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Produced by the NASA Center for Aerospace Information (CASI)
DSN 100-Meter X- and S-Band Microwave Antenna Design and Performance

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August 1, 1978

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ABSTRACT

This report covers the studies made of the RF performance of large reflector antenna systems (100 meters) when using the high efficiency dual shaped reflector approach. The JPL Shaping Program has been updated to obtain more accurate results and to permit the shaping calculations of very large systems. A new technique was added to also improve blockage efficiency and a new program was prepared which altered phase so that the scattered field from a shaped surface could be used in the JPL efficiency program.

A new dual band (X-S) microwave feed horn is used in the shaping calculations. A great many shaping calculations were made for various horn sizes and locations and final RF efficiencies are reported. A conclusion is reached that when using the new dual band horn, shaping should probably be performed using the pattern of the lower frequency.
1.0 INTRODUCTION

This report presents detailed results of a study to define microwave performance of a very large aperture system, 100 meters in diameter, operated at X- and S-bands with a common aperture feedhorn. Because it is cost effective, the maximum possible aperture efficiency (effective collecting area) is sought, especially at X-band for the future DSN high rate telemetry requirements. While seeking maximum efficiency, the related rear spillover, which contributes to system noise temperature, must be, and is, carefully considered.

In related studies, an overall microwave aperture efficiency of 75% at X-band appeared feasible. 75% includes the RF optics efficiency, which is addressed in this report and is typically 92-94%, a small term due to dissipative losses, as well as RF surface tolerance efficiency and RF blockage (feed support) efficiency. This report will not consider the dissipative losses nor the latter two factors which are a function of detailed structural design.

The first step in achieving high aperture efficiency is to obtain a uniform illumination across the reflector aperture, for maximum illumination efficiency, while at the same time maximizing all other efficiencies, i.e., reducing or nearly eliminating forward spillover from the cassegrain system and reducing rear spillover, while maintaining the (generally already high) remaining efficiencies of a standard cassegrain system: feed phase efficiency and cross-polarization efficiency.
The special shaped dual reflector antenna system is the solution selected to obtain the very high illumination efficiency. This technique was developed about 15 years ago and JPL has had a computer program for obtaining special shaped solutions for over 10 years [1,2]. Conventional (generally wideband) feedhorn technology is compatible with this synthesis. The object of this study is to update the dual shaped reflector program and exercise it for various feed horn and antenna parameters and various frequencies and obtain practical designs and design variations which achieve very high overall efficiencies.
2.0 SUMMARY

2.1 Program updating. When the shaping program was first used for 100 meter X-band synthesis, some shortcomings became evident. The program had not before been used on such a large (D/λ) reflector and the calculations of coordinates for the subreflector were not complete as a result. In this case, subreflector coordinates were not established all the way to the reflector axis of symmetry and these final points were determined by extrapolation of data near the axis. The result was a near flat or mirror-like subreflector in the central region with an undesirable peak of energy illuminating the primary reflector in its central region.

The program has been revised and now obtains accurate coordinates throughout this central region and also at the outer edge.

2.2 An Added Program Capability. A facility was added to the shaping program for obtaining a null in the central region of the illumination pattern. One chooses to do this to avoid significant illumination energy across that area which is blocked by the subreflector. Hence the blockage efficiency may be greatly increased, becoming greater than 99% for the large dual reflector systems. Additional benefits accrue in the far field; improved pattern response and reduction of large antenna self-multipath, a consideration in precision ranging and VLBI systems.

2.3 A New Program. A new computer program was written for making phase adjustments to the calculated scattered field from the shaped subreflector. This is necessary if the scattered pattern is to be used in the standard JPL efficiency calculation program. The scattered field from the subreflector (quasi-hyperboloid) illuminates the main reflector
(quasi-paraboloid). This near-uniform field has a large variation of phase, dependent upon reflector size. This variation is "corrected" by the quasi-paraboloid so that a uniform phase results across the final planar aperture of the quasi-paraboloid. In the true cassegrain antenna (the paraboloid/hyperboloid), this phase variation does not occur since geometrical path lengths are all equal, which is the fundamental cassegrain principle. The JPL efficiency calculation program is based upon the illumination of a paraboloid, so that exact uniform phase would yield a 100% phase efficiency. The normal phase variations that result from diffraction in the physical scattering result in a small reduction of this efficiency. If the scattered pattern from the quasi-hyperboloid is to be properly used in this efficiency calculation, then the correction of phase by the quasi-paraboloid must be included, without destroying the phase variation or ripple resulting from the physical optics.

The original shaping computer program included an output which determined these phase corrections for a scattered pattern. However, certain program assumptions made were not accurate enough for the large systems of this study and so this correction could not be used. Therefore, the true theory was determined without assumptions and an absolutely accurate program was prepared; the illumination patterns may now be properly evaluated.

2.4 An extensive study of shaping, using the various programs mentioned above, has been made. All samples were of an 100 meter system at X-band and S-band. Various sizes of the large dual band X-S horns were used in the study and applied in systems with a range of appropriate main reflector F/D ratios. Only the microwave optics efficiencies are considered; dissipation losses, surface accuracy and feed support blockage
as mentioned are not included in the study. Results will be tabulated in this report.

In general, central blockage efficiency can be made higher than 99% for the X-band cases by using the shaping synthesis with an axial null in the final illumination. Efficiencies are a bit less at S-band, going to 98.5%. Overall efficiencies of 96% are available at X-band, but with poorer rear spillover (hence noise) at S-band. When considering both bands, some compromise must be made and a typically good result would be 94% at X-band with rear spillover noise of only 0.15 K, and on the same antenna an S-band efficiency of 92% with rear spillover noise of 3.0 K.
3.0 THE PROGRAM AND TEST CASES

The following sections will discuss the work performed in designing various high efficiency 100 meter dual reflector systems. The shaping program will be described and modifications to it which were necessary for this study of very large apertures. This will then be followed by a discussion of a new computer program used to alter phase, a description of feed horns, and samples of near-final designs.

3.1 The Dual Reflector Shaping Program

The JPL dual reflector antenna shaping program is the result of work done prior to 1965. (1,2). The geometry of the problem is illustrated in figure 3-0. The main reflector shape is defined in the cartesian system (x,y), and the subreflector shape is described in the polar system (r, 0). The geometry is axisymmetric about the optical axis y. The theory is purely geometrical optics (ray tracing).

Conceptually the working of the program (SHAPER) is as follows:

1. An axisymmetric feed horn pattern is determined and an axial phase center location chosen. The feed pattern is internally represented by piecewise linear interpolation tables in $\theta$ both for intensity, $F(\theta)$ and relative phase, $\phi(\theta)$.

2. An outer radius, $x_{\text{max}}$, is chosen for the main reflector and the reflector outer edge is positioned at $x = x_{\text{max}}$, $y(x_{\text{max}}) = 0$. An inner (termination) radius, $x_{\text{min}} > 0$, is also chosen.

3. A corresponding outer radius and location for the subreflector are also chosen, $r(x_{\text{max}})$ and $\theta(x_{\text{max}})$.

*This section and section 3.2 are a result of efforts by L.D. Howard, Programming Consultant to JPL SEC. 333. Mr. Howard is presently a member of JPL Section 366.
4. The starting conditions are now defined and the problem solution
can proceed. The shape of both reflectors will be determined provided we take
x as an independent variable and can write down equations for the three remaining
variables y, r, e as functions of x. For instance,

\[ y(x) = - \int_{x_{\text{max}}}^{x} \frac{dy}{dx} \, dx + y(x_{\text{max}}) \quad x_{\text{max}} \geq x \geq x_{\text{min}} \]

\[ r(x) = - \int_{x_{\text{max}}}^{x} \frac{dr}{dx} \, dx + r(x_{\text{max}}) \quad x_{\text{max}} \geq x \geq x_{\text{min}} \]

\[ e(x) = - \int_{x_{\text{max}}}^{x} \frac{de}{dx} \, dx + e(x_{\text{max}}) \quad x_{\text{max}} \geq x \geq x_{\text{min}} \]

To determine the three unknown derivatives there must be auxiliary
conditions (constraints). Refer again to figure 3-0, and note the typical ray
shown finally impinging on the x axis at radius x. The first condition is that
the angle of incidence with the x axis may be chosen as a function of x; it is
made always perpendicular, thus giving a beam parallel to the y axis.

The second condition is that the length of the ray shown may be
chosen as a function of x; the choice is that all internal rays have the same
length as the peripheral ray passing thru \( r(x_{\text{max}}), e(x_{\text{max}}) \), \( x_{\text{max}}, y = 0 \). Since all path lengths across the aperture are equal the system introduces no
phase distortion (at any frequency).

The third condition is that the beam intensity may be chosen as a
function of x across the aperture. Beam intensity is chosen constant to produce
uniform illumination, a condition for optimal antenna efficiency.
The detailed derivation of equations 3-0 subject to these constraints was given by Williams in 1965. The original JPL SHAPER program did a direct solution of these coupled equations by numerical integration. Large antenna design resulted in several modifications to this approach.

**Modifications to SHAPER**

The total beam intensity is proportional to

\[
\int_{x_{\text{min}}}^{x_{\text{max}}} e(x_{\text{max}}) dx = F(\theta) \sin \theta,
\]

thus

\[
C_2 = \frac{2}{x_{\text{max}}^2 - x_{\text{min}}^2} \int_{x_{\text{min}}}^{x_{\text{max}}} F(\theta) \sin \theta dx,
\]

and

\[
C_2 \int_{x_{\text{min}}}^{x_{\text{max}}} x dx = F(\theta) \sin \theta
\]

or

\[
\frac{d\theta}{dx} = \frac{C_2 x}{F(\theta) \sin \theta}
\]

and finally we note that \( \theta(x) \) may be determined from the integral equation

\[
\int_{x_{\text{min}}}^{x} F(\theta) \sin \theta dx = C_2 \int_{x_{\text{min}}}^{x} x dx = \frac{C_2 (x^2 - x_{\text{min}}^2)}{2}
\]
Most of the problems found in the original program were related to the above equations (2). \( C_2 \) is a very important constant since it determines the correspondence between \( \theta \) and \( x \) (2d and 2e). In the old program, equation (2d) was numerically integrated by the trapezoidal rule, with up to 1\% error possible. The resulting problem was that the integration of equations (1) would "use up" intensity at the wrong rate, and as the solution neared the \( y \) axis the solution would "blow up". In addition equation (2d) is not suitable for integration near the axis (\( x \rightarrow 0, \theta \rightarrow \infty \) gives \( d\theta/dx \rightarrow \infty \)). Very small errors in \( x \) and \( \theta \) near the axis can cause \( d\theta/dx \) to be undefined (e.g. anywhere between \( \infty \) and 0).

The old program "solved" these problems by stopping the integration early (before it blew up) and then extrapolating the solution inwards. This patching did not show up on small or medium size antennas because it seldom involved a region of more than a square wavelength (at the center) and thus was masked in scattering studies. On large antennas the "patched" region was many wavelengths in extent and showed up as distinct axial anomaly in the scattered field patterns.

In the new version of the program the integral (2b) is done analytically which gives an accurate value for \( C_2 \). In addition \( \theta(x) \) is no longer determined by integration of (2d) but rather from relation (2e). This change not only improves the accuracy of \( \theta(x) \) but also of \( y(x) \) and \( r(x) \) since the number of coupled differential equations to be integrated (1) is reduced from 3 to 2. Lastly, the numerical integrator was replaced with a more accurate and efficient version in the JPL Library.

The accuracy of the resulting shapes is now felt to be on the order of the cumulative rounding error of the 1108, which for the large antenna problems would be \( \leq 10^{-3} \) inches. A definitive test of accuracy would be to rewrite the whole program in double precision, or to run on a longer word length machine (i.e. CDC 6600). To date this has not been done.
3.2 **A New Program Feature**

In the previous two sections we have made explicit mention of a lower limit to the main reflector radius, \( x_{\text{min}} \). This is the point at which a ray passing along the y axis from the horn, to \((\theta(x_{\text{min}}) = 0, r(x_{\text{min}}))\) on the subreflector, would strike the main dish. In Williams' original paper (1) and the old version of the program it was assumed that \( x_{\text{min}} \) would always be zero.

During the rewrite of the program it became obvious that the only requirement on \( x_{\text{min}} \) was \( 0 \leq x_{\text{min}} \leq x_{\text{max}} \). Non-zero \( x_{\text{min}} \)'s produce a uniform illumination just as before but only for \( x \) in the range \( x_{\text{min}} \leq x \leq x_{\text{max}} \). For \( x \) in the range \( 0 \leq x \leq x_{\text{min}} \) there is a pure geometric shadow. Diffraction effects modify this somewhat, but this new design variable has proved very useful, as this paper will illustrate. The complete listing of this new shaping program is given in Appendix A.

3.3 **Phase adjustment for efficiency calculation**

The scattered pattern from a typical shaped subreflector (quasi-hyperboloid) has a monotonically changing phase value, as opposed to the uniform phase obtained with the scattered pattern from a cassegrain hyperboloid. This changing phase is then altered, or "corrected," by the primary reflector to obtain the required uniform phase front.

A JPL computer program is designed to calculate paraboloid antenna efficiency as functions of the illuminating pattern [4]. These efficiencies are (1) spillover efficiency, (2) illumination efficiency, (3) cross polarization efficiency, (4) blockage efficiency (5) mode efficiency, and (6) phase efficiency. For the paraboloid, a uniform phase is required for 100% phase efficiency since the parabola simply alters the incident spherical phase pattern to produce a uniform phased aperture. The small phase
variations resulting from the diffraction by the subreflector results in phase efficiencies slightly below 100%. In the case of the dual shaped reflector system, all the above efficiencies calculate the same when using the efficiency program except the phase efficiency. For this efficiency, a geometrical phase correction must be used to alter the incident pattern just as the quasi-paraboloid does, without altering the normal diffraction phase ripple. In this case then a proper phase efficiency is obtained using the standard JPL paraboloid efficiency program.

The original shaping program provided geometrical path lengths and phase values to perform this alteration for phase efficiency calculation. However, although this straightforward approach was sufficient for smaller systems, its approximations failed for the large 100 meter system. Therefore a new and more accurate program was prepared to make this correction.

3.3.1 The "Shaperphase" program

Figure 3-1 presents the geometry used to determine the new phase alteration. Referring to this figure, the scattered pattern of the feed at focus "F" from the quasi-hyperboloid has its phase center shifted to some quasi-focus, a selected point "A." The far field phase pattern calculated then exists on some spherical surface at radius R about point A. These phases are tabulated at angular positions, θ_j. For each θ_j, there are reflector coordinates x_j, y_j for point "j", and this point is adjacent to reflector coordinates N and NN on each side of "j." These points, N and NN, each have angles defined, β_n and β_{nn}, which are the geometric directions of rays from the subreflector. These directions therefore represent the directional source of the phase data. The phase, ϕ_j, to be associated with the angle θ_j is not ϕ(θ_j) but is instead ϕ(β_j). The procedure then is as follows: Determine the point x_j, y_j, and β_j by interpolation between the points N and NN. Also determine the point x', y' on the reference sphere.
Now the phase on the sphere $\phi(\beta_j)$, is interpolated between the two adjacent tabulated values of phase, $\phi(\beta_j^+)$ and $\phi(\beta_j^-)$. A radial correction is then applied to $\phi(\beta_j)$ by the length, $\Delta R$ (phase advance).

$$\Delta R = R - x_j / \sin \beta_j - Z_j \cos \beta_j$$

where $Z_j$ has been determined:

$$Z_j = B + y_j - x_j / \tan \beta_j$$

A further length correction $y_j$ (phase retarded) is then applied to bring the final phase to the planar region across the front of the primary reflector. Of course, all these distances are translated to wavelengths and phase angles.

A similar correction is made to the amplitude function, $E$ at $\theta_j$. This is not as significant since this function varies very slowly. Amplitudes are translated from the value tabulated, $E$ at $\theta_j$ to the new value $E(\beta_j)$, again by interpolation between $E(\beta_j^+)$ and $E(\beta_j^-)$.

A program was prepared which obtained these values $x_j$, $\beta_j$ and finally the phase alteration. This is used with the scattered field output which determines a slightly modified new amplitude output and a nearly uniform phase, but one which still carries the variations caused by diffraction. This can then be used directly in the efficiency program to determine the final antenna characteristics. This program is listed in Appendix B.

### 3.4 Results of Antenna Calculations.

Many sample problems were solved in determining the parameter ranges for the 100 meter antenna, and in modifying the shaping program and developing the new phase alteration program. The final results of these very many tests will be discussed.
3.4.1 The Feed Horns

All sample designs and calculations in this study were done for the dual frequency application, S-band (2.1 to 2.4 GHz) and X-band (7.1 to 8.5 GHz). For this application, a new dual band horn technique, (3)(5), was used to feed and then determine the S- and X-band performance of the 100m system. A horn of this type is being used in a new X-S feed horn development for use at DSS 13 and possibly other antennas. A photograph of the horn is shown in figure 3-2. Most of the shaping calculations were made using the X-band pattern; however two were made using the S-band pattern and will be discussed later.

Figure 3-3 presents the horn geometry. For corrugated horn performance (very low sidelobes, equal E and H plane patterns) the grooves must be from $\lambda \left( \frac{2N-1}{4} \right)$ to $\lambda \left( \frac{2N+1}{4} \right)$ deep, where $N$ may assume any integer value. Grooves input impedance is then capacitive and fields are forced away from the walls; wall currents are reduced.

As the aperture diameter becomes larger, the pattern beamwidth becomes independent of aperture size (and frequency) and is only a function of the flare angle, $\theta$. This independence, or "beam saturation," occurs in the region when "$\Delta$" becomes greater than about 0.75 (6). (See figure 3-3.) In this case we have at least two phase reversals across the horn aperture. As the aperture becomes larger, the number of phase reversals will increase and the general pattern texture will change, but not the approximate beamwidth or gain. The chart below illustrates this point.

<table>
<thead>
<tr>
<th>$\theta$</th>
<th>$D$</th>
<th>$\Delta(2.295)$</th>
<th>$\Delta(8.415)$</th>
<th>10 dB-Beamwidth</th>
<th>20 dB-Beamwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>$14^\circ$</td>
<td>67&quot;</td>
<td>0.80</td>
<td>2.94</td>
<td>$10.49^\circ$</td>
<td>10.19$^\circ$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13.57$^\circ$</td>
<td>15.64$^\circ$</td>
</tr>
</tbody>
</table>

A $14^\circ$ horn with 67 inch aperture (used in some following calculations) is just large enough at S-band, $\Delta = 0.80$, to reach saturation. The 10 dB
beamwidths are very similar while the 20 dB beamwidths are different, indicating
different pattern texture. As the aperture is made much larger, \( A \) will become
greater in S-band and patterns will more closely resemble each other, at \(-20 \) dB
also. Figures 3-4 and 3-5 are the calculated patterns for this horn. It is
apparent that as flare angle \( \theta_0 \) is reduced, the horns must become very large
to achieve this beamwidth independence.

Dual band horns with flare angles from 9 degrees through 17 degrees
were used in the shaping and efficiency calculations during this study.

3.4.2 100 Meter Dish Configurations

Success of special antenna shaping to achieve high overall efficiency
depends upon obtaining high efficiency results for each of the various components
that make up the final result. The first efficiency component that has a
significant effect on the choice of configuration in the dual shaping approach
is the forward spillover efficiency, \( \eta_{FS} \). As the subreflector is enlarged to
capture more of the main horn beam, forward spillover efficiency increases
since less energy is allowed past this reflector. However, two factors are
working against any attempt at capturing all energy between the first nulls for
a near 100% efficiency in the case of the dual band horn. These are (1) extreme
shaping required to hold the uniform illumination will result in radii of
curvature unsuited to the geometric optics assumption and (2) horn phase patterns
behave radically near these null regions; shaping programs are based on uniform
horn phase and though a slight variation in phase can be ignored, larger ones
may result in a poor final phase result.

The shaping program could (and once did) provide a shaping correction
to account for this rapid phase change near the null region. However, this has
the disadvantage of limiting the shape to the one single horn at one frequency
only. Other similar horns would have very restricted use. Therefore, through-
out this study, an exactly uniform horn phase has been assumed.
A reasonable and practical choice for this spillover efficiency value based on calculation experience, and experiment, is about 99%. This is not to say that 99.5%, or even a bit more, is not reasonable but that 99% will give good overall results and allow one to define some configuration limits. A greater efficiency, 99.8% or so, would represent an extreme taper upon the subreflector edge and could lead to the shaping extremes unsuited to the geometrical optics approach.

Therefore a value, $\eta_{fs}$, of 99% will be chosen in order to define some configurations that will result from using a selection of dual X-S band horns. The 99% number will mean a taper of about 19 dB onto the subreflector edge when using this horn concept.

Figure 3-6 presents the general configuration of the special shaped antenna system. Note that "F/D" is defined directly by the dish depth and diameter; this is because the system does not have a definable focal position. Also note that for the dual band horn, the phase center is generally far back in the horn throat, in the vicinity of the horn vertex. The chart, figure 3-7, presents the calculations for configuration parameters when considering three choices of horn size, three approximate "F/D" values, and illumination tapers to provide a 99% forward spillover efficiency in the X-Band.

Figures 3-8 and 3-9 present much of this data in graph form. What one observes is that if a horn location near the vertex is desired, then the smaller flare angles (large horn) and smaller "F/D" values (a "deeper" main reflector) are required.
It must be emphasized that these values are only design guides. They depend entirely on the illumination angle "a" giving $\eta_{FS} = 99\%$. When a slightly different subreflector/main reflector diameter ratio is chosen (0.1 was used here), then different parameters will result. However, for practical systems, the parameters will remain very near to those indicated by the graphs.

3.4.3 **Some Samples of Shaping and Efficiency**

As was mentioned above, many test cases were calculated for shaping, scattering, and efficiency for horn sizes from 17 degrees down to 9 degrees, using no central hole cutout to reduce blockage and using control hole cutouts that equaled subreflector size down to about 0.8 of subreflector size. The shaping was nearly always done using the X-band pattern (for optimum X-Band performance) and scattering of both X- and S-Band was calculated.

All results had much in common, with only slight variation. (1) Best X-Band efficiency would approach 96\% with low rear spillover, less than 1.0 Kelvin; (2) generally the S-band performance would be poorer, in the region from 90\% to 92\%, with probably unacceptably higher rear spillover, about 6.0 to 8.0 Kelvin. The remainder of the report will deal with near final designs, using a 14 degree horn in an F/D ~ 0.325 system and an 11 degree horn in an F/D ~ 0.4 system.

**The 14-Degree Horn at 14-Degree Taper, X-band Shaping**

Figure 3-10 indicates the design dimensions when using the X-band horn pattern for the shaping calculations. The horn patterns of figure 3-4 and 3-5 are scattered from this shaped subreflector and the efficiencies are calculated. The taper at the edge of the subreflector is -21.54 dB in X-band and -16.67 dB in S-band. Forward spillover is then 99.49\% in X-band and 96.35\% in S-band. Following are the results for the 100 meter antenna.
and this typifies X-band shaping. Although efficiencies are probably acceptable in both bands, one would like to reduce the S-band rear spillover and hence the noise contribution. The scattered patterns are shown in figure 3-11 (a), (b), (c), and (d). These are fine illustrations of placing a null in the center of the illumination pattern. It can be seen that the X-band synthesis produces a deep distinct central null region. At S-band, it is not as effective, but still useful. Note in figure 3-10 that the angle \( \theta_1 \) defines a reflector radius of 1931 inches (49.05m) which is in line with the subreflector edge. This is the maximum extent to which the shaping is carried. The reason: When the feeding pattern is scattered from the subreflector (physical optics) the angle of final maximum efficiency and also acceptably low rear spillover (for low noise) occurs beyond the value of \( \theta_1 \), usually about 1 degree greater. For this reason, a slightly smaller reflector is chosen which, when increased in size to 100 meters, will be about right for acceptable rear spillover and nearly maximum overall efficiency.

The technique for defining the coordinates of the outer 1 meter of radius has not been developed as yet. It is assumed that this can be done without causing any additional phase error in the final illumination pattern, i.e. holding phase efficiency to its value at \( \theta_1 \).
At this point, it occurs to do the shaping synthesis at S-band to improve S-band spillover, and observe the final results on X-band.

**The 14-Degree Horn at 14-Degree Taper, S-band Shaping**

The feed chosen for this S-band shaping is the one just discussed; one simply uses the S-band radiation pattern as input to the shaping program. Since the 14 degree edge taper is only -16.67 dB at S-band, the "sharpness" of shaping, or variation from the hyperboloid should be different. Edge illumination remains, of course, the same in X-band as in the example above and forward spillover will remain unchanged.

Figure 3-12 indicates the design configuration for the 14 degree horn using its S-band pattern for the shaping calculations. The same horn patterns (figures 3-4 and 3-5) are now scattered from this slightly different shape and the resulting efficiencies are calculated. The following results for the 100m antenna:

<table>
<thead>
<tr>
<th></th>
<th>( f = 8.415 \text{ GHz} )</th>
<th>( f = 2.295 \text{ GHz} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \eta_{fs} ) (forward spillover)</td>
<td>0.99490</td>
<td>0.96345</td>
</tr>
<tr>
<td>( \eta_s ) (rear spillover)</td>
<td>0.99939 (0.15 Kelvins)</td>
<td>0.98658 (3.22 Kelvins)</td>
</tr>
<tr>
<td>( \eta_l ) (illumination)</td>
<td>0.96987</td>
<td>0.99025</td>
</tr>
<tr>
<td>( \eta_{ph} ) (phase)</td>
<td>0.99311</td>
<td>0.99356</td>
</tr>
<tr>
<td>( \eta_b ) (blockage)</td>
<td>0.99264</td>
<td>0.99068</td>
</tr>
<tr>
<td>( \eta_x ) (cross-pol)</td>
<td>0.99980</td>
<td>0.99950</td>
</tr>
<tr>
<td>( \eta_t ) (total)</td>
<td>0.95045</td>
<td>0.92601</td>
</tr>
</tbody>
</table>

These are to be compared to the figures above. X-band efficiency has been decreased by about 1%; S-band efficiency is increased by more than 1% and S-band rear spillover (noise) is significantly reduced. The cause of X-band reduction is seen in the fall off of illumination efficiency, as expected.

The scattered patterns for this example are shown in figure 3-13 (a), (b) (c), and (d).
By looking at these patterns at slightly greater angles (or changing geometry a trifle) different efficiencies can be obtained so that one may "optimize" the trade-off between X- and S-band, depending upon requirements. For instance, at 74 degrees on the illumination patterns, (a 102.2 meter antenna) the following efficiencies result: (remembering that a technique has not yet been developed which permits the calculation of coordinates for the larger dishes, beyond $\theta_1$).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$f = 8.415$ GHz</th>
<th>$f = 2.295$ GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta_F$ (forward spillover)</td>
<td>0.99490</td>
<td>0.96345</td>
</tr>
<tr>
<td>$\eta_S$ (rear spillover)</td>
<td>0.99975 (0.06 Kelvins)</td>
<td>0.99402 (1.44 Kelvins)</td>
</tr>
<tr>
<td>$\eta_i$ (illumination)</td>
<td>0.94172</td>
<td>0.97952</td>
</tr>
<tr>
<td>$\eta_{ph}$ (phase)</td>
<td>0.99311</td>
<td>0.99356</td>
</tr>
<tr>
<td>$\eta_b$ (blockage)</td>
<td>0.99264</td>
<td>0.99070</td>
</tr>
<tr>
<td>$\eta_x$ (cross-pol)</td>
<td>0.99980</td>
<td>0.99950</td>
</tr>
<tr>
<td>$\eta$ (TOTAL)</td>
<td>0.92320</td>
<td>0.92290</td>
</tr>
</tbody>
</table>

The X-band efficiency has reduced by about 3% while S-band remains about the same. The reason; the X-band illumination is reducing rapidly and the reduction in S-band illumination is nearly compensated by S-band rear spillover improvement. Note the S-band noise is becoming acceptably low. Carrying this approach farther is futile. Although S-band noise does continue to reduce, the falloff in overall efficiency increases rapidly to unacceptable levels.

The 11-deg. horn at 11 deg taper, S-band shaping

One further problem was solved to see if a gross change in F/D ratio would alter these general results of S-band spillover. Therefore, an 11 degree horn at 11 degree taper in a shallow dish, F/D $\sim 0.4$ was investigated. Such a configuration results in a feed focal point that is about the same distance from dish vertex as the previous two examples (see figure 3-14).
S-band taper is now -16.54 dB and X-band taper is -21.57 dB. Forward spillover becomes 99.46% at X-band and 96.09% at S-band. Following are the efficiency results at 100 meters, to compare directly to the 100m, 14 deg. problem.

<table>
<thead>
<tr>
<th></th>
<th>$f = 8.415$ GHz</th>
<th>$f = 2.295$ GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta_{fs}$ (forward spillover)</td>
<td>0.99457</td>
<td>0.96093</td>
</tr>
<tr>
<td>$\eta_s$ (rear spillover)</td>
<td>0.99913 (0.21 Kelvins)</td>
<td>0.98631 (3.29 Kelvins)</td>
</tr>
<tr>
<td>$\eta_{il}$ (illumination)</td>
<td>0.96795</td>
<td>0.98956</td>
</tr>
<tr>
<td>$\eta_{ph}$ (phase)</td>
<td>0.99122</td>
<td>0.99058</td>
</tr>
<tr>
<td>$\eta_b$ (blockage)</td>
<td>0.99106</td>
<td>0.98582</td>
</tr>
<tr>
<td>$\eta_x$ (cross + pol)</td>
<td>0.99980</td>
<td>0.99950</td>
</tr>
<tr>
<td>$\eta$ (TOTAL)</td>
<td>0.94470</td>
<td>0.91541</td>
</tr>
</tbody>
</table>

and the results are not significantly different from the above case of the 14 deg horn with 3.22K rear spillover in S-band. These patterns are shown in 3-15 (a), (b), (c), and (d).

3.5 **A Larger Horn**

The above results were obtained by using a dual-band horn that barely qualifies, i.e., "$\Delta$" is approximately 0.8 (see section 3.4.1, figure 3-3). As "$\Delta$" is made larger at S-band, the horn pattern at S-band will change rapidly and approach the X-band pattern for the larger horns. Although the X-band pattern will also slowly change, final results will become closer as "$\Delta$" becomes large.

Figure 3-16 presents this 14 degree horn pattern as the aperture enlarges to 120 inches, and $\Delta$ becomes 1.43. This is to be compared to figure 3-5, the 67 inch aperture, $\Delta = 0.80$. The pattern has "squared up" and becomes comparable to the X-band pattern, figure 3-4. A new shaped surface is calculated based on this new S-band pattern. Figure 3-17
presents the design configuration for this larger horn in the dual shaped system. The horn would be approximately 10 ft. in diameter by 20 ft. long. The practicality of this even in the context of a 100 meter antenna, cost effectiveness notwithstanding, is questionable, but instructive to study.

The S-band taper of this larger horn is now -18.32 dB at 14 degrees instead of -16.67 dB as above showing the change in beam detail. The forward spillover (\(\eta_{fs}\), the energy within ±14° of boresight) has become 98.5% as opposed to 96.35% for the smaller horn.

When scattered from these new shaped surfaces, the larger horn has the following results:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>f = 8.415 GHz</th>
<th>f = 2.295 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\eta_{fs}) (forward spillover)</td>
<td>0.99490</td>
<td>0.98488</td>
</tr>
<tr>
<td>(\eta_s) (rear spillover)</td>
<td>0.99936 (0.15 Kelvins)</td>
<td>0.98798 (2.88 Kelvins)</td>
</tr>
<tr>
<td>(\eta_l) (illumination)</td>
<td>0.98189</td>
<td>0.99275</td>
</tr>
<tr>
<td>(\eta_{ph}) (phase)</td>
<td>0.98750</td>
<td>0.98360</td>
</tr>
<tr>
<td>(\eta_b) (blockage)</td>
<td>0.99122</td>
<td>0.98773</td>
</tr>
<tr>
<td>(\eta_x) (cross-pol.)</td>
<td><strong>0.99980</strong></td>
<td><strong>0.99980</strong></td>
</tr>
<tr>
<td>(\eta) (TOTAL)</td>
<td>0.95540</td>
<td>0.93830</td>
</tr>
</tbody>
</table>

This has had the effect of increasing X-band efficiency by 0.5% and S-band by 1%, while decreasing S-band noise by about 0.5K. For this case, if one expands the illumination angle a bit, to 73.5 degrees, S-band rear spillover noise will further reduce to 1.67K with X- and S-band efficiency both at about 94%. S-band rear spillover is reduced further by going on to a 74 degree illumination angle. For this case, the noise is less than 1.0K (0.95) with 93.4% and 92.5% overall at S- and X-band respectively. These scatter patterns are depicted in figure 3-18 (a), (b), (c) and (d).
The results of section 3.4.3 are summarized in Table 3-1. These horns will each have its phase center about 45 feet (13 to 14 meters) from the main reflector vertex. The $14^\circ$ horns are used in small F/D reflectors $\sim 0.325$, while the 11 degree horn is suggested for the more conventional reflector, F/D $\sim 0.4$. 
<table>
<thead>
<tr>
<th>Type of Shaping</th>
<th>Desired Condition &amp; θ</th>
<th>Total Eff X-Band</th>
<th>Rear Spillover Noise, X-Band</th>
<th>Total Eff S-Band</th>
<th>Rear Spillover Noise, S-Band</th>
</tr>
</thead>
<tbody>
<tr>
<td>14° Horn 67&quot; Aperture X-Band Pattern for Shaping</td>
<td>Max. Efficiency, X-Band, θ = 73°</td>
<td>95.9%</td>
<td>0.41K</td>
<td>90.9%</td>
<td>6.98K</td>
</tr>
<tr>
<td></td>
<td>Max. Efficiency, S-Band, θ = 74.5°</td>
<td>92%</td>
<td>0.05K</td>
<td>92.3%</td>
<td>1.62K</td>
</tr>
<tr>
<td>14° Horn 67&quot; Aperture S-Band Pattern for Shaping</td>
<td>Max. Efficiency, X-Band, θ = 72°</td>
<td>96.1%</td>
<td>1.26K</td>
<td>91.3%</td>
<td>7.36K</td>
</tr>
<tr>
<td></td>
<td>Max. Efficiency, S-Band, θ = 73°</td>
<td>95%</td>
<td>0.15K</td>
<td>92.6%</td>
<td>3.22K</td>
</tr>
<tr>
<td></td>
<td>Lower Noise S-Band, θ = 74°</td>
<td>92.2%</td>
<td>0.06K</td>
<td>92.3%</td>
<td>1.44K</td>
</tr>
<tr>
<td>11° Horn 82&quot; Aperture S-Band Pattern for Shaping</td>
<td>Max. Efficiency X-Band, θ = 60.5°</td>
<td>95.8%</td>
<td>1.2K</td>
<td>90.6%</td>
<td>7.42K</td>
</tr>
<tr>
<td></td>
<td>Max. Efficiency S-Band, θ = 61.3°</td>
<td>94.5%</td>
<td>0.21K</td>
<td>91.5%</td>
<td>3.29K</td>
</tr>
<tr>
<td></td>
<td>Lower Noise S-Band, θ = 62.5°</td>
<td>91.4%</td>
<td>0.06K</td>
<td>91.4%</td>
<td>1.4K</td>
</tr>
<tr>
<td>14° Horn 120&quot; Aperture S-Band Pattern for Shaping</td>
<td>Max. Efficiency X-Band, θ = 72.3°</td>
<td>96.4%</td>
<td>0.71K</td>
<td>93.4%</td>
<td>4.8K</td>
</tr>
<tr>
<td></td>
<td>Max. Efficiency S-Band, θ = 73°</td>
<td>95.5%</td>
<td>0.15K</td>
<td>93.8%</td>
<td>2.88K</td>
</tr>
<tr>
<td></td>
<td>Lower Noise S-Band, θ = 73.5°</td>
<td>94%</td>
<td>0.07K</td>
<td>94%</td>
<td>1.67K</td>
</tr>
</tbody>
</table>

Table 3-1. Summary of Results
4.0 CONCLUSIONS

The large dual frequency band corrugated horn patterns have been used to calculate shaping coordinates for 100 meter antennas at maximum efficiency (uniform illumination). The horn patterns were then scattered from the shaped quasi-hyperboloid and efficiencies as well as zenith rear spillover noise were calculated.

The shaping determination also included a type of "vertex plate" which scattered the energy away from the central subreflector shadow region. This is done without adding phase error to the final illumination pattern.

The results indicate that highly efficient shapes are available at both bands of the X-S band system, generally with X-band being the most efficient. This is because the S-band horn pattern shape results in more forward spillover, the lower S-band frequency results in more rear spillover because reflector size is smaller (in wavelengths) and for the same reason blockage efficiency is a fraction of a percent smaller.

Overall efficiencies in excess of 92% are possible in both bands with the smallest possible dual band horn, i.e., one that can be said to be truly gain limited. This is with a rear spillover noise of about 1.5K at S-band and less than 0.1K at X-band. In one example of using a much larger horn, overall efficiencies reached 94% at X-band and 93.8% at S-band with about the same noise.

The dual band horn is well suited to use in a shaped reflector system. In general, a trade-off would be needed between horn size and allowable low frequency (S-band) degradation to determine a final design.
Some further work should be done in this program, as follows:

1. Coordinates of the outer region of the quasi-paraboloid need to be more accurately determined. These are beyond the angle $\theta$ in the various configuration figures. The phase of the scattered field here is erratic and must be studied to determine the proper approach to determining this extension.

2. The effect of symmetrical "warping" of the quasi-paraboloid must be studied. This "warping" is a result of quasi-homologous deflection design envisioned for a 100 meter X-band instrument. For the large antenna, at various elevation angles, the carefully designed shaped system will assume certain variations in shape. This effect, and the effect of re-setting the shaped subreflector for maximum gain must be evaluated to ascertain if the principles of high efficiency will not be significantly degraded.

3. Final tradeoffs of allowable S-band performance degradation as well as structural layout tradeoffs, particularly large microwave horn size and fabrication, its interaction on position above main reflector vertex, and main reflector "deepness" must be optimized between microwave and structural performance and associated costs. This has not been done, and is necessary to fully define a final design. For example, the typically "flat" main reflectors preferred in the DSN application result in the feeds being rather far above the main reflector vertex. For a 100 meter diameter antenna, a significant feed cone support structure results. Deepening the main reflector alleviates this significantly. The use of well-performing, but large "gain limited" dual band horns aggravates this situation.
REFERENCES


Figure 3-0. The Coordinate System for Shaping
Figure 3-1. Geometry for Phase Alteration
Figure 3-2. The Full Scale Horn
\[ \Delta = \frac{D}{2\lambda_0} \left( \tan \frac{\theta_0}{2} \right) \]

\[ \Delta > 0.75 \text{ FOR SATURATION OR GAIN LIMITED} \]

Figure 3-3. Corrugated Horn Geometry
Figure 3-4. The 14 deg Horn, 67 in. Aperture, 2.005 Grooves, 8.415 GHz
Figure 3-5. The 14 deg Horn, 67 in. Aperture, 2.295 GHz, Phase Center of X-Band
(141 inches behind aperture)
Figure 3-6. General Configuration for Shaped Antenna

- **THE 3937" (100 m) DIAMETER REFLECTOR**
- **APERTURE PLANE**
- **THE SHAPED SUBREFLECTOR (10 m) DIAMETER**
- **THE DUAL BAND HORN**
- **FEED PHASE CENTRE**
- **QUASI-FOCUS**

\[ \alpha = \text{ILLUMINATION } 1/2 \text{ ANGLE} \]
\[ \theta_0 = 1/2 \text{ HORN FLARE ANGLE} \]
\[ \phi = \text{SUBREFLECTOR SHADOW} \]
\[ \phi' = \text{HORN SHADOW - MUST BE LESS THAN } \phi \]

**EQUIVALENT F/D:**

\[ F/D = D/16 \text{ YM} \]

(Not related to \( \beta \))
### THE 39.7 INCH REFLECTOR (100 METERS)

<table>
<thead>
<tr>
<th>The Horn Size</th>
<th>17.1°</th>
<th>17.1°</th>
<th>13°</th>
<th>13°</th>
<th>13°</th>
<th>10°</th>
<th>10°</th>
<th>10°</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Horn</td>
<td>Horn</td>
<td>Horn</td>
<td>Horn</td>
<td>Horn</td>
<td>Horn</td>
<td>Horn</td>
<td>Horn</td>
</tr>
<tr>
<td>Aperture (in)</td>
<td>52</td>
<td>52</td>
<td>68</td>
<td>68</td>
<td>68</td>
<td>80</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Length L (in)</td>
<td>83</td>
<td>83</td>
<td>145</td>
<td>145</td>
<td>145</td>
<td>223</td>
<td>223</td>
<td>223</td>
</tr>
<tr>
<td>α (deg)</td>
<td>16.2</td>
<td>16.2</td>
<td>12.4</td>
<td>12.4</td>
<td>12.4</td>
<td>9.66</td>
<td>9.66</td>
<td>9.66</td>
</tr>
<tr>
<td>Taper (dB)</td>
<td>18.9</td>
<td>18.9</td>
<td>19.3</td>
<td>19.3</td>
<td>19.3</td>
<td>19.3</td>
<td>19.3</td>
<td>19.3</td>
</tr>
<tr>
<td>A (in)</td>
<td>281.2</td>
<td>-5.0</td>
<td>-265.9</td>
<td>497.3</td>
<td>211.2</td>
<td>-49.6</td>
<td>756.6</td>
<td>470.5</td>
</tr>
<tr>
<td>YM (in)</td>
<td>817.76</td>
<td>701</td>
<td>613.4</td>
<td>817.69</td>
<td>701</td>
<td>613.3</td>
<td>817.65</td>
<td>701</td>
</tr>
<tr>
<td>V = YM - A (in)</td>
<td>536.6</td>
<td>706</td>
<td>879.3</td>
<td>320.4</td>
<td>489.7</td>
<td>662.9</td>
<td>61.05</td>
<td>230.4</td>
</tr>
<tr>
<td>EQUIV F/D = ( \frac{D}{16YM} )</td>
<td>0.301</td>
<td>0.351</td>
<td>0.401</td>
<td>0.301</td>
<td>0.351</td>
<td>0.401</td>
<td>0.301</td>
<td>0.351</td>
</tr>
<tr>
<td>C = V + L (inches)</td>
<td>620</td>
<td>789</td>
<td>962</td>
<td>465</td>
<td>634.7</td>
<td>808</td>
<td>284</td>
<td>453.4</td>
</tr>
<tr>
<td>Approx Focal Length, inches</td>
<td>1258.5</td>
<td>1459.4</td>
<td>1661.7</td>
<td>1259.5</td>
<td>1461.1</td>
<td>1672.3</td>
<td>1261.6</td>
<td>1463.1</td>
</tr>
<tr>
<td>θ degrees</td>
<td>77.38</td>
<td>68.93</td>
<td>61.96</td>
<td>77.35</td>
<td>68.89</td>
<td>61.93</td>
<td>77.29</td>
<td>68.83</td>
</tr>
<tr>
<td>Not F/D related</td>
<td>8.89</td>
<td>7.68</td>
<td>6.76</td>
<td>8.88</td>
<td>7.67</td>
<td>6.71</td>
<td>8.87</td>
<td>7.66</td>
</tr>
<tr>
<td>φ (deg)</td>
<td>2.33</td>
<td>2.22</td>
<td>2.13</td>
<td>2.45</td>
<td>2.36</td>
<td>2.25</td>
<td>2.34</td>
<td>2.27</td>
</tr>
<tr>
<td>φ' (deg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3-7. Configuration Calculations
Figure 3-9. Clearance to Top of Horn
\[ F = \frac{D}{16 \text{ YM}} = 0.325 \]

\[ \theta_1 = 71.863^\circ \]

\[ \alpha = 8.22^\circ \]

**PEAK-TO-MAX DEVIATION FROM A PARABOLA = 2.85"**

RMS = 0.571"

\[ D = 3937.13" \quad (100.003 \text{ m}) \]

\[ \text{SYM} \]

\[ \text{NO SURFACE DEFINED} \]

\[ \alpha \]

\[ \theta_1 \]

\[ 14^\circ \]

\[ 196.9" \]

\[ 1931" \]

\[ 1968.565" \]

\[ 27.342" \]

\[ \sim 6" \]

\[ 723.963" \]

\[ \sim 508" \quad (42 \frac{1}{3}) \]

\[ 221.7" \]

\[ 632.521" \]

\[ 854.221" \]

\[ 605.197" \]

\[ 757.34" \]

\[ 730" \quad (60.8") \]

\[ \sim 730" \]

\[ \text{Figure 3-10. A "Best Fit" Solution Using a 14° Horn, 14° Taper, Shaped to X-Band Pattern} \]
Figure 3-11(a). 3938X Dish, 14DH-14T, V = 42.3 ft
The 170 in. Hole, X-Band
X14DH at 14 deg, 21.54 dB Taper
Figure 3-11(b). 3938X Dish, 14DH-14T, V = 42.3 ft
The 170 in. Hole, X-Band
X14DH at 14 deg, 21.54 dB Taper
Figure 3-11(c). 3938X Dish, 14DH-14T, V= 42.3 ft
The 170 in. Hole, S-Band
S14DH at 14 deg, 16.67 dB Taper
Figure 3-11(d). 3938X Dish, 14DH-14T, V=42.3 ft
The 170 in. Hole, S-Band
S14DH at 14 deg, 16.67 dB Taper
Figure 3-12. A "Best Fit" Solution Using the 14° Horn, 14° Taper, Shaped to the S-Band Pattern
Figure 3-13(a). 3938S Dish, 14 DH-14T, V = 42.5 ft
The 170 in. Hole, X-Band
X14DH at 14 deg, 21.54 dB Taper
Figure 3-13(b). 3938S Dish, 14DH-14T, V = 42.5 ft
The 170 in. Hole, X-Band
X14DH at 14 deg, 21.54 dB Taper
Figure 3-13(c). 3938S Dish, 0.325, V = 42.5 ft
The 170 in. Hole, S-Band
S14DH at 14 deg, 16.67 dB Taper
Figure 3-13(d). 3938S Dish, 0.325, V = 42.5 ft
The 170 in. Hole, S-Band
S14DH at 14 deg, 16.67 dB Taper
$F = \frac{D}{16 \text{ YM}} = 0.404$

$\theta_1 = 60.262^\circ$

$\alpha = 6.65^\circ$

PEAK-TO-PEAK MAX
DEVIAITON FROM
A PARABOLA = 3.51"
RMS = 0.717"

$D = 100.07 \text{ m}$

$1969.892\"$

$1930\"

$22.9"$

$23.152"$

$1012.962\"$

$1125.445\"$

$1102.545\"$

~586.5"

~580.326"

~6"

170"

11°

$\theta_1$

~47°

196.9"

Figure 3-14. The "Best Fit" Solution to the 11 deg Horn at
11 deg Taper (16.54 dB) - "S"-Band Shaping
Figure 3-15(a). 3938S Dish, 11DH, 11DT, V = 47 ft
The 170 in. Hole, S-Band Shape
X11DH at 11 deg, 21.57 dB Taper
Figure 3-15(b). 3938S Dish, 11DH-11DT, V = 47 ft
The 170 in. Hole, S-Band Shape
X11DH at 11 deg, 21.57 dB Taper
Figure 3-15(c). 3938S Dish, 11DH, 11DT, V = 47 ft
The 170 in. Hole, S-Band Shape
S11DH at 11 deg, 16.64 dB
Figure 3-15(d). 3938S Dish, 11DH-11DT, V = 47 ft
The 170 in. Hole, S-Band Shape
S11DH at 11 deg, 16.54 dB
Figure 3-16. The 14 deg Horn with 120 in. Aperture, Freq = 2.295 GHz
(phase center 225 inches behind aperture)
\[ \frac{F}{D} = \frac{D}{16 \text{ YM}} = 0.326 \]

\[ \theta_1 = 71.73^\circ \]

\[ \alpha = 8.24^\circ \]

Figure 3-17. The "Best Fit" Solution Using a 120" Aperture, 14° Horn, 14° Taper, Shaped to S-Band Pattern

PEAK-TO-PEAK MAX DEVIATION FROM A PARABOLA = 2.91"
RMS = 0.554"
Figure 3-18(a). 120 in. Aperture S-Dish, V = 42.5 ft
The 170 in. Hole, S-Band Shape
X14DH-67 at 14 deg, 21.54 dB Taper
Figure 3-18(b). 120 in. Aperture S-Dish, V = 42.5 ft
The 170 in. Hole, S-Band Shape
X14DH-67 at 14 deg, 21.54 dB Taper
Figure 3-18(c). 120 in. Aperture S-Dish, $V = 42.5$ ft
The 170 in. Hole, S-Band
S14DH-120 at 14 deg, 18.32 dB Taper
Figure 3-18(d). 120 in. Aperture S-Dish, V = 42.5 ft
The 170 in. Hole, S-Band
S14DH-120 at 14 deg, 18.32 dB Taper
APPENDIX A

The Program for Calculating a Dual Shaped Reflector System

The following computer program listing is for calculating a dual shaped reflector system (Cassegrain) that will provide final uniform illumination over a primary aperture for any input horn or feed pattern. The solution is based on geometric optics.

The significant output will appear on two temporary files, ENDFILE 20 and ENDFILE 21. ENDFILE 20 carries the coordinates of the quasi-paraboloid and quasi-hyperboloid in X,Y,R,0 (figure 3-0). ENDFILE 21 carries information on the quasi-hyperboloid suitable for use in the RUSCH symmetrical scattering program.

A feature of the program allows for a choice of a null illumination of the central region of the system. This can reduce the amount of energy that is blocked by the central reflector (quasi-hyperboloid) and hence to a greater blockage efficiency.

The input deck for the program is as follows:

1. XNMAX, YNMAX (2F10.5)
2. TITLE 1 (20A4)
3. TITLE 2 (20A4)
4. JIN (I5)
5. (TTABLE (I,J), J=1,5) I=1, JIN (5F10.6)

(5+JIN). NSKIP, MULT (2I5)
(6+JIN). INTP (I5)
(7+JIN). XMAX, THEMAX, PFDIAM, XMIN, C, FREQ. (6F10.4)
(8+JIN). AN, DELAMX, DELAMN (3F10.4)
Definitions:

**XNMAX**: See figure 3.0, the maximum quasi-paraboloid radius.

**YNMAX**: Figure 3.0, used if DELAMX is not equal to zero, defines the chosen paraboloid for best fitting.

**TITLE 1, TITLE 2**: arbitrary titles.

**JIN**: The number of cards (points) in the input horn pattern.

**T TABLE**: \( \text{THETA, E(\theta), EP(\theta), H(\theta), HP(\theta)} \)

where

\( \text{THETA: Angle in degrees for the horn pattern.} \)

\( \text{E(\theta): } \text{E - plane field (volts) of the horn.} \)

\( \text{EP(\theta): Phase of the E - plane.} \)

\( \text{H(\theta): } \text{H - plane field (volts) of the horn.} \)

\( \text{HP(\theta): phase of the H - plane.} \)

**NSKIP**: Set equal to 1 for printout.

**MULT**: Determines the number of coordinates of the output quasi-paraboloid.

\(=1, 251 \text{ points} \)

\(=2, 501 \text{ points} \)

\(=3, 751 \text{ points} \)

\(=4, 1001 \text{ points} \)

**INTP**: Becomes \( P \) (see program printout)

**XMAX**: The maximum "\( x \)" value, see XNMAX

**THEMAX**: The maximum illumination angle of the chosen horn pattern (edge illumination)

**PPDIAM**: The chosen diameter for the subreflector, i.e., quasi-hyperboloid.

**XMIN**: The radius of the central region chosen for a zero of illumination.

Equal to 0.0 if no central null is desired.

**C**: Set equal to \(-1000.0\), no longer used.

**FREQ**: Frequency in GHz, no longer used.

**AN**: Selected starting value for horn focus location. See figure 3-6. \( \text{AN} \) is positive in the direction toward the quasi-paraboloid vertex from the aperture plane.
DELAMX: First chosen increments (larger) for changing AN while looking for the best fit paraboloid. Equal to zero if no search is desired.

DELAMN: Second chosen (smaller) increments while searching for the best fit paraboloid.

All angles above are input in degrees, all linear dimensions are input in inches.
***** DUAL REFLECTOR ANTENNA SYSTEM DESIGN ******

** A FORTRAN 4 PROGRAM **
WRITTEN BY PHIL JARVIE II AND ROB GERRITSEN FOR ART LUDWIG JPL

THIS PROGRAM IS AN EXTENSION OF DAR WITH TWO ADDED OPTIONS.
THE FIRST OPTION IS INTERNAL VARIATION OF THE PARAMETER A, WHICH
DETERMINES THE Y COMPONENT OF THE CENTER OF THE POLAR CO-ORDINATE
SYSTEM.

THE VARIATION OF A IS CARRIED OUT SO THAT A BEST A IS FOUND,
WHERE THE BEST A IS THAT WHICH MINIMIZES THE NORMAL
DEVIATION OF THE MAIN REFLECTOR FROM A NOMINAL MAIN REFLECTOR.
FOR EACH VALUE OF A THE PROGRAM SOLVES THE THREE SIMUL-
ERNOUS DIFFERENTIAL EQUATIONS AS IN DAR,
RESULTS ARE PRINTED FOR THE DUAL REFLECTOR SYSTEM CORRESPONDING
TO THE BEST A.

THE OTHER OPTION IS A POSTPROCESSOR WHICH PUNCHES OUT A SET OF
DECKS.

FOR PUNCH OPTION P, USE 0 FOR NO PUNCHED OUTPUT, USE 1 FOR
STANDARD PUNCHED OUTPUT AND USE 2 FOR ROY LEVY PUNCHED OUTPUT
MODIFIED FOR DEMAND TERMINAL USE
P POTTER, SECTION 333
2/11/74

MODIFIED EXTENSIVELY DURING 1977 BY L. HOWARD AND W. F. WILLIAMS.
INCLUDED CHANGES TO THE EQUATIONS TO BE INTEGRATED; THE DETERMINATION
OF THEIR DERIVATIVES; METHOD OF INTEGRATION; CONSTANTS OF INTEGRATION;
FORM OF OUTPUT; ETC. (SEE DOCUMENT DETAILS)

COMMON/DERARG/A,C2,VAR(4),DER(4),EU(3),EL(3),TEMPS(41)
COMMON/ALWAYS/XNMAX,YNMAX
COMMON/AFTER/XSAXV(1004),YSAV(1004),YDRSAV(1004),NOD,FNOD
COMMON/FOGT/XXMAX,YMIN
COMMON/CPOST/RAD(1004),RPR(1004),THPR(1004),THE(1004),CP,MULT
COMMON ITABLE(200*8),HEAD1(20),HEAD2(20),HEAD3(20),PAGE,LINE
COMMON JMAX,J0,JMIN,IC1,IC2,RO,WL,TEND

INTEGER PAGE
REAL K,NORMAX,NORMIN,MAXX,MAXY,MINX,MINY
EQUIVALENCE (X,VAR(1),(THETA,VAR(2)),(Y,VAR(3),(R,VAR(4))),(XH,DER(1),(THEH,DER(2))),
XH,DER(1),(THEH,DER(2)),(YP,DER(3),(RP,DER(4)))

1000 WRITE(6,2000)
2000 FORMAT(///20X27HSYMMETRICAL SHAPING PROGRAM/)
WRITE(6,2010)
2010 FORMAT(3SH **INPUT XNMAX*YNMAX, 2F10.5, OR */*)
READ(5,2020,END=6000) XNMAX,YNMAX
WRITE(6,2011) XNMAX,YNMAX
2011 FORMAT(1X*8F12.5)
2020 FORMAT(8F10.5)

C START OF PROGRAM, READ IN MAINHEADER.

WRITE(6,2030)
2030 FORMAT(11H **INPUT MAIN HEADER/)
READ(5,1)HEAD1
1 FORMAT(20A4)
WRITE(6,2031) HEAD1
2031 FORMAT(1X*20A4)
LINE=0
PAGE=0

C NOW TO READ FIELD DATA HEADER, CONTROL PARAMETERS, AND DATA POINTS

WRITE(6,2040)
2040 FORMAT(13H **INPUT FIELD DATA HEADER*/)
READ(5,5)HEAD2
5 FORMAT(20A4)
WRITE(6,2031) HEAD2
CALL PR(0)
C WRITE(6,5)HEAD2
WRITE(6,2050)
2050 FORMAT(17H **INPUT JIN, I5/)
READ(5,2060) JIN
2060 FORMAT(16I5)
WRITE(6,2061) JIN
2061 FORMAT(1X*16I5)
JMAX=0
J0=0
IC1=1
IC2=1
WRITE(6,2070)
2070 FORMAT(14H **ADD VOLTAGE ILLUM PATTERN DECK*/)
READ(5,8) (TTABLE(I+J)+J=1,5)+J=1,JIN)
8 FORMAT(5F10.6)
C CALL PR(0)
C IF(1IC1)+81+82
C 81 WRITE(6,83)
83 FORMAT (1H012HTHETA(DEG), 8H E(V) 12H PHIE(DEG), 8H H(DB))
X12H PHIE(H(DEG))
GO TO 85
C 82 WRITE(6,84)
84 FORMAT(1H012HTHETA(DEG), 8H E(VOLT) 12H PHIE(DEG), 8H H(VOLT))
X12H PHIE(H(DEG))
CONTINUE
85 CONTINUE
DO 10 I=1,JIN
C CALL PR(0)
C WRITE(6,9) (TTABLE(I+J)+J=1,5)
9 FORMAT(5F11.5)
10 CONTINUE
C

NOW TO CONSTRUCT 3 FUNCTIONS F, PHI, AND PHI PRIME

CALL CONST

CALL PR(0)
WRITE(6,11)
11 FORMAT(1HOI2HTHETA(RAD) 6H E(VOLT) 12H PHI-E(INCH) 8H H(VOLT)
X12H PHI=H(INCH) 10H F(WATT/A) 10H PHI(INCH); 15H PHI(INCH/RAD))
DO 13 I=1,N
CALL PR(0)
WRITE(6,12)(TABLE(I,J)*J=1,8)
12 FORMAT(F12.9*7F10.6)
13 CONTINUE

END OF PHASE I *START PHASE II

READ CASE HEADER AND ARGUMENTS

WRITE(6,2080)
2080 FORMAT(/19H ***INPUT NSKIP, I5//)
1300 READ(5,2100) NSKIP,MULT
WRITE(6,2061) NSKIP,MULT
C 130 FORMAT (20A4)
WRITE(6,2090)
2090 FORMAT(/34H ***INPUT A 1 FOR RUSCH OUTPUT, I5)
WRITE(6,2095)
2095 FORMAT(35H ***INPUT A 2 FOR PSCATT OUTPUT, I5)
WRITE(6,3000)
3000 FORMAT(34H ***INPUT A 3 FOR BOTH OUTPUTS, I5//)
READ(5,2100) INTP
2100 FORMAT(16I5)
WRITE(6,2061) INTP
P= INTP
WRITE(6,2110)
2110 FORMAT(/1 ***INPUT XMAX,TETMAX,SUB DIAM,XMIN,C 5F10.5//)
READ(5,1310) XMAX,TETMAX,PPDIAM,XMIN,C,FREQ
WRITE(6,2011) XMAX,TETMAX,PPDIAM,XMIN,C,FREQ
WL=11.8028543/FREQ
K= PPDIAM/2.0
1310 FORMAT (6F10.4)
WRITE(6,2120)
2120 FORMAT(/31H ***INPUT A,DAMAX,DAMIN, 3F10.5//)
READ (5,131) AN,DELAMX,DELMN
WRITE(6,2011) AN,DELAMX,DELMN
131 FORMAT (3F10.4)
LINE=0
CALL PR(-1)
WRITE(6,2125)
2125 FORMAT(/)//
WRITE (6,132) XMAX,TETMAX,K,P,C
132 FORMAT (6H XMAX=F10.4,8H THEMAX=F10.4*3H K=F10.4*3H P=F4.1*3H C=F1DR101060
XU.4)
CALL PR(-1)
WRITE(6,133) AN,DELAMX,DELMN
133 FORMAT (11H A NOMINAL=F10.4*13H DELTA A MAX=F10.4*13H DELTA A MIN=DR101100
C CALCULATE C2 AND SET OTHER CONSTANTS
  THERMAX=0.0174532925*THERMAX
  Y0=0.
  R0=K/SIN(THERMAX)
  CALL PR(1)
  WRITE (6,1330) THERMAX,R0,Y0

1330 FORMAT(13H THERMAX(RAD)=F12.9,10H R0(INCH)=F12.4,9HY0(INCH)=F12.4)
  CALL CTWO(XMAX,XMIN,C2)

C

C CALL PR(1)
  WRITE (6,134) C2

134 FORMAT (1H,10X,3HC=E16.9)

C END PHASE II, START PHASE III

C TEST DELAMX=0, IF SO CALCULATE CURVE FOR AN AND GO TO NEXT CASE.
  IF (DELAMX) 1341:1301:1341

C PHASE III=A

C FIND A=AN+N*DELAMX SUCH THAT THE MAIN REFLECTOR WITH THIS A HAS
  LEAST RMS DEVIATION FROM NOMINAL MAIN REFLECTOR.

1341 CALL AOPT(AN,DELAMX,ABEST,RMS,B,NORMAX,NORMIN,MAXX,MAXY,MINX,MINY)
  IF (NOA) 1340:1300:1340
  WRITE FIRST PASS RESULTS.

1340 CALL PR(1)
  WRITE (6,135) ABEST,RMS,B

135 FORMAT (19H FIRST PASS. ABEST=F15.8,5H RMS=F15.8,3H B=F15.8)
  DIFF=NORMAX-NORMIN
  CALL PR(1)
  WRITE (6,136) NORMAX,NORMIN,DIFF

136 FORMAT (13H NORMAL MAX.=F15.8,13H NORMAL MIN.=F15.8,21H PEAK TO=)
  XPFAK MAX.=F15.8)
  CALL PR(1)
  WRITE (6,137) MAXX,MAXY,MINX,MINY

137 FORMAT(10H MAX AT X=F10.4,3H Y=F10.4,10H MIN AT X=F10.4,3H Y=F10.4)
  CALL AOPT(XABEST,DELAMN,ABEST,RMS,B,NORMAX,NORMIN,MAXX,MAXY,MINX,MINY)
  IF (NOA) 1370:1300:1370
  WRITE SECOND PASS RESULTS.

1370 CALL PR(1)
  WRITE (6,138) ABEST,RMS,B

138 FORMAT (20H FINAL PASS. ABEST=F15.8,5H RMS=F15.8,3H B=F15.8)
  DIFF=NORMAX-NORMIN
  CALL PR(1)
WRITE (6,136) NORMAX,NORMIN,D1FF
CALL PRO(-1)
WRITE (6,137) MAXX,MAXY,MINX,MINY
CALL YOFX TO CALCULATE AND PRINT BEST CURVE

LINE=0
CALL YOFX(1,ABEST+B,NSKIP)
CALL POSTPR IF P IS NOT ZERO
IF(INTP.EQ.1.OR.INTP.EQ.3) CALL POSTPR

************* END PHASE IV. RETURN TO START OF PHASE II *************
END

GO TO 1000

*************** END OF THE PROGRAM 70000 ***************

PROGRAM COMES TO THIS SECTION IF DELAMX=0, WHICH MEANS THAT NO BEST DR10194
IS TO BE FOUND, BUT RESULTS FOR AN ARE TO BE PRINTED.

1301 CALL YOFX(O,AN,0,NSKIP)
FIND B FOR SHIFTING YN
CALL RMSB(B)
ABEST=AN

CALCULATE THE ERRORS
CALL RMSERR(B,RMS)
CALL MAXMIN(NORMAX,NORMIN,MAXI,MINI,B)
MAXX*XSAV(MAXI)
MAXY*YSAV(MAXI)
MINX*YSAV(MINI)
MINY*YSAV(MINI)
GO TO 1370

6000 CONTINUE
NOW CLOSE FILE20=PSEUDO-PARABOLA OUTPUT &
FILE21=PSEUDO-HYPERBOLA OUTPUT AND QUIT
ENDFILE 20
ENDFILE 21
STOP
END
SUBROUTINE YOFL(XYPRFL,AN,BNSKIP)

C THIS IS THE SUBROUTINE THAT DOES THE MAIN CALCULATIONS.
C THIS SURR. FINDS THE MAINREFLECTOR FOR A GIVEN A.
C THE X,Y CO-ORDS. ARE SAVED IN XSAY,YSAY,YDSAY IF XYPRFL=0
C OTHERWISE RESULTS ARE PRINTED AS THEY ARE CALCULATED
C AS W AS DONE IN NAR

EXTERNAL DERIV

COMMON/DERARG/A+C2*VAR(4),DER(4),EU(3),EL(3),TEP(3),TIM(3)
COMMON/AFTER/YSAY(1004),YSAY(1004),YDSAY(1004),NOD,FNOD
COMMON/FORGET/XMAX,Y0,XMIN
COMMON/CPOST/PLAN(1004),RPH(1004),THPR(1004),THE(1004),C,P,MULT
COMMON/MTABLE(200+8),HEAD1(20),HEAD2(20),HEAD3(20),PAGE,LINE
COMMON/JMAX,J0,JINC1,JIC2,R0,WL,THEMAX

EQUIVALENCE (X*VAR(1)),(THE+VAR(2)),(Y*VAR(3)),(R*VAR(4)),
H*DER(1),THE+DER(2),Y+DER(3),(RP,DER(4))

INTEGER XYPRFL
DIMENSION KG(2),YNWORK(2),DTWORK(10,2),EP(2)

SET INITIAL CONDITIONS FOR INTEGRATION OF DIFFERENTIAL EQUATIONS

FMULT=1.0/MULT
A=AN
HMAX=.008*THEMAX*FMULT
HMIN=.000004*THEMAX*FMULT
X=XMAX
Y=Y0
THE+THEMAX
THSTOP=.002*THEMAX*FMULT
H=0
CALL DERIV
H=0.004*THEMAX*FMULT
NEO=2
KD=1
EP(1)=1.05
DELTX=-.004*(XMAX-XMIN)*FMULT
XNEW=XMAX
CALL THOFX(XNEW,DELTX,THEXX)
DEL=THEXX-THE
MXSTEP=1000*MULT
TFINAL=THEMAX
CALL SVOD(NEO,THETA,VAR(3),DER(3),KD,EP,IFLAG,
H,HMIN,HMAX,DEL,TFINAL,MAX,STEP,KSTEP,KMAX,
EMAX*KG,YNWORK,DTWORK)
NOD=0
IHCUT=0

DR102030
DR102040
DR102050
DR102060
DR102070
DR102080
DR102090
DR102100
DR102110
DR102120
DR102130
DR102140
DR102150
DR102160
DR102170
DR102180
DR102190
DR102200
DR102210
DR102220
DR102230
DR102240
DR102250
DR102260
DR102270
DR102280
DR102290
DR102300
DR102310
DR102320
DR102330
DR102420
GOTO 212

C INTEGRATION LOOP

20 XNEW=XNEW+DELTX
CALL DERIV
CALL PHI(THETA,PHIA)
TEMP=X*R*SIN(THETA)
BETA=ATAN2(TEMP,Y+R*COS(THETA)-A)
IF(ABS(BETA).GE.0.0001) C1=R+PHIA+ TEMP/SIN(BETA) + Y
IF(ABS(BETA).LE.0.0001) C1=2.*R+PHIA+2.*Y-A
THETAD=57.2957795*THETA
BETAD=57.2957795*BETA
SAVE
NOD=NOD+1
XSAV(NOD)=X
YSAV(NOD)=Y
YDRSAV(NOD)=YP*THETA
Dydx=YDRSAV(NOD)
DELX=X-XSAV(NOD-1)
DFLY=Y-YSAV(NOD-1)
TANG=DELY/DELX
IF(NOD,EQ.1) TANG=0.0
IF(CYPRL)=200,210,00
FIND YASA AND EX AND PRINT EVERYTHING.
200 CALL YN(X,YNOM)
201 YASA=YNOM+R
202 CALL NORMER(NOD,EX,B)
SAVE RESULTS FOR POSTPR
THE(NOD)=THETAD
RAD(NOD)=R
THPR(NOD)=THETA
RPR(NOD)=RP*THETA
PUNCH RESULTS IF P IS NOT ZERO.
IP=P
IF(IP.EQ.2)
C XPUNCH 2030+NOD,X,Y,BETA*DYDX*YNOM*YASA*EX
C2030 FORMAT(I10,7F10.5)
IF(IP.EQ.2) PUNCH 2020,X,Y,THETA,R,BETAD,YASA*EX
C ALSO PUNCH PSEUDO-PARABOLA ON FILE 20
IF(IP.EQ.2) WRITE(20,2020) X,Y,THETA,R,BETAD,YASA*EX
2020 FORMAT (7F10.4)
203 IF(NOD,EQ.1) CALL PR(1)
IPRINT=0
IF(NOD.LE.10.OR.((NOD/NSKIP)*NSKIP,EQ.NOD)) IPRINT=1
IF(IPRINT,EQ.1) WRITE(6,21) X,Y,THETA,R,C1,BETAD,YASA*EX
+ *DYDX,TANG,BETA
21 FORMAT(6F10.4,10X,3F10.5)
210 IF(THETA.LE.-THSTOP) GOTO 25
IF(XNEW.LT.-5*DELTX*XMIN) GOTO 25
IF(XNEW.LT.XMIN.-5*DELTX) XNEW=XMIN
CALL THOFX(XNEW,THENEW)
DELX=THENEW-THETA
211 CALL CSV01
IF(THETA.GE.0.) GOTO 212
WRITE(6,2115) THETA
C2115 FORMAT(1 ***THETA .LT. 0.**, INTEGRATION TERMINATED...!E15.6)
SUBROUTINE CTWO(XMAX,XMIN,C2)
C
THIS SUBROUTINE COMPUTES THE DEFINITE INTEGRAL CALLED C2. THE
METHOD USED IS THE TRAPEZOIDAL RULE. THE INTEGRAND IS
F(THETA)*SIN(THETA)*DTHETA AND THE LIMITS ARE
FROM THETA=THETA1 TO THETA MAX.
C
COMMON TTABLE(200),HEAD1(20),HEAD2(20),HEAD3(20),PAGE,LINE
COMMON JMAX,J0,J1,J0,J1,J2,R0,WL,THEMAX
DIMENSION CTAB(200)
DOUBLE PRECISION CHI,CHIM,STHI,STHIM,DTHI,DTHIM,DTH,DTH,DTH,CCTHI
DOUBLE PRECISION XSQ,XMINSQ
C

XMINSD*XMIN**2
C2=0.
CTAB(I)=0.
DO 20 I=2,JIN
  IF(TTABLE(I+1)-THEMAX) 19,21,21
  19 IM=I+1
  THI*TTABLE(I+1)
  THIM*TTABLE(IM+1)
  FTHI*TTABLE(I+6)
  FTHIM*TTABLE(IM+6)
  ASSIGN 17 TO IFROM
  GOTO 1000
  17 C2=C2+FAC
  CTAB(I)=C2
  IC2MAX=I
  CONTINUE
  WRITE(6,600) THEMAX,TTABLE(JIN+1)
  600 FORMAT(/1 SRC TWO ERROR* THEMAX=1,15.7 E15.7 TTABLE(JIN+1)=1
  STOP C2ERR
  21 CALL FPAT(THEMAX,FTHI,Z)
  IM=IM+1
  FTHIM*TTABLE(IM+6)
  THI*THEMAX
  THIM*TTABLE(IM+1)
  ASSIGN 22 TO IFROM
  GOTO 1000
  22 C2=C2+FAC
  IC2MAX=IC2MAX+1
  CTAB(IC2MAX)=C2
  C2=C2/(XMAX**2*XMINSD)
  WRITE(6,23) C2
  23 FORMAT(/1 TRUE C2 = 1*E15.7///)
  RETURN
  1000 DTHI=THI
  DTHM=DTHI
  DTHM=DTHM-DTHIM
  IF(DTHI.EQ.0.D0) FAC=0.
  IF(DTHI.EQ.0.D0) GOTO IFROM
  DPTH=FTHI-FTHIM
  CTHI=DCOS(DTHI)
  STHI=DSIN(DTHI)
  CTHIM=DCOS(DTHIM)
  STHIM=DSIN(DTHIM)
  SCTHI=STHI=DTHI*CTHI
  SCTHIM=STHIM=DTHM*CTHI
  CCHI=CTHI*CTHI
  FAC=(FTHIM-THEMAX*DPTH/DTH)*CCHI+
  *(DPTH/DTH)*(SCTHI-SCTHIM)
  GOTO IFROM
  ENTRY XOFTH(X,THETA)

C

FINDS X AS A FUNCTION OF THETA

THI*THETA
OTH=TTABLE(2+1)-TTABLE(1+1)
IF(THETA.LT.0.* OR THETA.GT.THEMAX) STOP THEERR
NTHET=(THETA-NTABLE(1+1))/DTH+1.
GOTO 1030
1020 NTHET=NTHET+1
1030 IF(THETA=NTABLE(NTHET+1)) 1020,1040,1040
1040 IF(THETA.LT.1) GOTO 1050
NTHET=NTHET+1
GOTO 1030
1050 THIM=NTABLE(NTHET+1)
CALL FPAT(THI+FTHI*X)
ASSIGN 1060 TO IFROM
GOTO 1000
1060 X=DSORT(2.*(CTAB(NTHET)+FAC)/CTAB+XMINSQ)
IF(X.GT.XMAX) X=XMAX
IF(X.LT.XMIN) X=XMIN
RETURN
ENTRY THOFX(X+THETA)

C
FINDS THETA AS A FUNCTION OF X
C
XSQ=X**X
SMALLX=.001+XMIN
XCNVRG=.0001
IF(SMALLX.LT.X.AND.X.LT.XMAX) GOTO 1090
IF(X.LE.XMIN) THETA=0.,
IF(X.GE.XMAX) THETA=THEMAX
IF(X.LE.SMALLX) THETA=DSORT((XSQ+XMINSQ)C2+NTABLE(1+6))
RETURN
1090 ITR=0
ITRMAX=100
XIOD=0.
XERR=1.E-7
CTABX=(XSQ+XMINSQ)C2+.5
IF(CTABX.GT.CTAB+ICTAB) CTABX=CTAB(ICTAB)
DO 1100 I=2,ICTAB
IF(CTABX.GT.CTAB(I)) GOTO 1100
INDEX=I
GOTO 1110
1100 CONTINUE
1110 IM=INDEX+1
C
WRITE(6,1111) INDEX+1
C1111 FORMAT(1 ***INDEX=IM=1+216)
TM=NTABLE(1+1)
THIM=NTABLE(1+6)
XIM=DSORT(2*CTAB(1M)/C2+XMINSQ)
THIN=TM
THIP=NTABLE(1+1)
IF(INDEX.EQ.ICTAB) THIP=THEMAX
XIP=DSORT(2*CTAB(INDEX)/C2+XMINSQ)
1120 DIST=(X-XIM)/(XIP-XIM)
TH=THIN+THIP+(THIP-THIN)*DIST
C
WRITE(6,1121) ITR+DIST+FAC*XIM*XIP+XI+THIN+THIP+THI
C1121 FORMAT(1 ***ITR+DIST+FAC*XIM*XIP+XI+THIN+THIP+THI=1/
C+4E15.6/A1+4E15.6)
CALL FPAT(THI+FTHI*X)
C
WRITE(6,1122) ITR+THI+FTHI+THIM+FTHIM
C1122 FORMAT(1 ***ITR=THI+FTHI+THIM+FTHIM=I/4+4E15.6/)
ASSIGN 1130 TO IFROM
GOTO 1000
1130 XI=SORT(2,*(CTAB(IM)+FAC)/C2+X*MINSQ)
C WRITE(6*1123) ITR,XI,FAC,THI,FTHI,THIM,FTHIM
C 1123 FORMAT(1 ***ITR, XI, FAC, THI, FTHI, THIM, FTHIM=1/I4,6E12.5/)
ITR=ITR+1
IF(ITR,GT,ITRMAx) GOTO 1170
XIOLD=XI
IF((X-XI).GT.XERR*X.AND.(X-XI).LT.XCNVRG) GOTO 1150
IF((X-XI).LT.XERR*X.AND.(X-XI).GT.XCNVRG) GOTO 1160
THETA=THI
RETURN
1150 XI=XI
THIN=THI
GOTO 1120
1160 XI=XI
THIP=THI
GOTO 1120
1170 WRITE(6*1180) ITR, XI, XIOLD, XERR
1180 FORMAT(1 CTWO, ITR, EXCEROS ITRMAX: ITR, XI, XIOLD, XERR=1/16,4E16.7/)
THETA=THI
IF(XIOLD.EQ.XI) RETURN
STOP C2ERR
END

SUBROUTINE PHI(THETA,PHIA)
C THIS SUBROUTINE COMPUTES PHI(THETA) BY LINEAR INTERPOLATION.
C COMMON TTABLE(200,B), HEAD1(20), HEAD2(20), HEAD3(20), PAGE, LINE
C COMMON JMAX, J0, JIN, IC1, IC2, RO, ML, THEMAX

C IF(THETA=TTABLE(I+1))1*3,3
1 WRITE(6*2) THETA
2 FORMAT(20M1 THETA OUT OF RANGE+F10.4)
3 CALL EXIT
4 DO 5 I=1,JIN
5 CONTINUE
6 CONTINUE
7 PHI=((THETA-1+1)(I+1)/TTABLE(I+1)+TTABLE(I+1))
6 CONTINUE
7 RETURN
END
SUBROUTINE FPAT(A+U*V)

THIS SUBROUTINE COMPUTES AS FUNCTIONS OF THETA,
1. THE PATTERN FUNCTION U=F(THETA) AND
2. THE PHASE FUNCTION DERIVATIVE V=PHI PRIME(THETA)
BY LINEAR INTERPOLATION

COMMON TTABLE(200*8),HEAD1(20),HEAD2(20),HEAD3(20),PAGE,LINE
COMMON JMAX,J0,JIN,IC1,IC2,R0,ML,THEMAX

IF(AGE,TTABLE(I+1))GO TO 2
1 WRITE(6,10A) CALL EXIT
2 WRITE(6,11A) CALL EXIT
3 DO 5 I=1,JIN
4 IF(ALE,TTABLE(I+1)) GO TO 6
5 CONTINUE
6 GO TO 3
7 IF(ANE,TTABLE(I+1)) GO TO 7
U=TTABLE(I+6)
V=TTABLE(I+8)
RETURN
7 TEMP=(A-TTABLE(I+1))/(TTABLE(I+1)-TTABLE(I+1))
U=TEMP*(TTABLE(I+6)-TTABLE(I+6))+TTABLE(I+6)
V=TEMP*(TTABLE(I+8)-TTABLE(I+8))+TTABLE(I+8)
RETURN
10 FORMAT(1H1 16HTHETA TOO SMALL *F10,6)
11 FORMAT(1H1 14HTHETA TOO BIG *F10,4)
END

SUBROUTINE AOPT(A+DELTA,SAVEA,SAVRMS,SAVEB,SAVBMAX,SAVMIN,SAVMXX, DR10291C
XSAVMXY,SAVMNXX,SAVMNY,RTRNFL)

THIS ROUTINE FINDS THAT VALUE OF A+DELTA FOR WHICH THE RMS ERROR
IS AT A LOCAL MINIMUM. NOTE: RMS IS ROOT-MEAN-SQUARE ERROR WHEN
COMPARSED WITH YNOMINAL.
DELTA IS ADDED TO OR SUBTRACTED FROM A IN THE DIRECTION OF DECREASE
SING RMS. ONCE RMS INCREASES, THE PREVIOUS VALUE OF A IS RETURNED
AS THE BEST VALUE OF A.

COMMON/AFTER/XSAV(1004),YSAV(1004),YDRSAV(1004),NOD,FNOD

INTEGER RTRNFL
REAL NORMAX,NORMIN

WRITE COLUMN HEADER.
CALL PR(-1)
WRITE (6*1)
1 FORMAT (1EH A RMS ERROR B SHIFT MAX NORM MIN NORM XX CO-ORDS MIN CO-ORDS )
C SET UP FOR FIRST YOFX CALL
C ATRY=A
CALL YOFX(0 ,ATRY ,0 ,*NSKIP)
C FIND ALL ASSOCIATED ERRORS AND THE B SHIFT.
CALL RMSB(B)
CALL RMSERR(B*RMS)
CALL MAXMIN(NORMAX,NORMIN,MAXI,MINI*B)
C SAVE EVERYTHING IN CASE THIS A IS OPTIMUM.
SAVMAXX=SAV(MAXI)
SAVMAXY=SAV(MAXI)
SAVMINX=SAV(MINI)
SAVMINY=SAV(MINI)
SAVEA=ATRY
SAVEB=B
SAVRS=RMS
SAVMAX=NORMAX
SAVMIN=NORMIN
C PRINT ALL DATA THIS A. A*RMS*B, NORMAX,NORMIN,MAX AND MIN CO-ORDS
CALL PRC=1)
WRITE (6*2) ATRY,RMS B,NORMAX,NORMIN,SAV(MAXI),YSAV(MAXI),
XXSAV(MINI),YSAV(MINI)
2 FORMAT (1H *5F10.4,4F8.2)
C SET UP FOR SECOND CALL TO YOFX WITH A+DELTA.
C ATRY=A+DELTA
CALL YOFX(0 ,ATRY ,0 ,*NSKIP)
C FIND ALL ASSOCIATED ERRORS AND B
CALL RMSB(B)
CALL RMSERR(B*RMS)
CALL MAXMIN(NORMAX,NORMIN,MAXI,MINI*B)
C PRINT DATA THIS TRY. A*RMS,B, NORMAX,NORMIN,MAX AND MIN CO-ORDS,
WRITE (6*2) ATRY,RMS B,NORMAX,NORMIN,SAV(MAXI),YSAV(MAXI),
XXSAV(MINI),YSAV(MINI)
C FIND DIRECTION OF CURVE A VS. RMS, PROCEED WITH LOOP BY INCREME-DR103450
TING A IN DIRECTION OF DECREASING RMS ERROR.
C STOP LOOP WHEN RMS ERROR STARTS INCREASING == THIS MEANS OPTIMUM
C A HAS BEEN FOUND
C SET UP LOOP INDEX
FI=3.
C TEST FOR DIRECTION OF DECREASING RMS ERROR.
IF (RMS,GT,SAVRS) GO TO 4
C INCREASE A TO DECFACE RMS ERROR
IFLAG=1
C SAVE NEW SET OF DATA AND ERRORS
SAVEA=ATRY
SAVEB=B
SAVRS=RMS
SAVMAX=NORMAX
SAVMIN=NORMIN
C
A-3.7

SAVMXX=XSAYV(MAXI)
SAVMXY=YSAV(MAXI)
SAVMNX=XSAV(MINT)
SAVMNY=YSAYV(MINT)
C INCREMENT A
3 ATRY=A+(FI-1.)*DELTA
GO TO 6
C DECREASE A TO DECREASE RMS ERROR.
4 IFLAG=0
C INCREMENT A
5 ATRY=A-(FI-2.)*DELTA
C FIND CURVE FOR ATRY
6 CALL YOFX(0+ATRY,0,NSKIPI)
C CALCULATE AND PRINT THE ERRORS AND B
C RMSB(B)
CALL RMSERR(B,RMS)
CALL MAXMIN(NORMAX,NORMIN,MAXI,MINTI,B)
WRITE (6,2) ATRY,RMS,B,NORMAX,NORMIN,MAXV(MAXI),MINTY,MAXV(MINTI),XSAV(MINTI)
C INCREMENT FI FOR LOOP
FI=FI+1.
C IS FI TOO LARGE
IF (FI.GT.20.) GO TO 8
C HAS THE OPTIMUM A BEEN PASSED? ARE THE RMS ERRORS INCREASING AGAIN?
IF (RMS.GT.SAVRMS) GO TO 7
C SAVE THE NEW ERRORS; A, B
SAVE=A,TRY
SAVEB=B
SAVRMS=RMS
SAVEAX=MAXAX
SAVMN=MIN
SAVMXX=XSAV(MAXI)
SAVMXY=YSAV(MAXI)
SAVMNX=XSAV(MINT)
SAVM NY=YSAYV(MINT)
C GO TO 3 TO INCREASE A; GO TO 5 TO DECREASE A.
IF (IFLAG) 3,5,3
C ABEST HAS BEEN FOUND; SET RETURN FLAG
7 RTNFL=1
GO TO 10
C ERROR = NO OPTIMUM A FOUND AFTER 20 INCREASES.
8 WRITE (6,9)
9 FORMAT (69H NO OPTIMUM A FOUND AFTER 20 INCREASES; CONTINUE WITH NEXT ANOMALY.)
C SET FLAG FOR RETURN
RTNFL=0
10 RETURN
END
SUBROUTINE PR(SW)
!
SUBROUTINE PR(SW)
!
C THIS SUBROUTINE PRINTS MAINHEADER AND PAGE NUMBER FOR EACH PAGE
ALSO PRINTS ASSEMBLY HEADER IF SW=1 OR +1
AND PRINTS COLUMN HEADER IF SW=+1
TO BE ENTERED J TIMES BEFORE A BLOCK OF J LINES ARE TO
BE PRINT
!
C
COMMON TABLE(200*8),HEAD1(20),HEAD2(20),HEAD3(20),PAGE,LINE
COMMON JMAX,J0,JINC,J1,J2,J0,WL,THEMA
INTEGER SW,PAGE
C
LINE=L1NE+1
L=MOD(LINE,50)
IF(L.EQ.1) GO TO 1
10 RETURN
1 PAGE=PAGE+1
C
WRITE(6,2)HEAD1,PAGE
C
WRITE(6,3)
3 FORMAT(1H1,20A4,8H PAGE +13)

C
IF (SW) 30+10+30
C 30 WRITE (6,31) HEAD3
C 31 FORMAT (1H0,20A4//)
LINE=LINE+2
IF (SW) 4+10+4
4 WRITE(6,2000)
C
2000 FORMAT(///)
WRITE(6,5)
5 FORMAT (80H X(INCH) Y(INCH) THETA(DEG) RADIUS(INCH) C1(INCH) BETA(DR105970)
XDEG) YAAAS(INCH) EX(INCH))
C
WRITE(6,6)
6 FORMAT(1H )
LINE=LINE+3
RETURN
END

SUBROUTINE RMSERR(B,RMS)
!
SUBROUTINE RMSERR(B,RMS)
!
C THIS SUBROUTINE FINDS THE NORMAL ROOT MEAN SQUARE DIFFERENCE
BETWEEN Y(X) AND YN(X)+B
!
C
COMMON AFTER/XSAV(1004),YSAV(1004),YDRSAV(1004),NOD,FNOD
C
RMS=0.
DO 1 I=1,NOD
- CALL NORMER(I,EX,B)
1 RMS=RMS+EX**2
RMS=SQRT(RMS/FNOD)
RETURN
END
SUBROUTINE MAXMIN(NORMAX,NORMIN,MAXI,MINI,B)

C THIS SUBROUTINE FINDS THE MAXIMUM POSITIVE AND NEGATIVE NORMAL
C DISTANCES FROM YN(X) THAT Y(X) ATTAINS AND THE COORDINATES ON Y(X)
C AT THESE MAXIMUM DISTANCES.

COMMON/AFTER/XSAV(1004),YSAV(1004),YDRSAV(1004),NOD,FNOD

REAL NORMAX,NORMIN
DENOM=0.

C FIND THE NORMAL DIFFERENCE AT X(I).
CALL NORMER(I,EX,B)

C INITIALIZE NORMAX,NORMIN,MAXI,MINI
NORMAX=EX
NORMIN=EX
MINI=1
MAXI=1

DO LOOP TO FIND MAXIMUMS.

DO 1 I=1,NOD
CALL NORMER(I,EX,B)
IF (EX.GT.NORMAX) GO TO 2
IF (EX.GT.NORMIN) GO TO 1
NORMIN=EX
MINI=I
GO TO 1
2 NORMAX=EX
MAXI=I
1 CONTINUE
RETURN
END

SUBROUTINE RMSB(B)

C FINDS OPTIMUM SHIFT B, SUCH THAT THE NORMAL RMS DEVIATION IS LEAST

COMMON/AFTER/XSAV(1004),YSAV(1004),YDRSAV(1004),NOD,FNOD
COMMON/ALWAYS/XNMAX,YNMAX

DENOM=0.
BNUM=0.

DO 1 I=1,NOD
CALL YN(XS,Y(I),YNOM)
YNPRI=2.*YNMAX*XSAV(I)/XNMAX**2
FX=SQRT((1.+YNPRI**2)/(1.+YNPRI*YDRSAV(I))
BNUM=BNUM+YSAV(I)-YNOM)*FX**2
1 DENOM=DENOM+FX**2
B=BNUM/DENOM
RETURN
END
SUBROUTINE CaNST

C
C THIS SUBROUTINE CONSTRUCTS THE 3 FUNCTIONS
     F(THETA), PHI(THETA), AND PHI PRIME (THETA)
C FROM THE INPUT DATA, AS WELL AS TRANSFORMING THE INPUT
C TO THE PROPER UNITS.
C
C COMMON TTAPE(200,8), HEAD1(20), HEAD2(20), HEAD3(20), PAGE, LINE
C COMMON JMAX, J0, JHR, IC1, IC2, R0, WL, THEMAX
C
DO 4 I=1, JIN
   TTAPE(I,1)=TTAPE(I,1)*0.174532925
   IF(JC1)*1+1, 2
   1 TEMP1=TTable(I,2)/20
   TEMP2=TTAPE(I,4)*20
   TTAPE(I,2)=TEMP1
   TTAPE(I,4)=TEMP2
   GO TO 3
   2 TEMP1=TTAPE(I,2)
   TEMP2=TTAPE(I,4)
   3 TTAPE(I,6)=(TEMP1**2+TEMP2**2)2
   IF(IC2.GT.0) GO TO 35
   TTAPE(I,3)=TTAPE(I,3)*W/L/360
   TTAPE(I,5)=TTAPE(I,5)*W/L/360
   TTAPE(I,7)=TTAPE(I,3)+TTAPE(I,5)/2
   GO TO 4
   35 TTAPE(I,7)=0
   TTAPE(I,3)=0
   TTAPE(I,5)=0
   4 CONTINUE

NOW TO COMPUTE PHI PRIME (TABLE OF DERIV.)
NOTE WELL-------THETA ASUMMED TO BE EQUALLY SPACED-------

U1=1/(2*TTAPE(2,1)*TTAPE(1,1))
   TTAPE(1,6)=U1*(TTAPE(3,7)+TTAPE(2,7))=3*TTAPE(1,7)
   TTAPE(JHR)=U1*(3*TTAPE(JIN+7)+4*TTAPE(JIN+17)+TTAPE(JIN+27))
   X(JIN+27)
   K=JIN=1
   DO S I=K, K
   TTAPE(I,8)=U1*(TTAPE(I+1,7)=TTAPE(I-1,7))
   5 CONTINUE
   RETURN
END
SUBROUTINE DERIV
SYSTEM OF 2 SIMULTANEOUS DIFFERENTIAL EQUATIONS
INDEPENDENT VARIABLE IS THETA
DEPENDENT VARIABLES ARE Y AND R

COMMON /DERARG/A,C2,VAR(4),DER(4),EU(3),EL(3),TEMPS(41)
COMMON TTABLE(200,8),HEAD1(20),HEAD2(20),HEAD3(20),PAGE.LINE
COMMON JMAX,J0,JIN,IC1,IC2,RO,RL,THEMAX

EQUIVALENCE(X,VAR(1)),(THETA,VAR(2)),(Y,VAR(3)),(R,VAR(4))
X(H,DER(1)),(THETAP,DER(2)),(YP,DER(3)),(RP,DER(4))

THETAP=THETA
IF(THETA.LT.0.) THETA=0.
TEMP=8IN(THETA)
call xofig(x,THETA)
BETA=ATAN2(X-R*TEMP,Y+R*COS(THETA)-A)
call fpat(THETA,FPATA,PHIPR)

YPFAC=0.
IF(X.LE.0003) YPFAC=SQRT(TTABLE(16)/C2)
IF(X.GT.0003) YPFAC=FPATA*TEMP/(C2*X)
THETAP=1.E+10
IF(YPFAC.LE.0.) THETAP=1./YPFAC
YP=TAN(BETA/2.)*YPFAC
RP=R*TAN((BETA+THETA)/2.)*PHIPR/(1.+COS(BETA+THETA))

THETA=THETAP
RETURN
END

SUBROUTINE NORMER(I,EX,B)
THIS SUBROUTINE FINDS THE NORMAL DISTANCE FROM YN AT A POINT I ON Y.

COMMON/AFTER/XSAV(1004),YSAV(1004),YDRSAV(1004),NOD,FNOD
COMMON/ALWAYS/XNMAX,YNMAX

CALL YNXS(AV(I),YNCN)
YPNPR1=2.*YNMAX*XSAV(I)/XNMAX**2
EX= (YSAV(I)-YNCN-B) *SQRT(YPNPR1*YPNPR1+1.)/(1.+YDRSAV(I)*YPNPR1)
RETURN
END
SUBROUTINE POSTPR

THIS IS THE POSTPROCESSOR CONTROL SUBROUTINE. AFTER PUNCHING THREE HEADER CARDS, DECK2, DECK3, AND DECK4 ARE CALLED TO PUNCH VARIOUS DECKS.

COMMON T_TABLE(200,8), HEAD1(20), HEAD2(20), HEAD3(20), PAGE, LINE
COMMON JMAX, J0, JIN, IC1, IC2, R0, WL, THEMAX

CALL DECK2
RETURN
END

SUBROUTINE DECK2

THIS SUBROUTINE IS CALLED BY POSTPR TO PUNCH 3 DECKS WITH 100 VALUES EACH WHERE ALL VALUES ARE FUNCTIONS OF THETA, WHERE THETA VARIES AS UNIFORMLY AS POSSIBLE OVER THE RANGE 0-THETAMAX, THE VALUES USED TO CALCULATE THE PUNCHED VALUES ARE THE RESULTS FROM THE FINAL INTEGRATION.

DECK2 CONTAINS \( \frac{1}{R} \)
DECK2 CONTAINS \( \frac{RPR}{\text{THER.PR.R}^{*2}} \)
DECK2 CONTAINS THEBAR=\( \frac{\pi}{\text{THETA}} \)

COMMON/AFTER/XSAV(1004), YSAV(1004), YDRSAV(1004), NOD, FNOD
COMMON/CPOST/RAD(1004), RPR(1004), THPR(1004), THE(1004), C, P, MULT

DIMENSION DECK21(:), DECK22(100), DECK23(100)

\( \pi = \frac{3.1415927}{2} \)
DO 100 IX=1,100
IF(IX,LE,12) I=252-IX

100 CONTINUE
IF (IX .EQ. 13) I = 238
IF (IX .GE. 14 .AND. IX .LE. 87) I = 236 + (IX - 14)
IF (IX .EQ. 88) I = 15
IF (IX .EQ. 89) I = 13
IF (IX .GE. 90) I = 101 + IX
I = I * MULT = (MULT .EQ. 1)
DECK21 (IX) = 1 . / RAN (I)
DECK22 (IX) = DPR (I) / (THPR (I) * RAD (I) ** 2)
DECK23 (IX) = PI * THE (I) * 0.174532925

C PUNCH THE THREE DECKS AND RETURN
C ALSO PUNCH PSEUDO-HYPERBOLA ON FILE 21
C
PUNCH 2* (DECK21 (J) * J = 1 * 100)
WRITE (21, 2) (DECK21 (J) * J = 1 * 100)
PUNCH 2* (DECK22 (J) * J = 1 * 100)
WRITE (21, 2) (DECK22 (J) * J = 1 * 100)
PUNCH 2* (DECK23 (J) * J = 1 * 100)
WRITE (21, 2) (DECK23 (J) * J = 1 * 100)
WRITE (6, 200)

200 FORMAT (1 IH1)
WRITE (6, 210) (DECK21 (J) * J = 1 * 100)
WRITE (6, 210) (DECK22 (J) * J = 1 * 100)
WRITE (6, 210) (DECK23 (J) * J = 1 * 100)

210 FORMAT (1 X E 15.8, 1 X E 15.8, 1 X E 15.8, 1 X E 15.8, 1 X E 15.8)
2 FORMAT (5 E 15.8)
RETURN
END

SUBROUTINE YN (X, YNOM)
C THIS ROUTINE CALCULATES YN(X) (Y NOMINAL)
C COMMON / ALWAYS / XNMAX, YNMAX
C YNOM = YNMAX * (1 - (X / XNMAX) ** 2)
RETURN
END
APPENDIX B

The Program for Phase Adjustment of Scattered Pattern for Efficiency Calculations

Following is a listing of the program that performs the alterations of phase on the subreflector scattered pattern so that it may be used with programs which calculate the feed efficiency for paraboloids. Refer to figure 3-1 within the text for a more complete description of the input parameters.

The "SHAPERPHASE" Program

C
C & PROGRAM FOR PHASE "CORRECTION" OF THE SCATTERED FIELDS FROM A SHAPED
C SUBREFLECTOR -- TAKING OUT THE VARIATION FROM SHAPING BUT LEAVING IN
C TACT THE RIPPLE FROM PHYSICAL OPTICS. THIS IS DONE FOR USING THE RESULT
C IN THE EFFICIENCY PROGRAM WHICH ASSUMES A PARABOLA.
C
C
C W. F. WILLIAMS, DECEMBER, 1977
B-2

C FREQ= FREQUENCY IN MEGAHERTZ. B= THE Y DIMENSION, GIVEN AS A POSITIVE
C NUMBER FROM THE ORIGIN BELOW REFLECTOR EDGE) TO THE SCATTERED PATTERN
C PHASE CENTER. "IE." THE QUASI-PARABOLOID FOCUS. IPUNCH=0 FOR A PUNCHED
C OUTPUT FOR THE EFFICIENCY PROGRAM. JMAX=THE NUMBER OF INPUT ANGLES OF
C SCATTERED DATA. IC1=1; (INPUT IN VOLTS)
C SUMR=0.0, NOT USED. BLK=0.0, NOT USED.
C Y(N) AND X(N) ARE THE COORDINATES OF THE MAIN SHAPED
C REFLECTOR. BETA(N) IS THE ANGLE (DEGREES) BETWEEN THE
C SUBREFLECTOR REFLECTED RAY AND THE REFLECTOR AXIS.
C ALL DIMENSIONS IN INCHES (8* X(N), Y(N) )
C INPUT PATTERN IN DEGREES(THETA), VOLTS (ET AND HT)
C AND DEGREES PHASE (ETP AND HTP).

****INPUT DECK*****
1. FREQ, B, IPUNCH (2F10.5,I5)
2. TITLE1 (10A4)
3. TITLE2 (20A4)
4. JMAX, IC1 (2I5)
5. SUMR, BLK (8F10.5)
6. THETA(J), ET(J), ETP(J), HT(J), HTP(J), (8F10.5)
   ETC ***
7. X(N), Y(N), BETA(N) (8F10.5)
8. ETC **

** PUNCHED OUTPUT ***
1. TITLE1 (10A4)
2. TITLE2 (20A4)
3. JMAX, IC1 (2I5)
4. SUMR, BLK (E15.8X, F10.5)
5. THETA(J), ET(J), ETP(J), HT(J), HTP(J), (8F10.5)
6. ETC****

DIMENSION THETA(721), ET(721), ETP(721), HT(721), HTP(721)
DIMENSION X(1004), Y(1004), BETA(1004)
DIMENSION TITLE1(10), TITLE2(20)
PI=3.141592654
CONV=PI/180.0
CINCH=11.0028526
READ(5,140) FREQ, B, IPUNCH
140 FORMAT(2F10.5,I5)
   READ (5,100) TITLE1
100 FORMAT (10A4)
   READ (5,110) TITLE2
110 FORMAT (20A4)
   READ (5,120) JMAX, IC1
120 FORMAT (2I5)
   READ (5,150) SUMR, BLK
150 FORMAT (E15.8X, F10.5)
   SUMR=0.0
   WRITE(6,250) TITLE1
250 FORMAT(I1,10A4/)
   WRITE(6,230) FREQ, B
230 FORMAT(5X,H,FREQ=F10.5,3X,2HB=F10.5,/)

ORIGINAL PAGE IS OF POOR QUALITY
IF(IPUNCH .GT. 0) GO TO 20
  PUNCH 100, TITLE1
  PUNCH 110, TITLE2
  PUNCH 120, JMAX, IC1
  PUNCH 150, SUMR, BLK
20 CONTINUE
  DO 5 J=1, JMAX
5    READ(5,130) THETA(J),ET(J),ETP(J),HT(J),HTP(J)
130  FORMAT(8F10.5)
    N=1
  21 READ(5,160,END=10) X(N), Y(N), BETA(N)
160  FORMAT(2F10.5,20X,F10.5)
    N=N+1
    GO TO 21
10 NMAX=N-1
    WVL=2*PI/NMAX
    THEONE=ATAN(X(1)/(B+Y(1)))
    THEONE=THEONE/CONV
    R=SQRT((B+Y(1))**2+X(1)**2)
    WRITE(6,240) R, THEONE, NMAX
240  FORMAT(5X*2HR=F10.5,4X,10HTHETANMAX=F10.5,4X,5HNMAX=F10.5)
    WRITE(6,260)
260  FORMAT(//10X*1HN,7X,4HX(N),10X,4HY(N),10X,7HBETA(N),/)
    DO 30 N=1,NMAX
       WRITE(6,270) N, X(N), Y(N), BETA(N)
30    FORMAT(5X*2NBT=BETA(N)*CONV)
270  FORMAT(7X*15,3X,F10.5,5X,F10.5,5X,F10.5)
    WRITE(6,280)
280  FORMAT(//10X*14H INPUT PATTERN,//14X,5HTHETA,12X,2HET,12X,3HETP,
         **14X,2HHT,11X,3HHTP,*/
         DO 15 J=1, JMAX
30    WRITE(6,210) THETA(J), ET(J), ETP(J), HT(J), HTP(J)
15   FORMAT(10X*5F10.5,5XF10.5,5XF10.5,5XF10.5)
    WRITE(6,220)
220  FORMAT(//10X*14H OUTPUT PATTERN,//6X,5HTHETA,8X,2HET,9X,3HETP,
         **9X,2HHT,8X,3HHTP,7X,1HN,5X,2HNN,7X,7HBETA(N),6X,8HBETA(NN),
         **5X,5HBBETA J=1)/
    WRITE(6,230)
230  FORMAT(7X*15,3X,F10.5,5X,F10.5,5X,F10.5)
    WRITE(6,240)
240  FORMAT(//10X*15H THEETA .GT. THEETA) GO TO 105
    J=J+1
    GO TO 25
105 JSAVE=J
    NMX=NMAX-1
85   DO 35 NN=NMX,1,-1
       THETA=ATAN(X(NN)/(Y(NN)+E))
       IF(THETA .GT. THEETA(J)) GO TO 25
       GO TO 35
25   NN=NN+1
       THEETN=ATAN(X(NN)/(Y(NN)+E))
         YBN=Y(NN)+E
         FN=(YBN+SQRT(X(NN)**2+YBN**2))/2.0
         YBNN=Y(NN)+E
         FNN=(YBNN+SQRT(X(NN)**2+YBNN**2))/2.0
         TK=(THETA-THEETA(J))/(THEETA-THEETN)
         FJ=FN-((FN-FNN)*TK)
HJ=FJ/(COS(THETA(J)/2.0)**2)
YJ=HJ*COS(THETA(J))
XJ=HJ*SIN(THETA(J))
BETA=BETA(N)-(THETAN-THETA(J))*(BETA(N)-BETA(NN))/(THETAN-THETNN)
DO 26 I=1,JMAX
IF(BETA(I).LT.0.0) GO TO 27
26 CONTINUE
27 II=I-1
FRAC=(BETA(I)-THETA(II))/(THETA(I)-THETA(II))
ETC(J)=ET(I(I))+FRAC*(ETC(I)-ET(I(I))
HTC(J)=HT(I(I))+FRAC*(HTC(I)-HT(I(I))
IF(ETP(I(I)).LT.0.0) AND ETP(I).GT.0.0) ETP(I)=ETP(I(I))+360.0
IF(HTP(I(I)).LT.0.0) AND HTP(I).GT.0.0) HTP(I)=HTP(I(I))+360.0
ETP(J)=ETP(I(I))+FRAC*(ETP(I)-ETP(I(I))
HTP(J)=HTP(I(I))+FRAC*(HTP(I)-HTP(I(I))
IF(ETP(I)).GT.180.0) ETP(J)=ETP(I)-360.0
IF(HTP(I)).GT.180.0) HTP(J)=HTP(I)-360.0
ZJ=B*YJ-XJ/TAN(BETA(I))
DELR=DEL-(YJ*SIN(BETA(I)))-ZJ*COS(BETA(I))
DELD=DELR-YJ
DELLAM=DELD/WVL
K=DELLAM
DELDEG=(DELLAM-K)*360.0
ETP(J)=ETP(J)+DELDEG
HTP(J)=HTP(J)+DELDEG
IF(ETP(J)).LT.-180.0) ETP(J)=ETP(J)+360.0
IF(HTP(J)).LT.-180.0) HTP(J)=HTP(J)+360.0
IF(ETP(J)).GT.180.0) ETP(J)=ETP(J)-360.0
IF(HTP(J)).GT.180.0) HTP(J)=HTP(J)-360.0
THETA(J)=THETA(I)/CONV
THETA(N)=BETA(N)/CONV
THETA(NN)=BETA(NN)/CONV
BETA=2*CONV
IF(J.LT.JSAVE) GO TO 27
MM=JSAVE-1
DO 65 M=1,MM
ETP(M)=ETP(JSAVE)
HTP(M)=HTP(JSAVE)
THETA(M)=THETA(M)/CONV
WRITE(6,280) THETA(M),ETP(M),HTP(M)
IF(IPUNCH.GT.0) GO TO 65
PUNCH 130, THETA(M),ETP(M),HTP(M)
65 WRITE(6,280) THETA(J),ET(J),ETP(J),HTP(J),N,NN,
* BETA(N),BETA(NN),BETA(J)
IF (IPUNCH.GT.0) GO TO 55
PUNCH 130, THETA(J),ET(J),ETP(J),HTP(J)
55 BETA(N)=BETA(N)/CONV
BETA(NN)=BETA(NN)/CONV
THETA(J)=THETA(J)/CONV
J=J+1
35 CONTINUE
K=J
DC 45 L=K,JMAX
THETA(L)=THETA(L)/CONV
WRITE(6,290) THETA(L),ET(L),ETP(L),HT(L),HTP(L)
290 FORMAT(2X,F10.5,1X,F10.5,2X,F10.5,1X,F10.5,2X,F10.5)
IF(IPUNCH.EQ.0) GO TO 45
PUNCH 130, THETA(L),ET(L),ETP(L),HT(L),HTP(L)
45 CONTINUE
75 END
APPENDIX C
"SAMPLE RUN" OF SHAPING AND PHASE ALTERATION

Following is a sample computer run of the shaping program and the phase altering program. The X-Band pattern of a 14 degree horn is used to calculate a shape for optimum illumination efficiency on a 98.1 meter dish, using a 10 meter subreflector. An 8.6 meter section at the center of the main reflector is left in a complete optical shadow to increase final subreflector blockage efficiency.

The subreflector edge taper (edge illumination) from the 14° horn is at 13.12° or about -18.4 dB. The final focus location is at A = 283.5 inches, measured from the aperture toward the vertex. Note the final shape has an RMS variation from a paraboloid of 0.61 inches.

751 values of X, Y, R, and θ are tabulated followed by three groups of 100 values each that define the subreflector surface, suitable for application in a JPL scattering program. These values are:

1. \(-1/R\), inverse of the distance from the focus to the subreflector surface.
2. \(d(-1/R)/d\theta\), where \(\theta\) is the particular angular coordinate corresponding to \(R\).
3. \(\theta\), the angle between the reflector axis and \(R\), in radians. \(\theta = \pi\) when \(R\) is along the axis to the subreflector vertex.

The phase altering program re-tabulates the main reflector coordinate values and the input pattern (obtained from a scattering computer program, the horn pattern from the shaped subreflector). This is then followed by the computed slightly altered amplitude pattern and a near uniform phase pattern suitable for efficiency calculation.
SYMETRICAL SHAPING PROGRAM

***INPUT XNMAX*YNMAX, 2FIN,S OR *

1931.00000 731.50000

***INPUT MAIN HEADER

3862 IN, DISH F/D=.325, 170 IN, HOLE

***INPUT FIELD DATA HEADER

A 10 DH AT 13.12 DEG(18.4 DB)* X SHA

***INPUT JIN* IS

181

***ADD VOLTAGE ILLUM PATTERN DECK

***INPUT NSKIP* IS

1 3

***INPUT A 1 FOR RUSCH OUTPUT* IS
***INPUT A 2 FOR PSCATT OUTPUT* IS
***INPUT A 3 FOR BOTH OUTPUTS* IS
### Input Parameters

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<td>INPUT THETAMAX</td>
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<td>INPUT DMIN</td>
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### Calculations

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<tr>
<td>A NOMINAL = 283.00000 DELTA A MAX = 1.00000 DELTA A MIN = -1.00000</td>
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### True C2 Value

| C2 = 0.321854-08 |

### RMS Error & Shift

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### Table of Data Points

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### Conclusion

- The true C2 value is 0.321854-08.
- The parameters and calculations are presented in detail for input and output data points, demonstrating the process and results.
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# BRKPT PUNCH

**ED0Y 20,14350*FIL,PA140H=325**

THIS IS A FORTRAN FILE

CASE UPPER ASSUMED

EDIT 14,05H03/20=21:31=(0+)

EDIT LINES1751 FIELD DATA
CPU1,865 CTPI.014 SUP518,633

**ED0Y 21,14350*FIL,HYX140H=325**

THIS IS A FORTRAN FILE

CASE UPPER ASSUMED

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EDIT LINES160 FIELD DATA
CPU1,081 CTPI.004 SUP514,409

**PACK 94350*FIL**

FURPUR 27=Q 03/20/78 21:31123

END PACK. TEXT=256+TOC=1+SYM#95+REL=2+ABS=14

CPU1,048 CTPI.004 SUP511,827

**FIN**
### THE 170 INCH HOLE; X-BAND

**FREQ** 8.41500  **B=625.02497**

| \( R=2029.63474 \) | \( \text{THETAMAX}=72.06430 \) | \( \text{NMAX}=1751 \) |

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