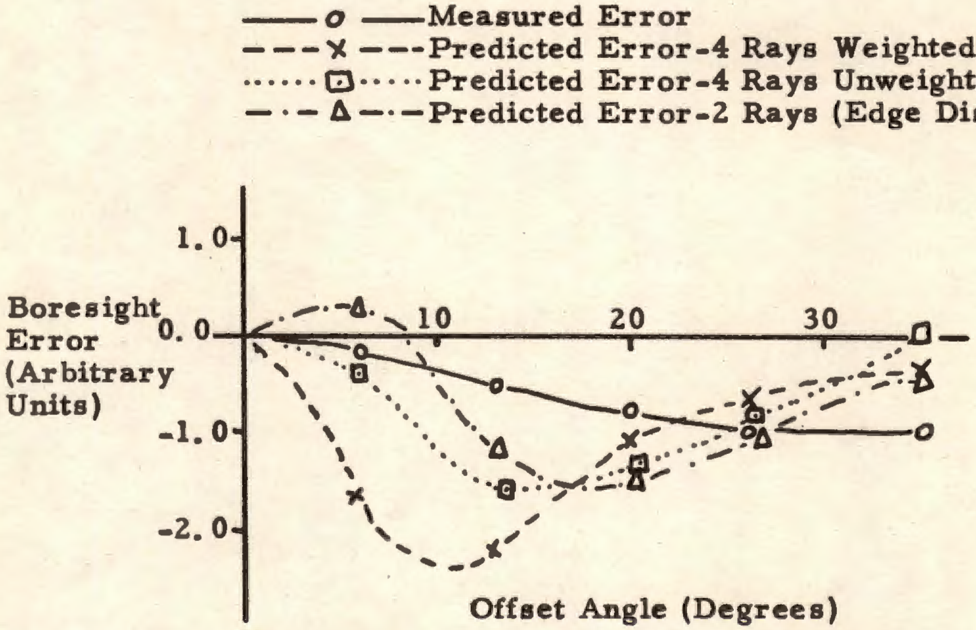

Figure 5 - Measured and Predicted Errors of Compensated Radome - Parallel Polarization

REFERENCES

(1) O. J. Snow, "Report on Applications of the Impedance Concept to Radome Wall Design", Aeronautical and Electrical Laboratory, U. S. Naval Air Development Center, Johnsville, Pa., Report No. NADC-EL-52196; April 1953.

(2) H. F. Mathis, "Transmission Characteristics of Sandwiches", IRE Transactions on Microwave Theory and Techniques, Vol. MTT-3 pp 57-58, October 1955.