Bima Memo #25

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The BIMA Directional Couplers.

In the BIMA receivers directional couplers are used on the LO plates to feed a part of the signal from the Gunn oscillators to the phase-lock circuit, and in the case of one of the plates to split the LO signal between Band A (70-90 GHz) and Band C (210-270 GHz). It was decided to build the couplers in-house, because: 1) it would be cheaper than buying commercial couplers; 2) we could achieve better directivities; and 3) in the case of Bands A/D we could build a compact double coupler, rather than using two independent couplers in series. It was determined that in the case of WR-12 (70-90 GHz) couplers, the coupling level for Band A (relative to C) should be ~17 dB, and that for the phase-lock system should be ~25 dB. In the case of WR-10 couplers (90-115 GHz) the coupling required by the phase-lock system is higher, ~20 dB. The directivity was required to be >30 dB.

We decided to build narrow-wall couplers, because the coupling level is better determined a priori, and because we believed it would be structurally stronger, especially in the case of the double coupler (since one has to machine off two opposite walls from a waveguide). In principle broad-wall couplers have a broader useful bandwidth, but we thought that we might have to spend more time getting the coupling levels right. The couplers are built by machining off one or two of the narrow walls from two sections of waveguide, inserting a thin shim with a series of holes drilled into it, and soldering together the two waveguide sections with the shim sandwiched between them. The most critical part of the process is drilling the holes into the shim, because the size of the holes needs to be well controlled (the amplitude of the wave coupled through a circular hole is proportional to the *cube* of the hole diameter). The directivity increases with the number of holes, which are spaced by one quarter of the guide wavelength. We built couplers with linear arrays of 20 holes. The bandwidth over which the directivity is maintained depends on how one tapers the sizes of the holes along the array. For a large number of holes Chebyshev coefficients are normally used to determine the hole sizes. For 20 holes, the optimal hole sizes vary by ~10% over the array, but given the difficulty of controlling hole sizes to that accuracy, we just used arrays with constant hole size. This proved to be a good approach. At either end of the array a single hole with a diameter one half the size of array holes can be placed to improve slightly the VSWR, but even this made very little difference in the final results. Special jigs were built to drill the shims, and to assemble and solder the couplers.

Sample measurements of coupling values and directivities for the WR-12 (double) couplers and the WR-10 couplers are presented in Tables 1 and 2. If in the future changes in the coupling level are required, one can extrapolate from the values in the tables with the following formula:

$$\chi_1 - \chi_2 = 20log\{(\frac{\lambda_{g1}}{\lambda_{g2}})(\frac{d_1}{d_2})^3(\frac{a_2}{a_1})^3(\frac{b_2}{b_1})(\frac{C_1}{C_2})\}$$

In this equation χ is the coupling level, λ_g is the wavelength in the waveguide at the center of the band, d is the hole diameter, a is the waveguide large dimension, b is the waveguide small dimension, and C is a correction factor for the thickness of the shim and the large area of the hole:

$$C = \frac{exp\{(-2\pi tA)/\lambda_c[1-(f^2/f^2{}_c)]^{0.5}\}}{1-(f^2/f^2{}_c)}$$

where λ_c and f_c are cutoff wavelength and frequency for the appropriate coupling mode ($\lambda_c = 1.705d$ for narrow wall coupling), t is the shim thickness, and A is a correction factor of order unity. This formula has proved to be quite reliable for small (~5 dB) changes in the coupling level, and even for extrapolating from WR-12 to WR-10.

References.

1. R. Levy, in Advances in Microwaves, L. Young ed., Academic Press, New York 1966, page 135.

2. R. Levy 1968, IEEE-MTT, 16, 995.

3. P.A. Rizzi, Microwave Engineering Passive Circuits, Prentice Hall, New Jersey 1988.

Table 1.

Measured Coupling Level of WR-12 Double Directional Couplers.

ν (GHz)	Hole Diameter (mils)					
	19.5	20.6[a]	22.0	24.0	25.5[b]	29.0
70	25.0	22.2	20.0	17.3	14.5	12.6
80	27.0	24.2	23.0	19.4	16.4	13.7
90	28.5	25.6	23.0	21.0	17.8	14.3

[a] Final value for BIMA coupler. Use drill #75 for shim holes. At 80 GHz, other parameter values are: Directivity >30 dB, Insertion Loss 0.5 dB, VSWR 1.2. [b] Final value for BIMA coupler. Use drill #71 for shim holes. At 80 GHz, other parameter values are: Directivity >35 dB, Insertion Loss 0.5 dB, VSWR 1.1.

Table 2.

Measured Coupling Level of WR-10 Directional Couplers.

ν (GHz)	Hole Diameter (mils)	
	18.0	21.0[a]
90	23.2	18.2
100	23.8	19.4
110	24.5	20.5

[a] Final value for BIMA coupler. Use drill #75 for shim holes. At 110 GHz, other parameter values are: Directivity 23 dB, Insertion Loss 0.53 dB.

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WR-12 Double Directional Coupler.

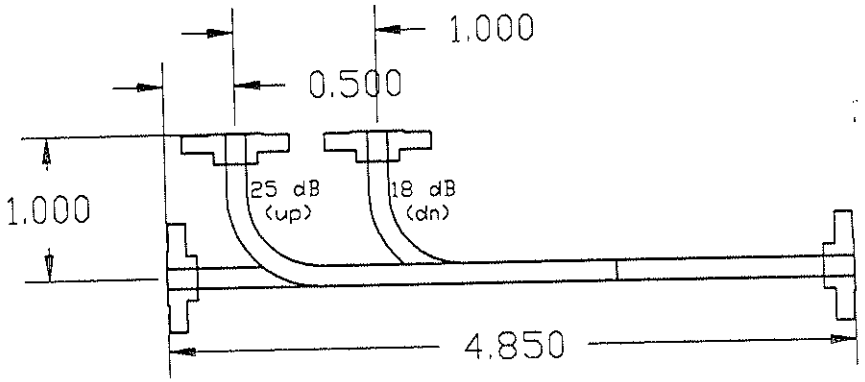
*Dimensions shown are for finished coupler- cut waveguide initially to larger sizes.

* A: 2 pieces, with opposing symmetry
  Use bending jig to bend WR-12 waveguide. Bending radius 0.5"
  Machine down one side of narrow wall in each piece.

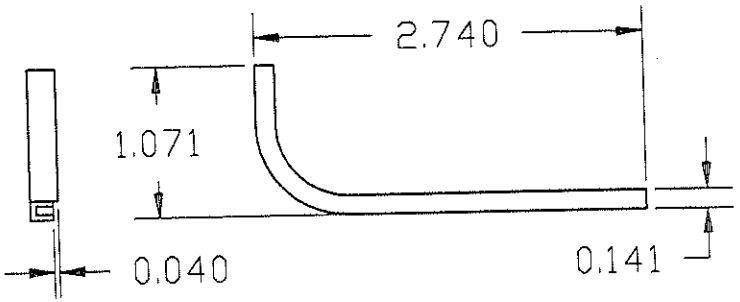
* B: make from 0.002" thick BeCu
  Drill 20 holes 0.021" Dia (#75) for 25 dB coupling level
  Drill 20 holes 0.0255" Dia (#72) for 18 dB coupling level
  Drill 1 hole half size above at each end of hole array
  Hole separation 0.046"

* C: use WR-12 Cu waveguide
  Machine down two narrow walls.

Use soldering jig to assemble and solder. Machine down flange faces by 0.005" after soldering.



A



B

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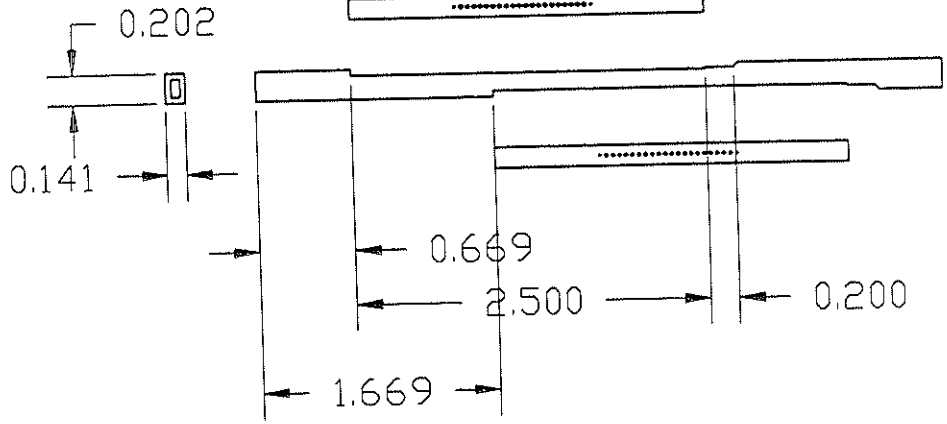
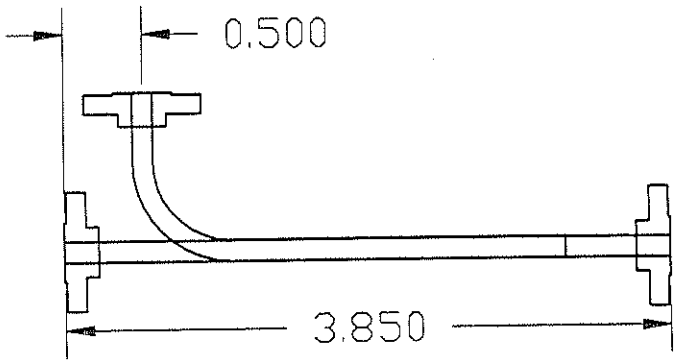
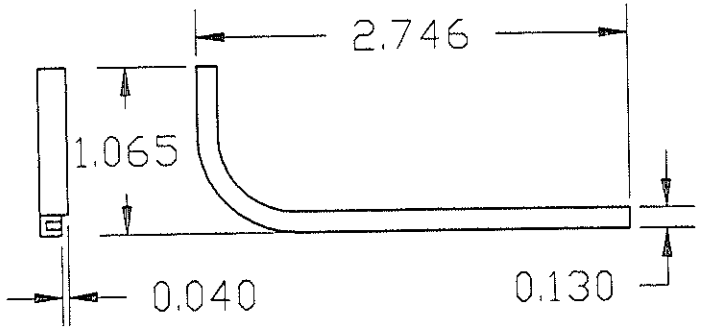




A



B

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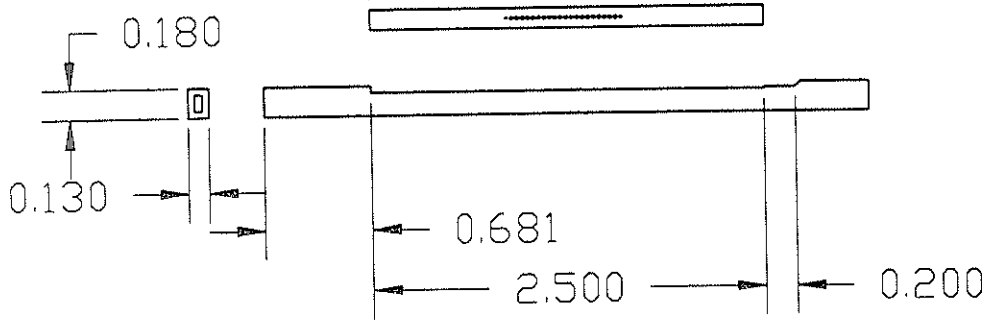

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WR-10 Directional Coupler

Dimensions are for finished coupler; cut waveguide to larger size initially.

* A: make one piece from WR-10 waveguide. Use bending jig to bend; bending radius 0.5". Machine down one narrow wall after bending.
* B: make from 0.002" thick BeCu. Drill 20 holes 0.021" Dia. (#75) for 20 dB coupling level. Optionally drill two holes half-size at either end of hole array.
* C: make one piece from WR-10 waveguide. Machine down one narrow wall.

Use soldering jig to assemble and solder. Machine down flange faces 0.005" after soldering.