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S BAND MODE COUPLER DESIGN FOR ANTENNA FEEDS

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ABSTRACT

The design and testing of an S-Band TE_{21} mode coupler is presented. The coupler is used in a simultaneous receive (autotracking)/transmit feed antenna. Theoretical coupler designs and performance are compared with measured test results for a prototype and production unit.

INTRODUCTION

The design and testing of an S-Band TE_{21} mode coupler is presented. The coupler is used in the transmit/receive feed antenna for the satellite earth ground station antenna for the Automated Remote Tracking Station (ARTS) program.

The coupler provides three important feed functions: 1) the coupler generates a TE_{21} waveguide mode that is converted into a difference pattern by the antenna feed horn to provide the autotracking capability, 2) the coupler allows the TE_{11} mode corresponding to the communication (center pattern) channel to propagate with very low insertion loss, and 3) the coupler provides inherent transmit band power rejection for the feed receive tracking (difference pattern) channel.

PROTOTYPE DESIGN

The geometry of the prototype mode coupler is shown in Figure 1. The coupler is formed by an overmoded circular waveguide as the coupling line, and dominant mode rectangular waveguides as the coupled lines. Coupling between the guides is controlled by the size and spacing of coupling holes located in a common wall between guides. The holes are located in the narrow wall of the rectangular guides. The design parameters are the size of the circular and rectangular guides and the size and spacing of the coupling holes.

The prototype coupler was designed with the ARTS operating parameters in mind. The ARTS receive band is 2200 to 2300 MHz while the transmit band is 1750 to 1850 MHz with 5 KW maximum transmit power. The waveguide sizes were selected to allow circular TE_{11} mode propagation in both bands and circular TE_{21} mode propagation in the receive band in the circular guide as well as TE_{10} mode propagation in the rectangular guides.

WR284 (2.840 in. x 1.340 in. inside dimensions) waveguide was selected for the rectangular guides because its size allowed TE_{10} mode propagation in the receive band while providing inherent TE_{10} cut-off attenuation at the transmit band. This attenuation keeps the transmit power from degrading the feed tracking channel performance. The use of WR284 allowed standard waveguide flanges to be used.

The power transfer between the coupling and coupled lines is enhanced by making the propagation constants (guide wavelengths) identical in each line (1). Equating the circular TE_{21} and rectangular TE_{10} cut-off wavelengths, one finds that

$$A = .51425D \tag{a}$$

where A is the inside broad wall dimension of the rectangular guide and D is the inside diameter of the circular guide. The inside diameter calculated using (a) is 5.523 inches. In this size of circular waveguide, the only unwanted mode which can propagate is TM_{01}, however it is not excited due to the symmetry and excitation of the coupler.

The prototype coupler was built to allow the characterization of individual hole coupling versus hole size. The prototype had removable plates forming the outer WR284 side walls to allow access to the coupling holes. The prototype was an eleven equal hole (uniform distribution) coupler. The prototype was constructed from electroformed copper. The coupler wall thickness at the coupling holes was .030 inch.

The prototype hole spacing was selected at 2.400 inches. This selection was based upon the coupling hole distribution. Analogous to antenna array theory, the relative forward and reverse coupling between the possible waveguide modes is determined by the relative amplitude and spacing between the coupling holes in a Fourier transform. The result of the transform is a coupling array distribution (analogous to an antenna array pattern) whose transformed variable is theta which is defined from the sum and difference of mode propagation constants (betas). To inhibit unwanted coupling between modes, their corresponding theta variables must fall within the "sidelobe" range of the coupling distribution, hence the selection of 2.400 inches. The array distribution is given by (b) (c).

$$\theta_D^C = \frac{L}{2\pi}\left(\beta_1 \mp \beta_2\right) \tag{b}$$

$$\text{Coupling / Directivity} = \frac{a_0 + 2\sum_{i=1}^{P} a_i \cos\left(\frac{2i}{N-1}\right)\pi\,\theta_D^C}{a_0 + 2\sum_{i=1}^{P} a_i} \tag{c}$$

where θ_C is the theta coupling parameter, θ_D is the theta directivity parameter, β_1 is the propagation

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constant of the coupled line for a particular mode, β_2 is the propagation constant of the coupling line for a particular mode, L is the length of the coupling section and a_i are the relative coupling strengths of each coupling hole. The coupling section length can be found from

$$L = (N-1)s \tag{d}$$

where N=2P+1 is the odd number of holes and s is the hole spacing. The coupling holes are numbered -P to +P with zero corresponding to the center hole.

The coupling α from an individual hole can be found by replacing the coupling hole with an equivalent magnetic dipole that radiates into the coupled line (4)

$$\alpha = -j\,\frac{1}{2}\,P_m\,K_{c_{10}}\left(\frac{2}{AB}\right)^{0.5} K_{c_{21}}^{\,2}\left(\frac{2}{\pi\left[X_{21}^2-4\right]}\right) \cdot \left(\frac{1}{\beta_{10}\,\beta_{21}}\right)^{0.5} \tag{e}$$

$$P_m = \frac{1}{6}\,d^3 \tag{f}$$

where pm is the magnetic polarizability of the hole, d is its diameter, $K_{c10} = K_{c21} = \pi/A$ which is the TE_{10} cut-off wave number, A and B are the broad and narrow wall dimensions of the rectangular guide, $X_{21} = 3.054$ and $\beta_{10} = \beta_{21}$ which is the TE_{10} propagation constant. Equation (e) assumes zero wall thickness. The total coupling C from all the holes is given by (2)

$$C = \sin\left[\sum_{i=-P}^{P} \sin^{-1}(2a_i\alpha)\right] \tag{g}$$

PROTOTYPE DATA

The prototype coupling was measured by using a coax probe to sample the peak electric fields present in the circular waveguide for both the TE_{11} and TE_{21} modes and comparing relative levels. The test equipment set-up is shown in Figure 2. The total coupling C is found from the measured relative TE_{21} and TE_{11} voltages from

$$C = \frac{V_{P21}}{V_{P11}} + \frac{1}{4}\,\frac{\beta_{21}}{\beta_{11}}\,\frac{(X_{21}^2-4)}{(X_{11}^2-1)} \tag{h}$$

where V_{p21}/V_{p11} is the measured relative voltage, β_{11} and β_{21} are the TE_{11} and TE_{21} propagation constants, and $X_{21} = 3.054$ and $X_{11} = 1.841$. The right hand term of (h) is a power flow correction factor for the two modes.

Table 1 shows the calculated versus measured individual and total coupling for the prototype. The .030 wall α column was generated using equation (e) and treating the hole as a circular waveguide below cut-off and including the additional cut-off attenuation.

PRODUCTION DESIGN

In order to provide better unwanted mode rejection in the coupling distribution sidelobe region, a 25 dB equal sidelobe Chebyshev distribution was selected. With such a distribution utilizing tapered hole sizes, 15 holes were required to provide 0 dB total coupling between TE_{21} and TE_{10} modes. The production mode coupler is shown in Figure 3. The unit is an aluminum machined assembly.

PRODUCTION DATA

Two couplers were placed back to back to allow direct measurement of Vin/Vout (2 x Coupling C) as shown in Figure 4. The measured data is shown in Figure 5. The measured midband coupling was 0.28 db.

As another check of the design, the TE_{11} forward to TE_{21} forward coupling and the TE_{11} forward to TE_{21} reverse directivity were measured. The measured data is plotted with the theoretical coupling or directivity in Figures 6 and 7.

The measured TE_{11} and TE_{21} VSWR were 1.05:1 and 1.10:1 respectively. The coupler handled 7.5 KW cw at the ARTS transmit band during a power handling test.

CONCLUSION

A prototype and production S-band mode coupler were successfully designed and tested. The production coupler provides excellent feed capability for autotracking, low insertion loss, and power handling.

REFERENCES

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Table 1. ARTS Prototype Mode Coupler: Theory vs. Data at 2250 MHz

d (In.)	Zero Wall α (db)	Zero Wall C (dB)	.030 Wall α (db)	.030 Wall C (dB)	Measured α (db)	Measured C (dB)
.625	-36.47	-9.78	-37.97	-11.23	-38.2	-11.5
.719	-32.82	-6.34	-34.12	- 7.54	-34.5	- 7.9
.781	-30.67	-4.43	-31.86	- 5.47	-32.7	- 6.2
.938	-25.89	-0.92	-26.86	- 1.50	-28.3	- 2.5
1.094	-21.88	+0.19	-22.70	+ 0.10	-25.3	- 0.6

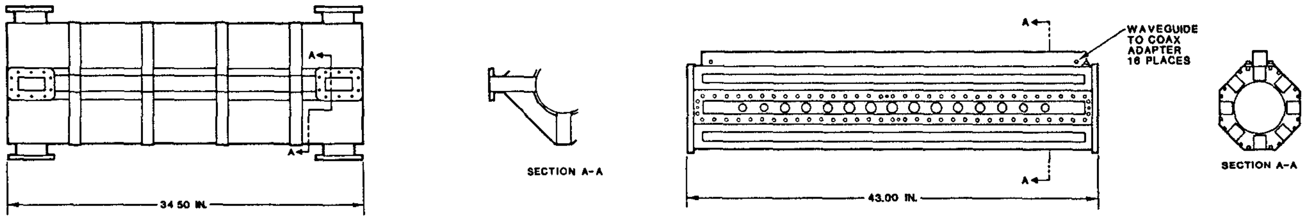


Figure 1. Prototype Mode Coupler

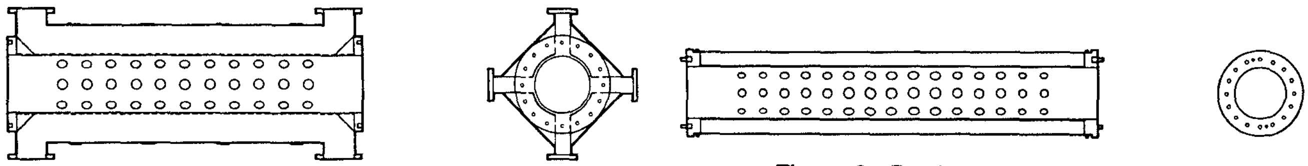
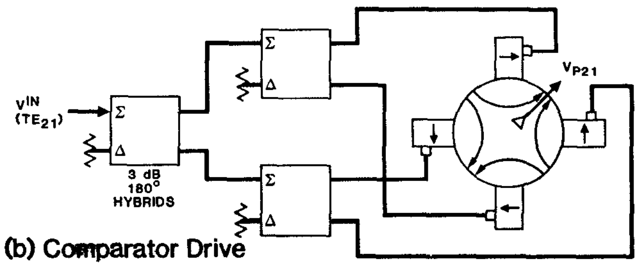


Figure 3. Production Mode Coupler



(b) Comparator Drive

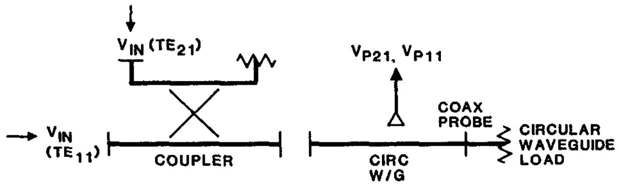


Figure 2. Waveguide Field Probe (a) Probe Sampling

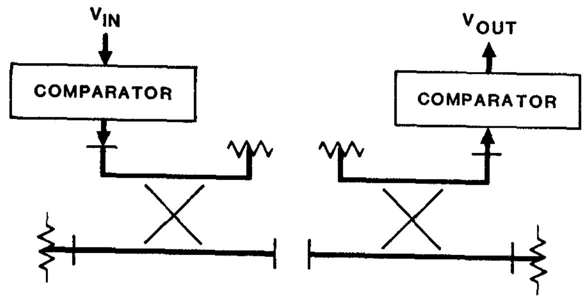


Figure 4. 2x Coupling Test

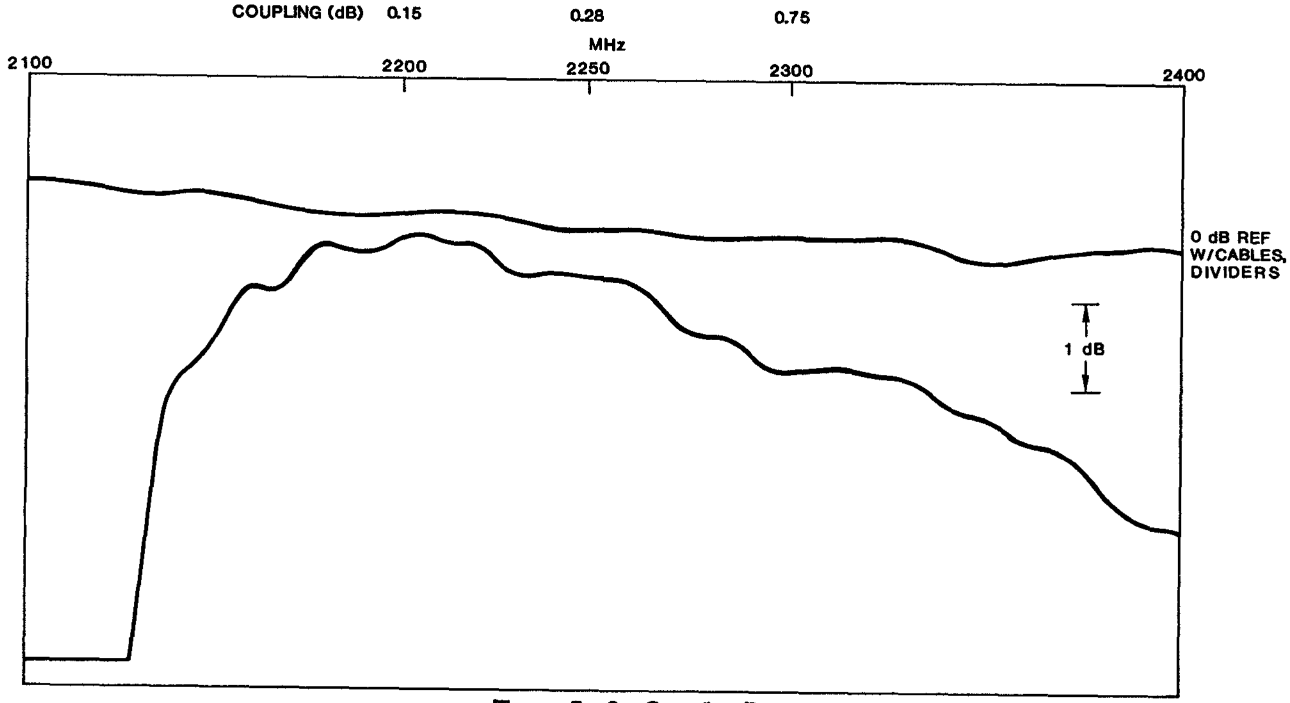


Figure 5. 2x Coupling Data

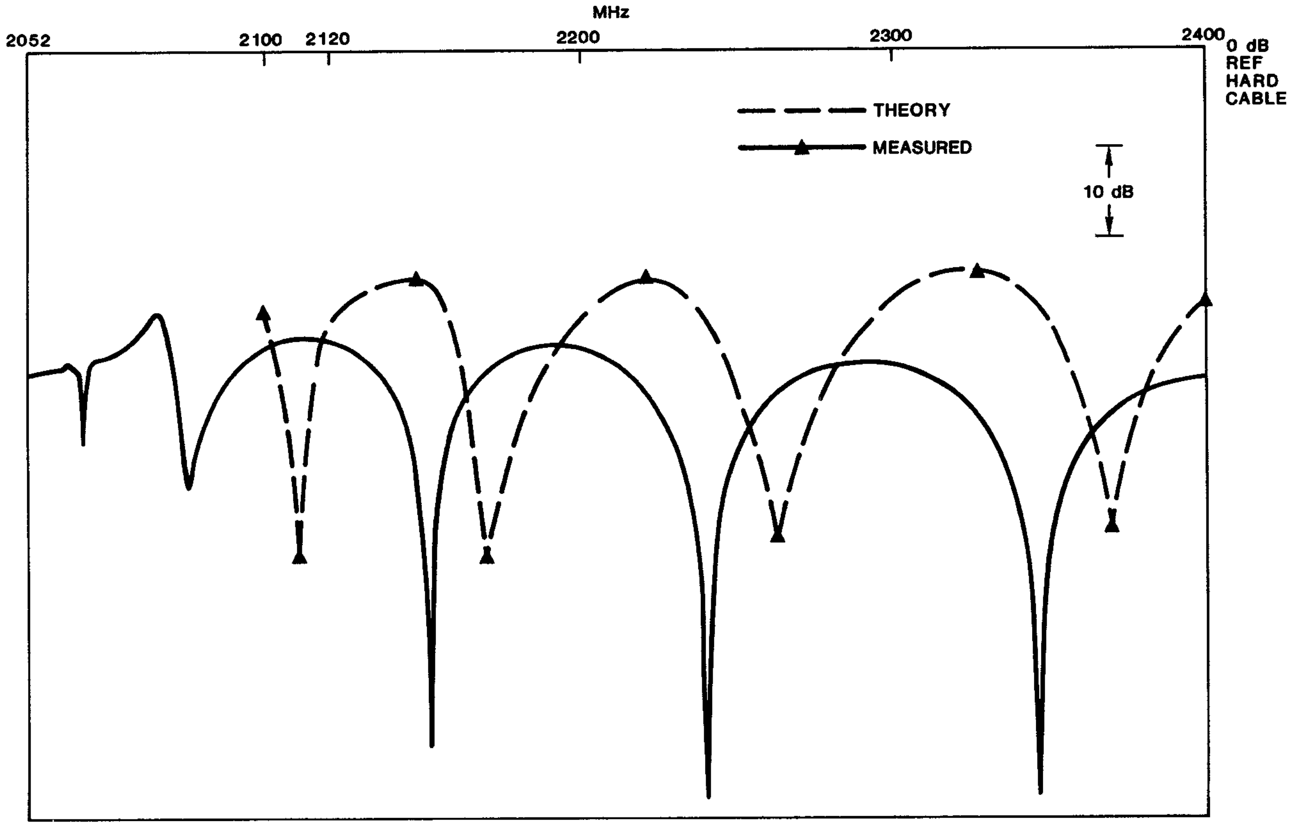


Figure 6. Forward TE11 to Backward TE10 Directivity

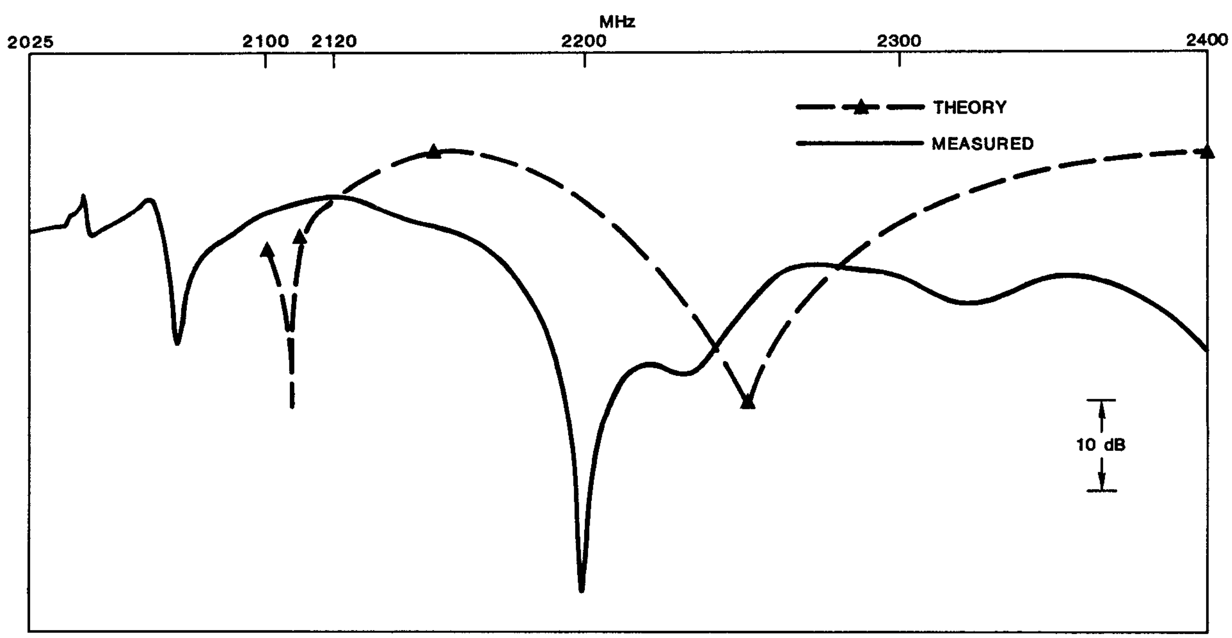


Figure 7. Forward TE11 to Forward TE10 Coupling