(NASA-CR-147835) SPACE SHUTTLE ENGINEERING AND OPERATIONS SUPPORT. ISOLATION BETWEEN THE S-BAND QUAD ANTENNA AND THE S-BAND PAYLOAD ANTENNA. ENGINEERING SYSTEMS ANALYSIS (McDonnell-Douglas Astronautics) G3/33

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HOUSTON ASTRONAUTICS DIVISION

SPACE SHUTTLE ENGINEERING AND OPERATIONS SUPPORT

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ISOLATION BETWEEN THE S-BAND QUAD ANTENNA AND THE S-BAND PAYLOAD ANTENNA

ENGINEERING SYSTEMS ANALYSIS

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1.0 SUMMARY

The isolation between the Upper S-Band Quad Antenna and the S-Band Payload Antenna on the Shuttle Orbiter is calculated using a combination of plane surface and curved surface theories along with worst-case values. A minimum value of 60 dB isolation is predicted based on recent antenna pattern data, antenna loactions on the Orbiter, curvature effects, dielectric covering effects and edge effects of the Payload Bay. The calculated value of 60 dB is significantly greater than the baselined value of 40 dB. Use of the new value will result in the design of smaller, lighter weight and less expensive filters for S-Band TDRS Transponder and the S-Band Payload Interrogator.

2.0 INTRODUCTION

The isolation between the Upper S-Band Quad Antenna and the S-Band Payload Antenna is a significant factor for determining the amount of filtering needed to prevent the transmitter of one system from adversely affecting the receiver of the other system. The initially specified isolation between the antennas was conservatively given as 40 dB without specific knowledge of the antenna design or the exact placement of the antennas. It is the purpose of this report to calculate a worst-case value which includes some of the factors not previously known. Factors in this report include the free-space transmission loss, the antenna power gains in a direction parallel to the antenna surface, the effect of the Orbiter body curved surface, the effect of the thermal protection system dielectric covering and a factor to account for edge effects associated with the opening of the payload bay doors. Because of the worst-case asssumptions, it is believed that future measured values of isolation will.show more isolation than that calculated in this analysis.

The current configuration of the Upper S-Band Quad Antenna and S-Band Payload Antenna is shown in Figure 1. The area around the Payload Antenna is covered with a felt material having a thickness of .32 inches which is bonded to the Orbiter metallic skin with RTV-560. A weather proof coating of silica is planned for use over the felt. The Upper Quad Antenna is covered with the standard LI-900 tiles having a thickess of 0.41 inches. The normals to the antenna surfaces are

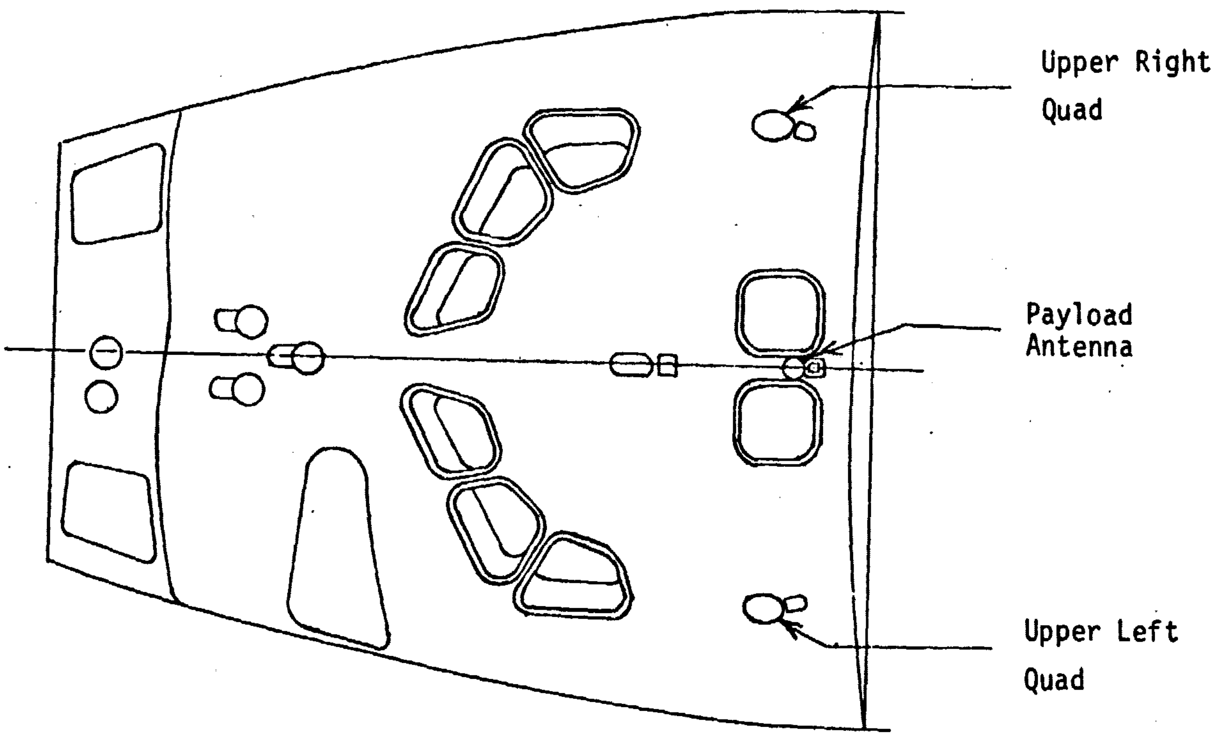

Figure 1. Upper Quad Antenna and Payload Antenna Configuration

approximately 45 degrees apart and the surface of the Orbiter may be approximated as a cylinder in this region with a radius of 100 inches (see Rockwell drawing number VC70-001001).

The calculations in this paper do not include the possible increased coupling due to reflections from an EVA astronaut or deployed payload in close proximity to the S-Band Payload and Quad Antennas.

3.0 DISCUSSION

The isolation, I, between the S-Band Quad Antenna and the S-Band Payload Antenna may be computed using Equation (1) such that

$$I\,(dB) = -10 \log C \qquad (1)$$

where C is the mutual coupling given in Equation (2) which may be derived from Reference A

$$C = L_{fs}\, G_p\, G_q\, L_c\, G_d\, G_e \qquad (2)$$

where L_{fs} = free-space transmission loss

G_p = power gain of Payload Antenna in a direction parallel to the antenna surface

G_q = power gain of Quad Antenna in a direction parallel to the antenna surface

L_c = loss due to curvature of Orbiter

G_d = gain due to thermal protection system dielectric layers

G_e = gain due to edge effects of Payload Bay, Payload Bay Doors, radiator panels, star tracker door and miscellaneous factors

Each of the previous parameters may be expressed in decibels (dB's) so that the factors are added instead of multiplied. Each factor and the rationale for its use is explained in this section.

3.1 Free-Space Transmission Loss

The free-space transmission loss may be accurately applied to determine coupling between two antennas on a common surface provided the antennas are separated by 2 wavelengths or the far field distance ($2L^2/\lambda$) whichever is greater. The distance L represents the largest linear dimension of the largest antenna and λ is the wavelength. For the case being considered two wavelengths is 10.5 inches and the far field is 42 inches assuming the largest dimension for the Quad Antenna to be 10.5 inches. The free-space loss, L_{fs}, is given by

$$L_{fs} = \frac{\lambda^2}{(4\pi R)^2} \qquad (3)$$

where $\lambda = \frac{11{,}808}{f\ (\mathrm{MHz})}$ = wavelength in inches

R = distance between antennas measured along surface in inches = 78.5"

For a frequency of 2250 MHz with a spacing of 78.5" the free-space loss expressed in dB is found to be

$$L_{fs}\ (\mathrm{dB}) = -45.5\ \mathrm{dB}$$

3.2 Antenna Power Gain

The antenna power gain may be obtained assuming radiation in a direction parallel to the antenna surface. The power gains are obtained for the worst-case condition from patterns in a recent report (Reference B). The Payload Antenna pattern is shown in Figure 2 and the maximum power gain, G_p, at the angle of interest is found to be -6.0 dBci with respect to a perfect circular isotropic level. The Quad Antenna pattern is shown in Figure 3 and the maximum power gain, G_q, is found to -6.5 dBci with respect to a perfect circular isotropic level. The polarization of the antennas has not been measured at angles parallel to the antenna surface; however, it is expected to be predominately linear with the electric field parallel to the antenna surface. Also, it is expected that the predominate component of the electric field will be perpendicular to the plane of propagation. This mode is frequently referred to as H-plane propagation since the H-plane is essentially in the plane of propagation. If this condition does not exist (i.e. H-plane propagation) the effective antenna power gains may easily be reduced an additional 10 dB; thus, the numbers used in this evaluation are considered to be maximum power gain levels.

The above power gains are specified with respect to a circular isotropic level and do not accurately represent the worst-case power gain levels since both of the antennas expected to be predominantly linear in the plane parallel with the antenna surface. A 3 dB circular-to-linear factor may be assumed resulting in a Quad Antenna power gain of G_q = -3.5 dBli with respect to a perfect linear isotropic level and the Payload Antenna power gain becomes -3.0 dBli. The Payload Antenna, however, is

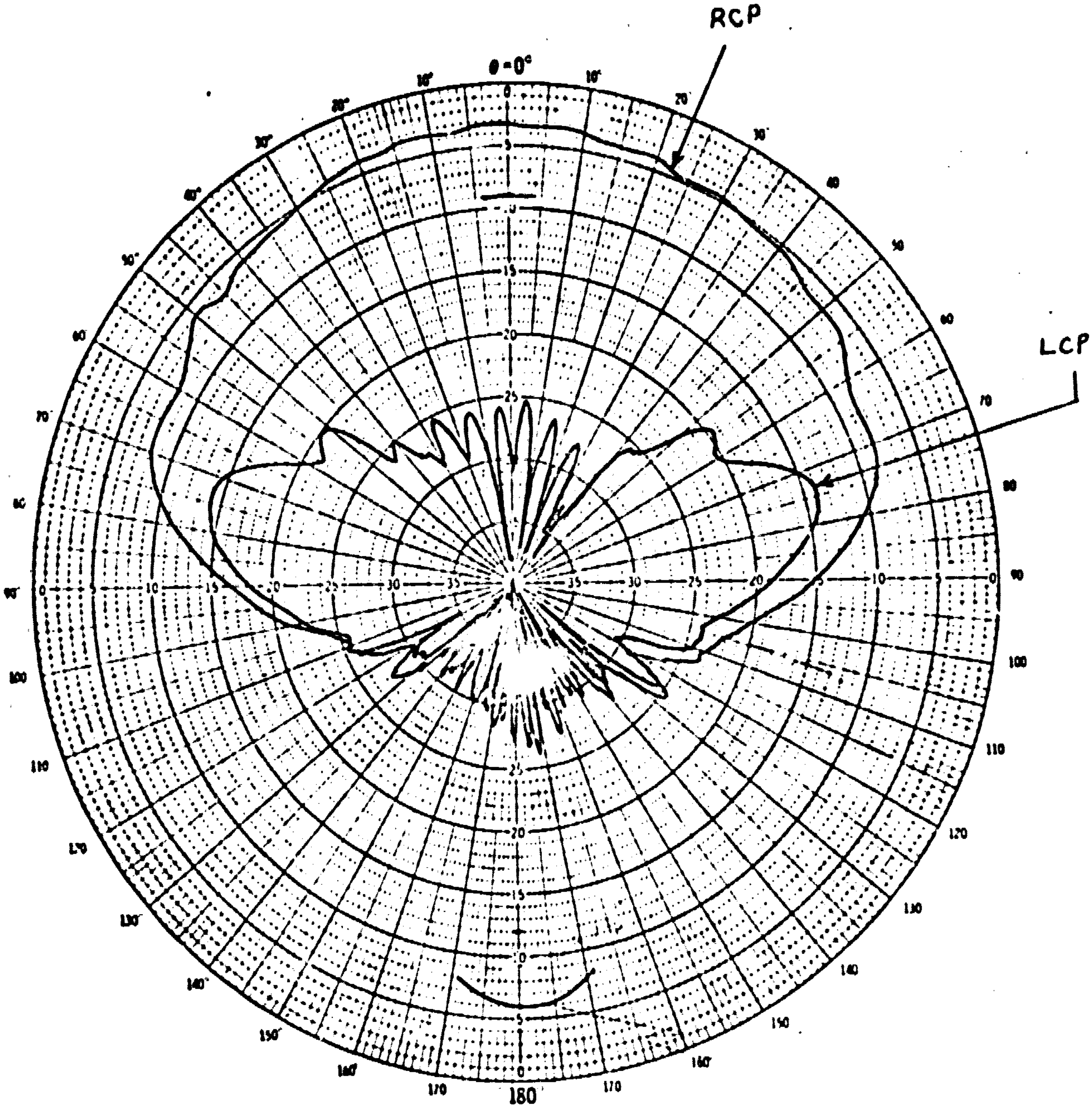

Figure 2. S-Band Payload Antenna Pattern (Reference B)

PERFECT ISOTROPIC LEVEL = 9 dB
MAXIMUM POWER GAIN AT Θ = 90° -6 dBci
MAXIMUM POWER GAIN AT Θ = 0° + 5.8 dBci

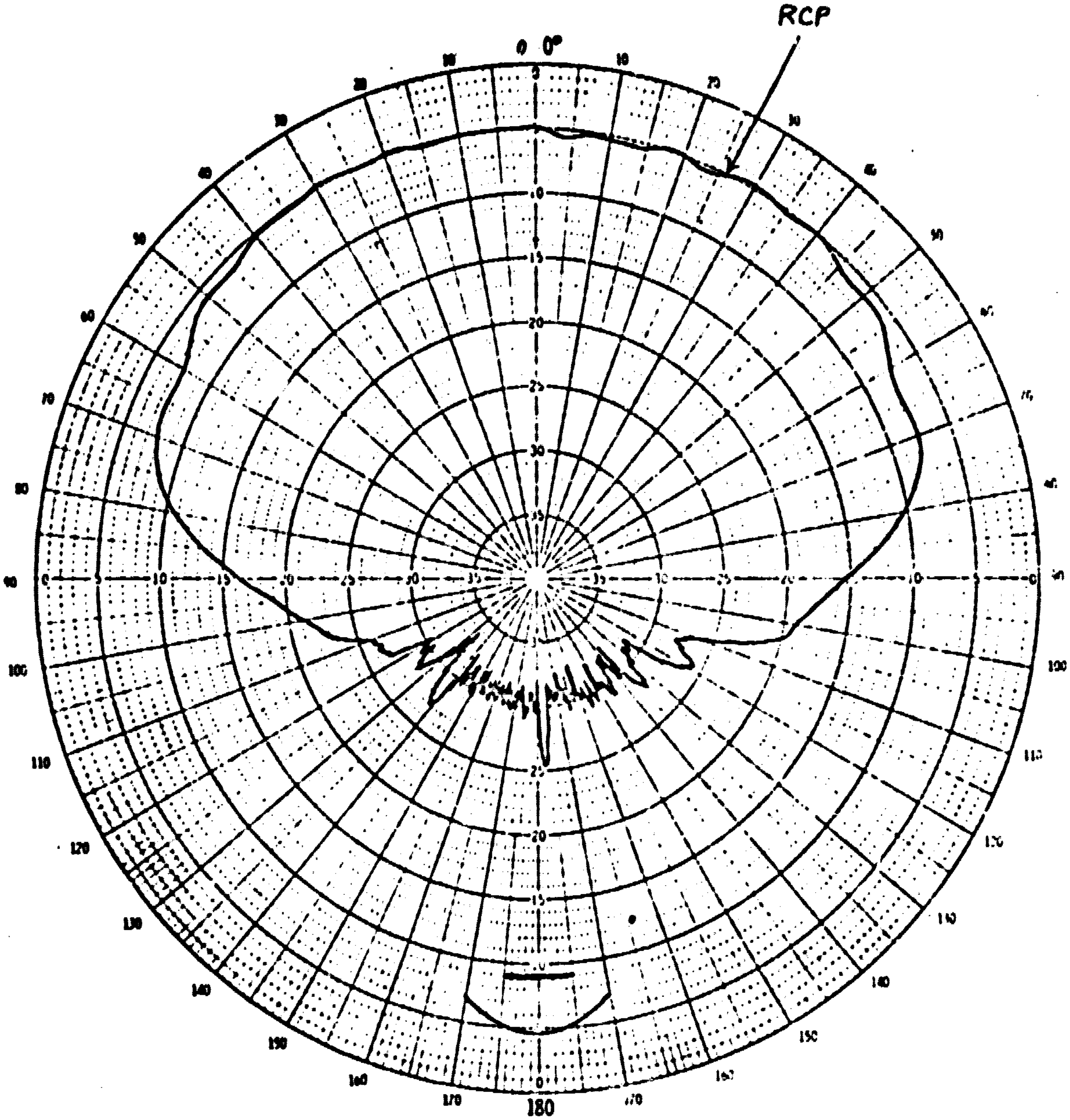

Figure 3. S-Band Quad Antenna Pattern (Reference B)

PERFECT ISOTROPIC LEVEL = 9 dB
MAXIMUM POWER GAIN AT Θ = 90° -6.5 dBci
MAXIMUM POWER GAIN AT Θ = 0° +4.0 dBci
REPRESENTATIVE PATTERN FOR ORBITER ROLL PLAN

being designed with a minimum of two chokes surrounding the outside of the antenna to reduce mutual coupling effects. Under this condition the effective power gain of the Payload Antenna for a linear response is estimated to be G_p (two chokes) = -6.0 dBli (Reference B).

3.3 Loss Due to Curvature Effect

The loss due to the curvature has been determined using a procedure developed by J.A.M. Lyon (Reference C) for a cylinder with a radius much larger than a wavelength. For the example considered in this paper the radius is estimated from Rockwell drawing number VC70-001001 to be 100 inches (19.1λ) which is significantly greater than the wavelength of 5.25 inches (1λ). The angle between the two planes, each containing one antenna centroid and the center axis of the hypothetical cylinder is estimated as 45 degrees. The distance between antennas measured along the surface is estimated to be 78.5 inches (15λ). A nomograph was developed by J. A. M. Lyon and is reproduced in Figure 4 for the particular problem of interest. The following values are used.

$a/\lambda = 19.1$ (radius of cylinder)

$r_s/\lambda = 15.0$ (distance between antennas measured along surface)

$\phi = 45°$ (angle between planes containing antennas and axis of cylinder)

The previous values are used to determine the parameter y which in turn is used for determination of the curvature factor $f(y)$. The curvature factor is obtained from the graph in Figure 5 also obtained from Reference C. The value of y from Figure 4 is 7.5 and the curvature loss factor $f(y)$ from Figure 5 is found to be -14.0 dB. The additional isolation which occurs from the curvature of the Shuttle Orbiter between the S-Band Payload Antenna and the Upper S-Band Quad Antenna is found to be 14 dB.

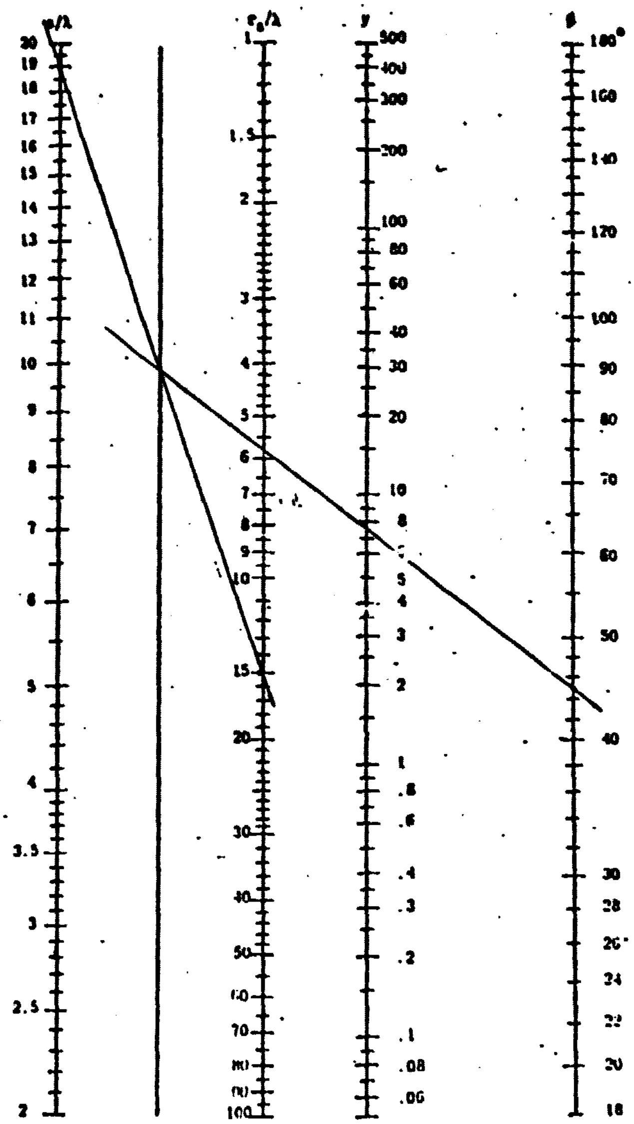

Figure 4. Nomograph for Y Factor on a Cylinder (Reference C)

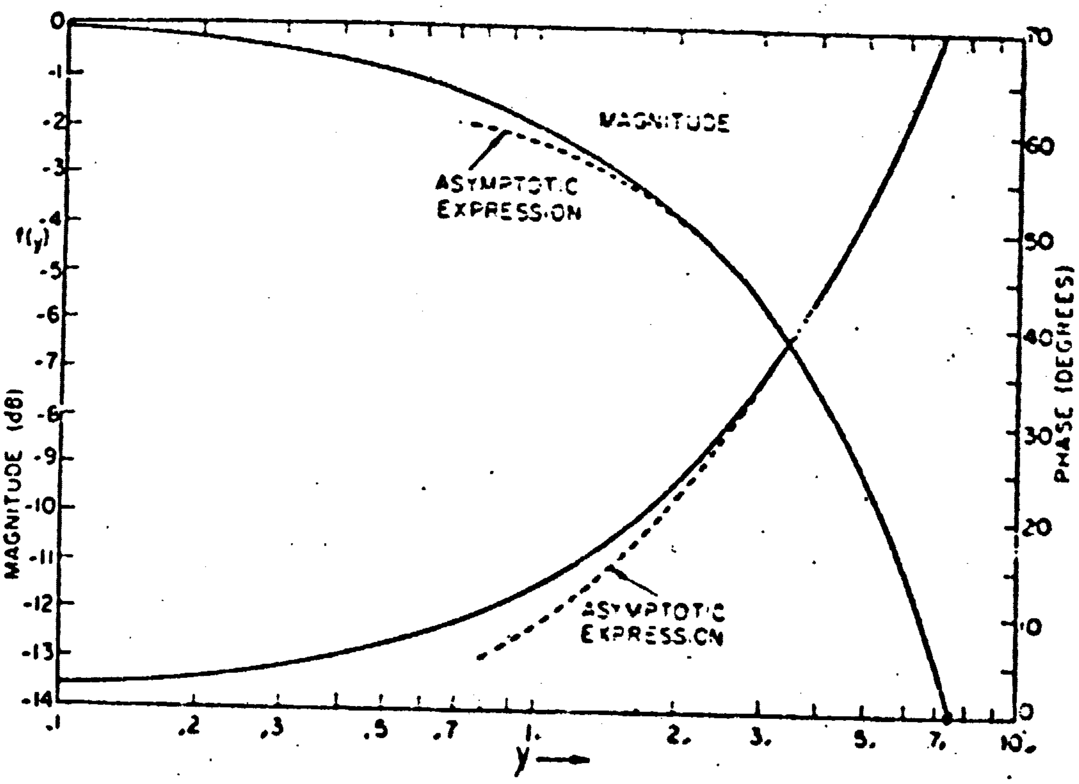

Figure 5. Curvature Factor f(y) versus Y (Reference C)

3.4 Effect of Dielectric Covering

The effect of the dielectric covering which includes the .41 inch thick LI-900 tiles over the Upper Quad Antenna and the .32 inch thick felt over the Payload Antenna is to generally increase the coupling between the two antennas. For the purpose of this evaluation a factor is determined based on the difference in mutual coupling between that obtained with and without a dielectric covering. The factor is extrapolated from some data for a flat ground plane given in Reference D and the graph is reproduced in Figure 6. The antennas in Figure 6 are annular slots which would correspond to the worst case of E-plane coupling. The effect of the dielectirc covering is to increase the coupling by 5.5 dB. Since a curve for the exact S-Band frequency and dielectric thickness was not available a series of scale factors are used to represent the dielectric covering on the Orbiter. The spacing of 162 inches between antennas at 1090 MHz corresponds to 78.5 inches at 2250 MHz. Also, the thickness for 1 inch of covering at 1090 MHz with a dielectric constant of 1.2 is scaled using Equation (3) for a dielectric constant of 1.3 at 2250 MHz.

$$t_{2250} = t_{1090} \times \frac{1090}{2250} \times \sqrt{\frac{1.2}{1.3}} = .465'' \qquad (3)$$

The equivalent thickness is found to be .465 inches which is slightly greater than that in the region of either the Upper Quad or Payload Antennas. The typical thickness ranges between .3 and .4 inches as previously discussed. The increased coupling for this condition is obtained from Figure 6 as 5.5 dB.

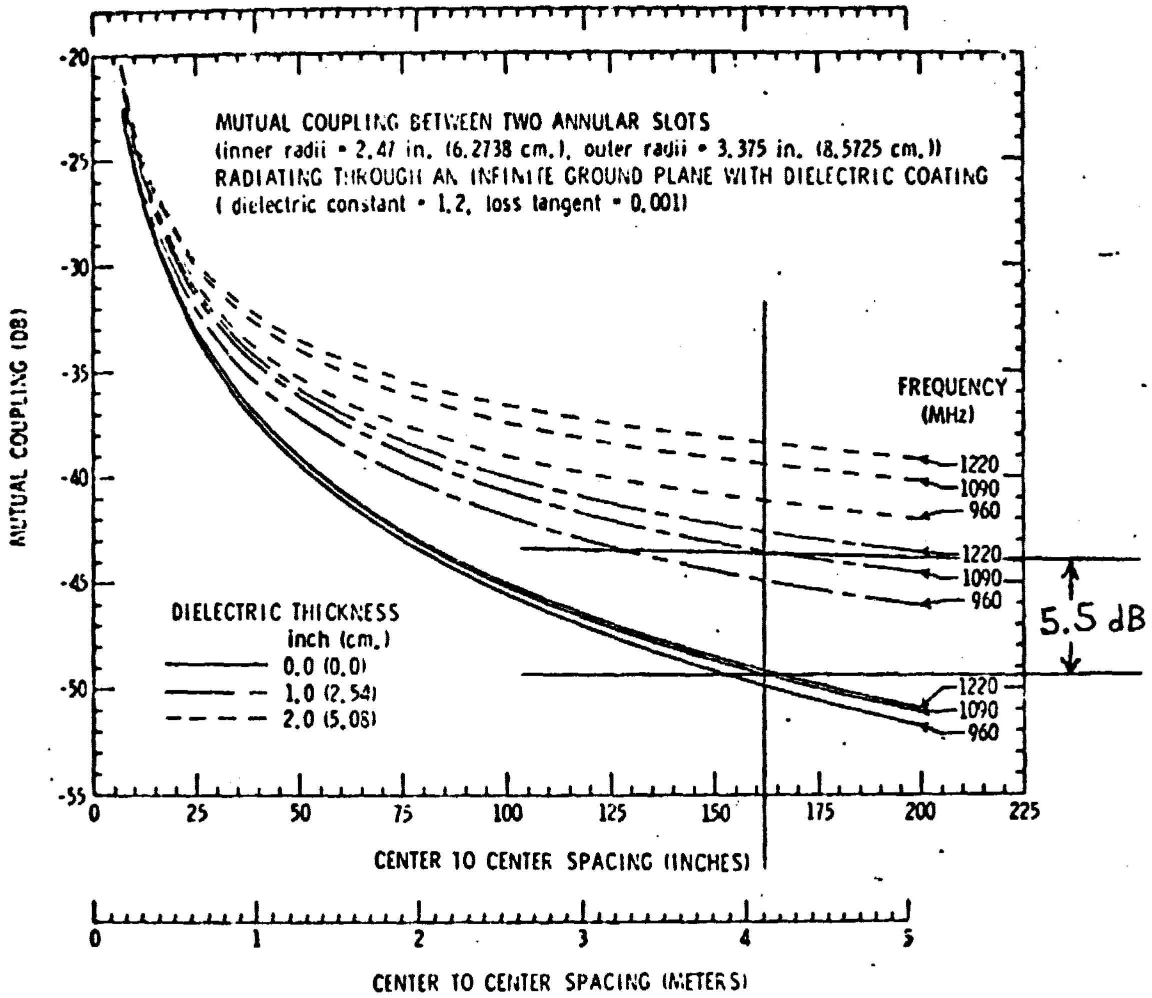

Figure 6. Mutual Coupling Curves.(Reference D)

3.5 Effects due to Payload Bay

The edge of the Payload Bay is located approximately 18 inches from the Payload Antenna and approximately 25 inches from the Upper Quad Antenna. The spacing is in the range of 3 to 5 wavelengths at the frequency of interest. Typical edge effects for a large ground plane contribute variations in the effective antenna radiation pattern of up to ± 1 dB. For the purpose of this evaluation a worst-case factor of 3.5 dB increased coupling is assumed. This factor is conservative enough that it also accounts for possible adverse effects of the observation window, the star tracker door and the payload radiators.

4.0 RESULTS

Each of the parameters developed in the previous section may be combined using Equation (2) in dB form to determine the worst case coupling between the S-Band Payload Antenna and Upper Quad Antennas. The results are

1.	Free-space transmission loss (L_{fs}) R = 78.5" f = 2250 MHz	-45.5 dB
2.	Payload Antenna Power Gain in direction parallel to antenna surface with two chokes (G_p)	- 6.0 dBLi
3.	Upper Quad Antenna Power Gain in direction parallel to antenna surface (G_q)	- 3.5 dBLi
4.	Curvature Effect of Orbiter	-14.0 dB
5.	Effect of Dielectric Covering (G_d)	+ 5.5 dB
6.	Edge Effects of Payload Bay (G_e)	+ 3.5 dB
	Mutual Coupling Between Antennas	- 60 dB*

The intent of this evaluation is to determine the minimum value of isolation to enable the design of smaller, lighter weight and less expensive filters for the TDRS transponder and Payload Interrogator. The calculated minimum, worst-case value of 60 dB is based on a combination of flat surface and curved surface theories in that the dielectric layer effect is obtained from a plane surface. The use of worst-case values and the superposition of flat surface and curved surface effects results in a minimum isolation value. The actual measured isolation value may easily be 20 dB greater than the value predicted in this report.

* Value becomes -59.7 dB at 2050 MHz.

5.0 CONCLUSION

The minimum worst case isolation between the Upper S-Band Quad Antenna and the S-Band Payload Antenna is calculated in this design note to be 60 dB which is significantly greater than the baseline level of 40 dB. Future measured values of isolation may easily exceed 80 dB since worst-case values were assumed in this report. Use of the 60 dB value will enable the design of smaller, lighter weight and less expensive filters for the S-Band TDRS Transponder and the S-Band Payload Interrogator.

Isolation lower than that predicted in this paper could occur as a result of strong reflections from an EVA astronaut or deployed payload in close proximity to the S-Band Payload and Quad Antennas.

6.0 REFERENCES

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C. Lyon, J. A. M., R. M. Kalofus, Y-K Kwon, C. J. Digenis, M. A. H. Ibrahim and C-C Chen, "Derivation of Aerospace Antenna Coupling Factor Interference Prediction Techniques", The University of Michigan Radiation Laboratory, Report No. 6633-1-F, April 1966.

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APPENDIX A

7.0 APPENDIX

To further substantiate the theory used a comparison was made with the C-Band data in which the mutual coupling between antennas was determined to be -95 dB with no dielectric covering. The free-space loss at 4300 MHz is determined from Equation (3) to be -48 dB and the resulting antenna power gain along the surface is found to be -23.5 dB which agrees reasonably well with measured pattern data. The peak power gain is approximately 11 dBli. The increased coupling due to the 2 inch thick thermal protection system tiles was measured to be 19 dB. This number is significantly greater than the 5.5 dB used for the S-Band isolation; however, the electrical thickness of the dielectric covering at S-Band is less than .1 wavelength and the electrical thickness of the tiles over the C-Band antennas is greater than .75λ. This means that a waveguide type mode is possible since 4300 MHz is above the lower cutoff frequency. In the S-Band case the thickness so small electrically that 2250 MHz is well below the minimum waveguide cutoff frequency of approximately 11000 MHz.