MECHANICAL ALIGNMENT ERROR STUDY OF LARGE SECTIONALIZED COMPACT RANGE REFLECTORS

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ABSTRACT

Scientific-Atlanta has recently begun work on a large 55 ft.(W) x 45 ft.(H) compact range reflector. The reflector is a Model 5738 with a 45 ft. focal length and a 38 ft. diameter by 38 ft. long cylindrical quiet zone. Due to the large size of the reflector, it is necessary to form the surface as several large, independent sections and assemble and align the reflector at the installation site. The 5738 reflector is shown in Figure 1 with the 38 ft. quiet zone superimposed.

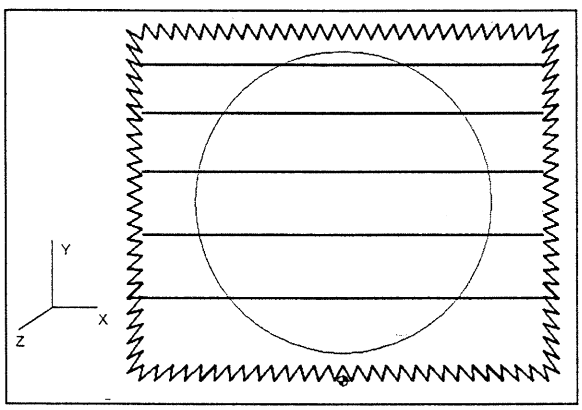

Figure 1. Front View of 5738 Reflector Showing Sections

The independent and predictable behavior of large sections proves to be very beneficial for performing an electrical alignment of the reflector based on field probe phase data. This paper discusses the required alignment tolerances and analytic tools developed to predict the effects on quite zone performance due to alignment errors in the sections of the reflector.

Keywords: Compact Range, Geometric Optics, Quiet Zone, Field Probe, Beam Deviation Factor.

1. Introduction

The standard Scientific-Atlanta compact range reflector is a continuous surface, offset fed paraboloidal reflector with serrated edges. It has long been the approach of Scientific-Atlanta to build continuous surface compact range reflectors as opposed to the small stretch formed panels or "bed of nails" approach used by others[1].

An advantage to a large continuous surface is that very little alignment is required other than locating the feed position and required feed tilt. Therefore, the quality of the quiet-zone field is largely dependent on the reflector surface accuracy and not the accuracy of the alignment. Due to shipping and handling size constraints, the Model 5738 reflector must be constructed from sections. The approach is to maintain as large a continuous surface as possible so that the reflector is composed of a small number of large, precision sections.

The assembly of a large reflector surface from large parabolic sections requires precision surface tolerances for each section and precise alignment of each section during assembly. During the surface finishing of the sections, the focal length must be held constant and the coordinate system must be translated correctly to each section.

The required alignment between the sections is a key concern for the installation. The possible errors in alignment of each section are translation and rotation. The frame support allows each section six-degrees of freedom. The translation of each section and rotation about the y- and z-axes can be easily aligned and set using gauge blocks and other mechanical alignment equipment.

The most troublesome source of error in the alignment is the rotation of each section about the x' axis, which is parallel to the x-axis. This scenario is shown in Figure 2. This tilt error directly effects the phase front in the quiet-zone by introducing a phase slope with the break point at the point of the section joint. As will be shown, the tolerance for the rotation around x' can be directly related to the phase taper specification for the compact range.

From Figure 2 we can see that tilting a section of the reflector by an angle α tilts the *z*-axis of that reflector section by the same amount above the primary *z*-axis. We will call this tilted axis the *z'*-axis. This tilt angle also rotates the surface normal vectors of the section by the angle α which means that the angle between the incident ray $\bar{i}'$ and the surface normal is increased by α. This steers the reflected ray off the *z'*-axis by α. Therefore, the total angle as referenced from the *z*-axis becomes 2α. This shows us that a tilt of α in one section of the reflector produces a slope in the quiet-zone phase of 2α.

The effect of the section tilt on the quiet-zone phase front is therefore analogous to an off axis shift of the feed location by the angle 2α and can be modeled using standard methods such as geometric optics[2] (GO) or physical optics (PO). We will develop the geometric optics expressions for the offset feed case and implement it in Matlab®. We will then confirm the GO model by physical optics simulation and finally by actual experimental data from measurements.

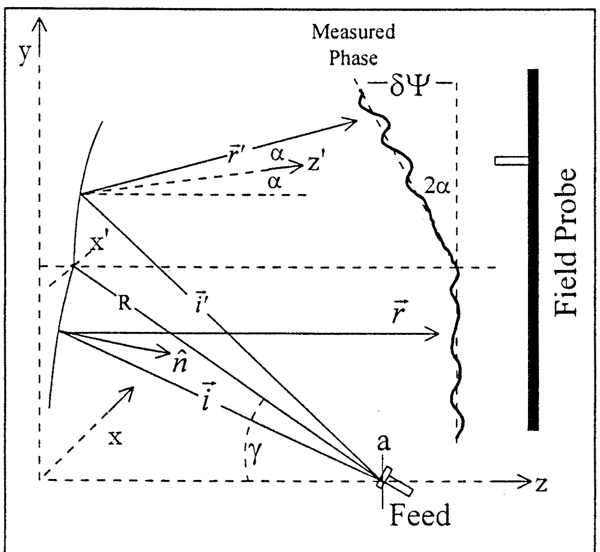

Figure 2. Reflector with Upper Section Tilted.

2. Analysis by Geometric Optics

Consider a parabolic reflector whose surface is given by $\xi = x^2 + y^2 - 4az = 0$, where *a* is the focal length of the reflector. The illumination vector from the focal point to a point P(x,y) on the reflector surface is, (1) $\bar{i} = x\cdot\hat{x} + y\cdot\hat{y} + (z-a)\cdot\hat{z}$. The magnitude of the illumination vector is,

(2) $|\bar{i}| = \sqrt{x^2 + y^2 + (z-a)^2} = z + a$, where

$$(3)\quad z = \frac{x^2 + y^2}{4a}$$

Now, if we consider a translation of the focal point by an amount (Δx,Δy,Δz), then the defocused illumination vector becomes:

$$(4)\quad \bar{i}' = (x-\Delta x)\cdot\hat{x} + (y-\Delta y)\cdot\hat{y} + (z-a-\Delta z)\cdot\hat{z}$$

with a magnitude of:

$$(5)\quad |\bar{i}'| = \sqrt{(x-\Delta x)^2 + (y-\Delta y)^2 + (z-a-\Delta z)^2}$$

The reflected rays can be written as (6) $\bar{r} = |\bar{r}|\cdot\hat{r}$. The unit vector $\hat{r}$ is in the direction of the reflected ray and is given by (7) $\hat{r} = \hat{n}\times\hat{i}\times\hat{n} - (\hat{n}\cdot\hat{i})\cdot\hat{n}$. The unit vector $\hat{r}'$ for reflected ray from a de-focused feed can be computed by replacing $\hat{i}$ with $\hat{i}'$ in (7).

The magnitude of the reflected ray, $|\bar{r}|$, is the path length from the reflector surface to the point at which the reflected ray intercepts the focal plane. The reflected ray magnitude is expressed as:

(8) $|\bar{r}| = \dfrac{a-z}{\hat{r}\cdot\hat{z}} = \dfrac{a-z}{\cos\phi}$ where ϕ is the angle between the reflected ray and the *z*-axis. By geometry we can write, $\cos\phi = \cos 2\alpha$. The surface normal vector is expressed as:

$$(9)\quad \hat{n} = \frac{-\nabla\cdot\xi}{|\nabla\cdot\xi|} = \frac{-x\cdot\hat{x} - y\cdot\hat{y} + 2\cdot a\cdot\hat{z}}{\sqrt{x^2 + y^2 + 4\cdot a^2}}.$$

We now have expressions for the incident and reflected rays for both a focused and de-focused reflector. We can check the focused case by adding $|\bar{i}| + |\bar{r}| = z + a + a - z = 2a$ which gives the familiar result of constant path length from the focal point to any point in the focal plane.

We are looking to keep the change in path length from the feed to the focal plane of the focused and de-focused cases to remain within the bounds of (10) $-\frac{\Delta\psi}{k} \le \Delta r_T \le \frac{\Delta\psi}{k}$. We will write Δr_T as the change in total path length from the focused case to the de-focused case or $\Delta r_T = r_T' - r_T$. Therefore,

$$(11)\quad \Delta r_T = |\vec{i}\,'| + |\vec{r}\,'| - |\vec{i}| - |\vec{r}| = |\vec{i}\,'| + \frac{a-z}{\cos 2\alpha} - 2a$$

We now have a compact expression for the change in path length for the defocused reflector. Remaining to be computed is Δx, Δy, and Δz so that (5) can be calculated. At the present we are only considering a rotation about **x'** therefore, $\Delta x=0\ \forall\ \alpha$. The focal shifts Δx, and Δz can be calculated by (12).

$$(12)\quad \Delta y = -R(\sin\gamma - \sin(\gamma - 2\alpha))$$
$$\Delta z = -R(\cos\gamma - \cos(\gamma + 2\alpha))$$

In (12), R is the path length from the focal point to the location of the rotation axis x' and γ is the angle from horizontal to R as shown in Figure 2. In the following section, we will use (11) and (12) to implement a geometric optics simulation via Matlab®

3. Simulation Results

In section 3.1 we model reflector tilts by inducing a shift of the feed off of the z-axis by the angle 2α. We will first use the geometric optics (GO) expression developed in (11). We will check the geometric optics approximation by a physical optics (PO) simulation. If the PO and GO simulations agree, then we have verified that the GO method is adequate for predicting phase of the focal region field and we will use the GO code to analyze the quiet-zone phase front since the GO code is orders of magnitude faster that the PO code.

3.1. Geometric Optics Model

The Matlab® code is shown in Figure 3. Simulation results are shown in Figure 4 for the Model 5712 reflector which has a focal length of 288" and a section joint approximately 91" above the vertex. From Figure 2, and using the focal length and section joint location, we can determine R≈295.2", and $\gamma\approx18°$. Therefore, from (12), Δy=-1.44" and Δz=-0.47". Using these numbers, the GO code predicts the change in path length as shown in Figure 4. The slope of this line is 0.276° which is approximately 2α. The difference is attributed to the beam deviation factor.[3]

```
function r=focus_shift(x,y,dx,dy,dz,a);
z=(x.^2+y.^2)/(4*a);
Ix=x; Iy=y; Iz=z-a;
IIx=x-dx; IIy=y-dy; IIz=z-(a+dz);
I=vecmag(IIx,IIy,IIz);
M=mdot(IIx,IIy,IIz,Ix,Iy,Iz);
r=I.*(1+(a.^2-z.^2)./M)-2.*a;
```

Figure 3 Matlab GO Code

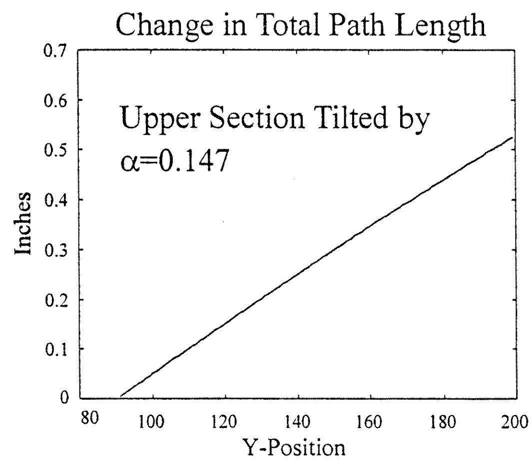

Figure 4 Total Change in Path Length for 5712 Reflector with Upper Section Tilted.

3.2. Physical Optics Model

To verify the reflector behavior predicted by GO, the Scientific-Atlanta PO code[4] was modified for to model reflectors with sections tilted about x'. The PO code was used to predict the performance of the Model 5738 reflector for section tilts at each section joint shown in Figure 1. A typical case at 8 GHz for

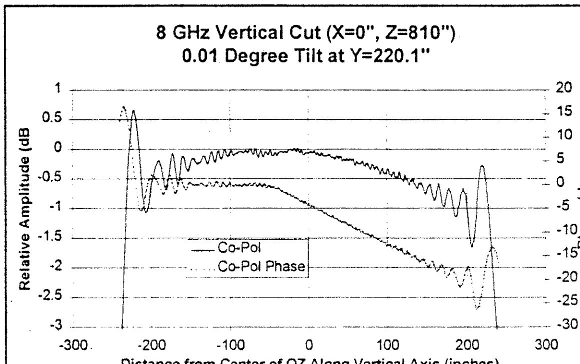

Figure 5 Tilt of 0.01 deg at 2nd Section Joint of 5738 Reflector

a tilt of 0.01° at the second joint, 50" below the center of the quiet-zone (y=220.1"), is shown in Figure 5. From the phase slope, the tilt angle of the reflector can be calculated as (13) $2\alpha = \tan^{-1}(\frac{\delta\psi \cdot \lambda}{360h})$, where $\delta\psi$ is the phase run-out in degrees across the focal plane, and h is the height of the tilted reflector section. In Figure 5 we can see that $\delta\psi \approx 25°$, and $h \approx 300$ inches. For this example the calculated tilt, using (13), is α=0.0098. Again, the 2% error can be attributed to beam deviation factor.

4. Measurement Results

An experiment was conducted on a Scientific-Atlanta Model 5712 two section reflector to verify the PO and GO simulations. The Model 5712 reflector was fitted with an inclinometer on the upper section and the section was rotated away from the feed in the increments of approximately 0, 10, 20, 40, 90, 180, 270, 360 arc-sec. The position error of the field probe was measured and k-correction applied to the processed data. A typical case for measured α=0.01472° is shown in Figure 6. From the phase slope in Figure 6, Equation (13) predicts α=0.01346.

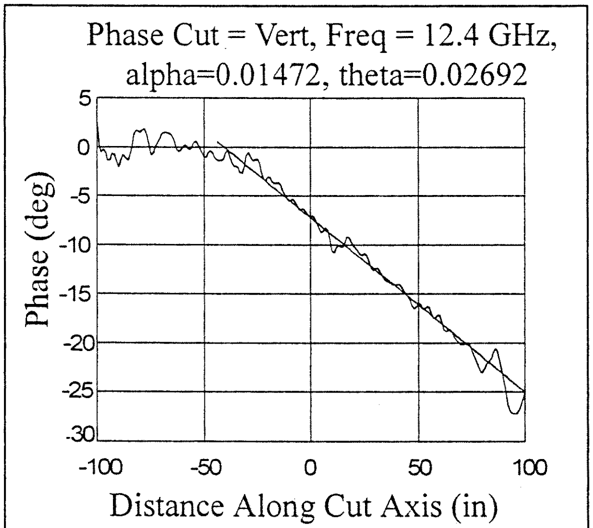

Figure 6. Phase Probe Data for Model 5712 Reflector with Upper Section Tilted.

The reflector behaved as predicted down to tilt angles as small as 0.005°. For smaller angles, the accuracy of the true tilt vs. measured tilt and the phase measurement noise prevented us from accurately determining the slope of the phase break.

5. Summary

We have shown that the reflector alignment error can easily be predicted by phase probe measurements of the quiet-zone phase. The 2x magnification effect of tilt increases the sensitivity for determining small reflector tilt angles with the phase probe data.

We have shown that the geometric optics method does an adequate job of predicting the phase in the focal region of the field. We have also presented the simple relation of (13) to predict the tilt angle from a measured phase run-out error in the quiet-zone.

Based on measurement results, we feel we will be able to successfully align the Model 5738 reflector electromagnetically using field probe phase data. Alignment is possible to within 0.005° which will produce no more than 5°-6° of phase error in the quiet-zone.

During the installation of the Model 5738, a laser tracking system will be used to align key points on the reflector surface to the desired parabolic shape. After all of the reflector sections have been rough aligned with the laser tracking system, vertical and horizontal field probe measurements will be made to determine the quiet-zone phase front.

The field probe data will be used to calculate alignment error between the reflector sections and the reflector will be adjusted accordingly. An iterative process will continue until the phase is within the specification in the horizontal and vertical planes. At that time field probe measurements will be made on a polar grid where the linear axis of the phase probe is rotated about the phi axis in increments of 15°.

6. References

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