NATIONAL RADIO ASTRONOMY OBSERVATORY
Charlottesville, Virginia
VERY LARGE ARRAY PROJECT

VLA Electronics Division Memo No. 125

October 1974

NOTES ON DIRECTIONAL COUPLERS FOR 60 mm CIRCULAR WAVEGUIDE

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I discuss below several design principles for directional couplers that couple directly between rectangular and 60 mm TE_{01} (circular) waveguides in the VLA transmission system. A final design will necessarily be a trade-off between several of these. I also describe a coupler incorporating these ideas.

1.1. Maximization of coupling to the TE_{01} as opposed to spurious modes:

The highest obtainable field strengths in an overmoded circular waveguide excited to a given Poynting flux level are much lower for the TE_{01} than for many higher order modes (e.g. the ratio for TE_{01}/TE_{81} is -20 dB). The frequency response of the coupled passband is degraded by interaction between the desired and these spurious modes, in the coupler and elsewhere. The Poynting flux ratio $S_{TE_{01}}/S_{spurious}$ should be maximized to minimize this degradation. One means toward this end is to physically locate the coupling holes to maximize the coupling into the TE_{01} mode. In the circular guide, the strongest H field for the TE_{01} mode is the radial component which peaks at a radial distance of about half of the radius of the waveguide. This field is 17 dB stronger than the structurally more accessible axial H field at the waveguide wall. A special physical structure, such as a pair of transitions from circular to two separate but parallel semicircular waveguides and back (see Fig. 1) is required to locate the coupling holes where they can couple into the radial H field. Unfortunately, such a structure may introduce un-desirable perturbations into the trunk line waveguide.

1.2. Suppression of non TE_{01} modes by choice of wall structure:

A further reduction in the fine structure in the coupled passband that results from scattering and trapped resonances in spurious modes can be obtained by designing the wall structure of the coupler to absorb non-TE_{01} modes in the manner of helix waveguide (i.e. by providing conductivity in the circumferential direction only). Such a structure is generally difficult to fabricate. However, in some designs this end could be achieved by making the main body of the coupler from scraps of helix waveguide.

1.3. Minimization of coupling into spurious modes by choice of the coupling hole location:

The coupling holes may be located at minima in the field distribution of certain particularly troublesome spurious modes. For the configuration discussed in (1.1.), minima for TE_{0m}, m even, modes occur at about the same radii and about at the radii of the maxima TE_{0n}, n odd, modes. Thus, one can discriminate strongly against coupling to the TE_{02} mode while exciting TE_{01} (and, unfortunately, TE_{03}, TE_{05}....) modes.

1.4. Mode discrimination by selection of the axial distribution of coupling holes:

The phase velocities of modes in the circular waveguide differ from each other (with one degeneracy between the TE_{01} and TM_{11} modes) and these differ from the velocity in the side arm rectangular waveguide. Consequently, arrangements must be made to insure that the phases of the waves in the rectangular and circular guides match at the coupling holes. In a coupler design by R. Predmore this is accomplished by wrapping the rectangular guide in a helix around the circular guide to reduce the projected phase velocity in the rectangular guide to match that in the circular. The coupling holes are then separated by $\lambda g/4$ as in standard practice. Alternatively, the phase requirement may be satisfied by placing coupling holes only at regions that are separated by an integer number of TE_{10}-TE_{01} beat wavelengths. (This periodic design is simpler mechanically but it may not provide enough coupling holes.) The coupler center frequency is determined by choosing the pitch angle of the helix or the coupling hole spacing for the periodic coupler. These couplers will couple strongly into other modes only at center frequencies that differ from the TE_{01} coupling center frequency. Thus, mode discrimination is obtained if narrowband frequency excitation is applied to the coupler (as it will be in the VLA). The discrimination will be maximized if the length of the coupling structure is set to reduce the coupling bandwidth to just that value required to pass the signals to and from the antenna. This minimizes the overlap between desired and spurious coupled bands. However, the periodic design is analagous to a unfilled aperture array and there may be spurious coupling into unwanted modes ("sidelobes").

2. An Experimental Coupler

This development effort did not produce an entirely satisfactory coupler, but it did produce a device that meets many of the essential requirements. The structure of the device is shown in Figure 1, and its principal specifications are as follows:

Average Coupling	-25.5 dB
Coupling variation over 1.9 GHz	$\pm$ 1 dB
Coupling variation over 100 MHz	<0.1 dB
Main line mode conversion, TE_{02} mode	min. 12 dB below applied TE_{01} signal

In comparison with Predmore's helix coupler (described in 1.4.) the coupling is substantially stronger in accordance with the remarks of 1.1, and the passband ripple is effectively suppressed by the mode suppressing lining. However, looking at the trunk line ports, the device scatters a seriously excessive amount of the applied TE_{01} signal into the TE_{02} mode, and this property renders it unusable without further development.

The reduction of coupling-passband ripple obtained by introducing a mode suppression lining (as discussed in 1.2.) into the walls of the coupler may be seen by comparing "before" and "after" plots of the coupling value versus frequency, Figs. 2a and 2b respectively. For the data of Figure 2b a mode-suppression lining on the inside of the semi-circular walls of the center section (item #5 on Fig. 1) absorbs any interacting non-TE_{0n} modes. This lining is made by longitudinally cutting and finish-machining these pieces from helix waveguide. For the Fig. 2a data, the center section walls were semi-circular pieces cut from 60 mm I.D. brass tubing. Both couplers are otherwise identical.

Examination of the available data on the frequency dependence of the coupler mode generation effects suggests, but does not conclusively prove, that the TE_{02} mode generation takes place at the small-angle mitered joints in the semi-circular waveguides. Experiments with a dummy device lacking only the coupling holes demonstrated that the spurious mode is not generated by the coupling holes. Also, experiments with dummy devices where a circular waveguide is split into two semicircular guides by an "infinitely thin" septum (thus reducing the angles at the mitered joints from 1.7° to zero) show, as expected, no spurious mode generation. Thus, a process of elimination suggests that the spurious mode generation occurs at the mitered joints.

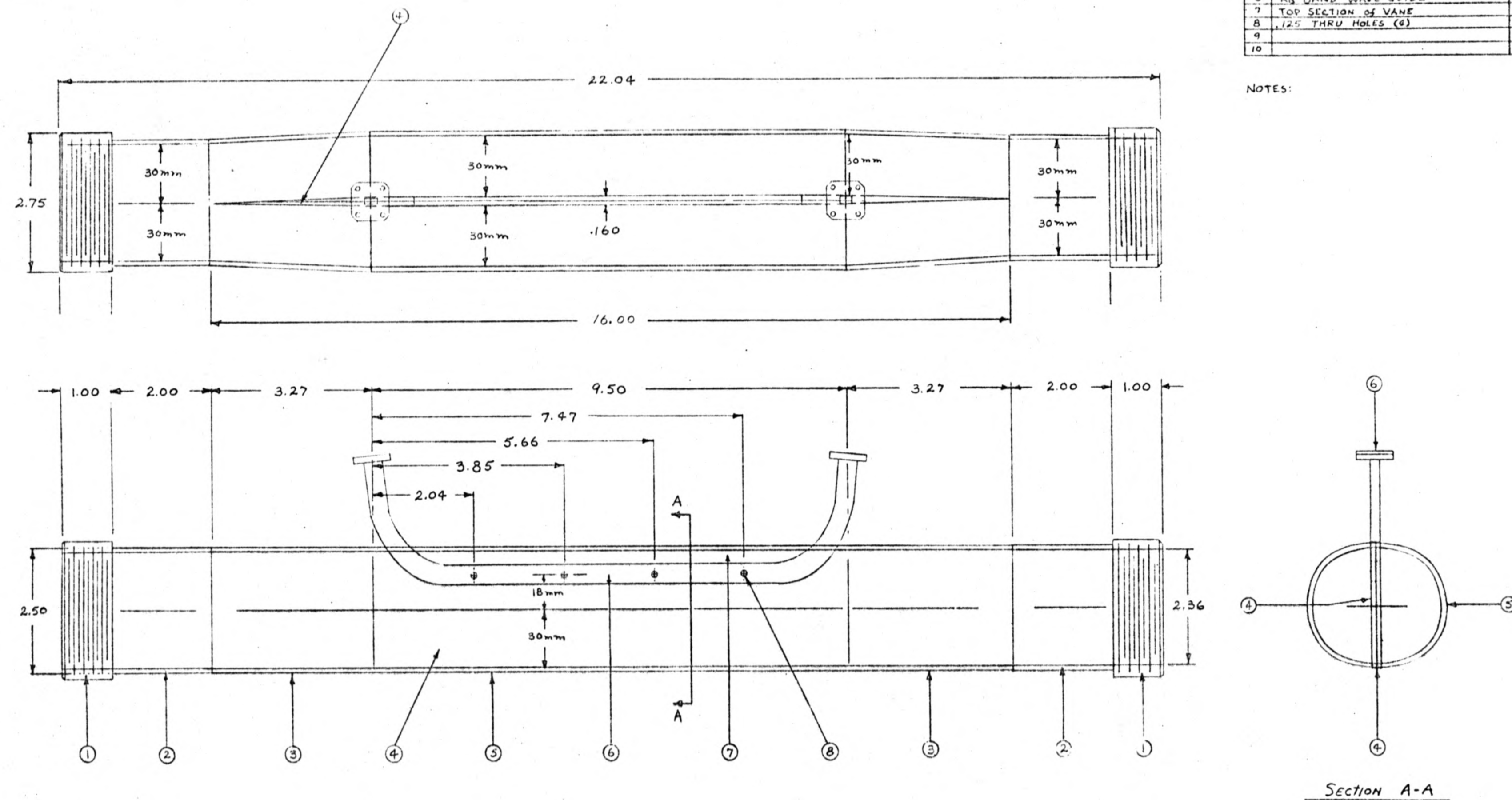
It appears that a satisfactory coupler can be developed from this experimental model if the main line generation problem is understood and eliminated. However, it may be difficult to reduce the unwanted mode generation in the trunk line sufficiently, so the development of Predmore's helix coupler should also be continued.

Predmore's couplers have inherently very little effect on the trunk line characteristics and so appear ideal for use on the numerous close-in stations. If such couplers having adequate coupling and side arm passband characteristics could be developed, they could probably be left in the trunk line at all such stations. Such a coupler employing the mode suppression linking of (1.2.) should be built in an attempt to obtain a cleaner coupled passband. A helix coupler of this type would be difficult to fabricate, but it would be possible to make an equivalent periodic coupler by carefully milling a long, longitudinal slot in a length of helix waveguide into which a thinwall rectangular waveguide containing the coupling holes was fastened by means of a conducting epoxy cement.

MATERIAL LIST

ITEM	DESCRIPTION	REMARKS
1	10 FT 60mm HELIX WAVE GUIDE	BRASS
2	STRAIGHT SECTION 2.5" OD .055 WALL	"
3	TAPERED SECTION	"
4	CENTER VANE	BRASS
5	SECTION 60mm HELIX WAVE GUIDE	SPLIT
6	Ka BAND WAVE GUIDE	
7	TOP SECTION of VANE	BRASS
8	.125 THRU HOLES (4)	
9		
10		

NOTES:



ALL DIMENSION IN INCHES EXCEPT WHERE NOTED

REV.	DATE	DRAWN BY	APPR'D BY	
VLA	TH WAVE GUIDE COUPLER — ASSEMBLY			NATIONAL RADIO ASTRONOMY OBSERVATORY, CHARLOTTESVILLE, VA. 22901; DRAWN BY ...; DESIGNED BY ALAN PARRISH; APPROVED BY
DATE 10/1/74	SHEET NUMBER	DRAWING NUMBER D15330P1	REV	SCALE FULL

FIGURE 1

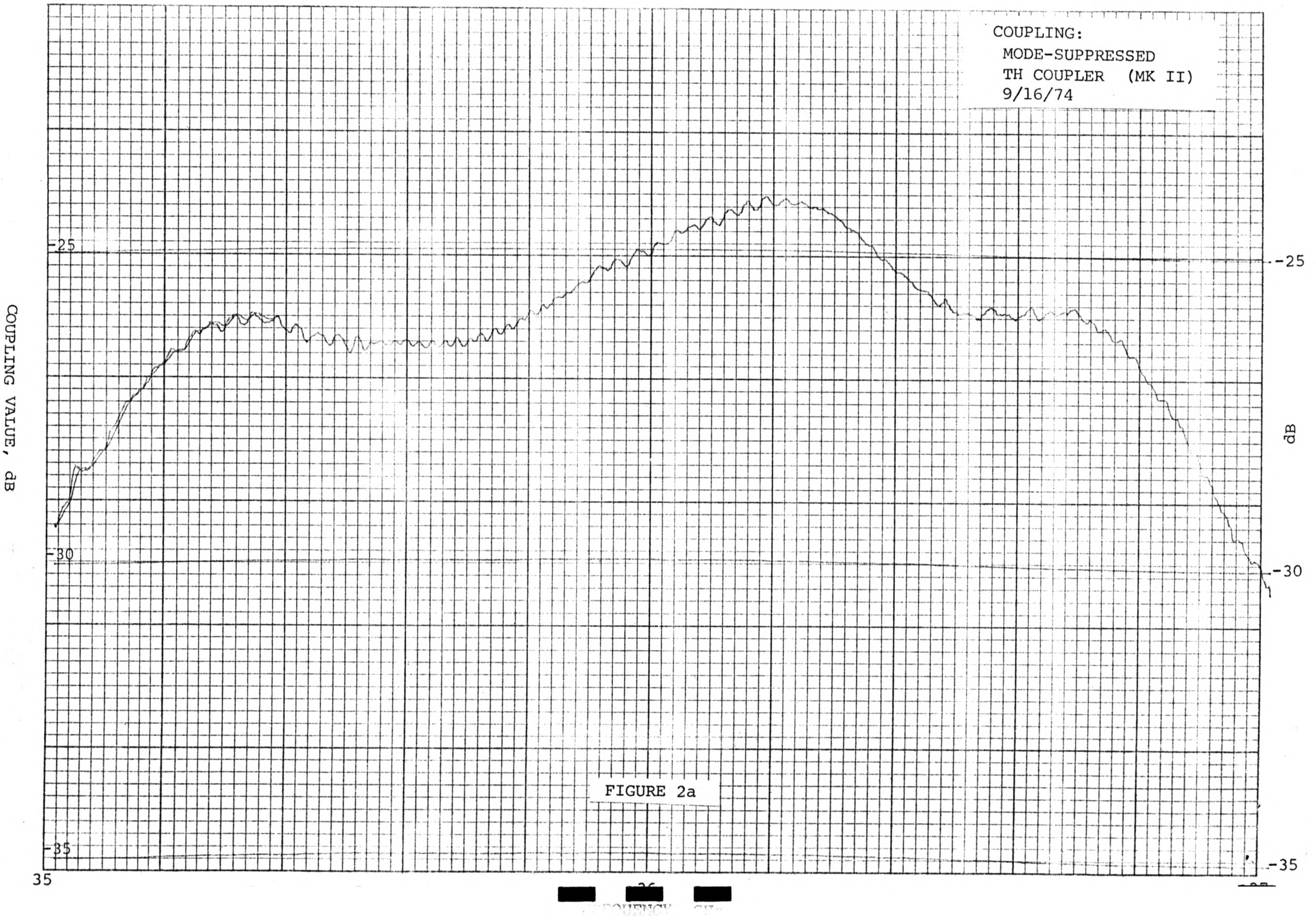

COUPLING:
MODE-SUPPRESSED
TH COUPLER (MK II)
9/16/74
COUPLING VALUE, dB
dB
-25
-30
-35
-25
-30
-35
35
[redacted]

FIGURE 2a

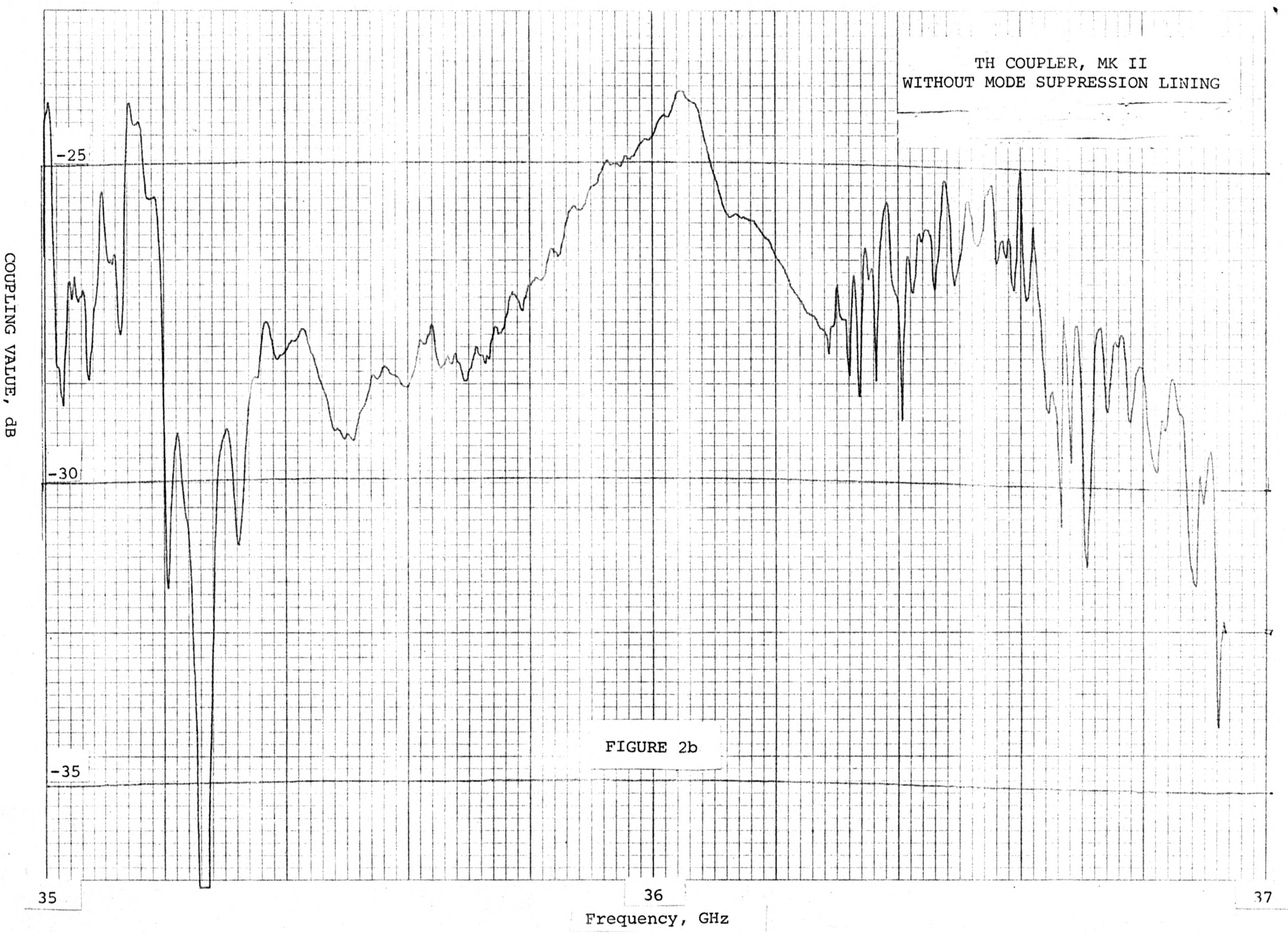

TH COUPLER, MK II
WITHOUT MODE SUPPRESSION LINING
-25
-30
-35
COUPLING VALUE, dB
35
36
37
Frequency, GHz

FIGURE 2b