NATIONAL RADIO ASTRONOMY OBSERVATORY
GREEN BANK, WEST VIRGINIA

ELECTRONICS DIVISION TECHNICAL NOTE NO. 147

Title: **EVALUATION OF EDM FOR SMALL WAVEGUIDE FABRICATION**

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M. Crawford and N. Horner

Date: July 5, 1988

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EVALUATION OF EDM FOR SMALL WAVEGUIDE FABRICATION

A. R. Kerr, J. W. Lamb, N. J. Bailey, M. Crawford, and N. Horner

Electric Discharge Machining has a number of attractive features as a procedure for fabricating short sections of millimeter waveguide. In particular, the low cost -- $35 per hole -- and 1-2 week turnaround seems competitive with electroforming. Some structures, such as deep but very narrow coupling slots for directional couplers, seem inherently well suited to fabrication by EDM.

Initially, a number of copper and brass sample blanks were sent to an EDM specialist, Rudolf Albinsky, 1108 High Country Road, Towson, MD 21204 (301-828-5002). We asked him to EDM waveguides of various sizes and depths in these pieces. Later, we sent him some copper and aluminum WR-4 (170-260 GHz) branch-line couplers requiring 0.002"-wide x 0.0215"-deep coupling waveguides.

The results below indicate that, especially in aluminum, EDM can produce very small slots with good precision.

Brass and Copper Waveguide Test Pieces

We asked for 0.100" x 0.050" and 0.043" x 0.005" waveguides of various depths as indicated in Figs. 1 and 2. A tolerance of ± 0.0002" was specified on all waveguide dimensions.

For the 0.100" x 0.050" holes, Albinsky requested a 0.040" diameter pilot hole 0.010" less than the finished depth. For the 0.043" x 0.005" holes, the maximum depth he could do was 0.030".

The results are summarized in Table I and Figs. 3 and 4 show photographs of typical results. The waveguide height and width have mostly been held within ± 0.0010" of the nominal dimensions (cf. the specified tolerance of ± 0.0002"), while the depth of the blind holes is greater than specified by as much as 0.0030". The surfaces of both brass and copper waveguides had a "sandblasted" appearance under the microscope. We have not attempted to measure the electrical loss of the samples, nor have we tried plating the EDM'ed surfaces.

Copper and Aluminum WR-4 Branch-Line Couplers

The WR-4 (170-260 GHz) split block branch-line coupler shown in Fig. 5 has two 0.0020"-wide x 0.0215"-deep coupling slots in each half-block. Alignment between the slots in the two halves is important. ETP copper and 6061 aluminum blocks were supplied to Albinsky with the two main waveguides already machined. The results are summarized in Tables II-V using the parameters defined in Fig. 6.

Results for the copper couplers are summarized in Tables II and III. The slot widths, nominally 2.0 mils, were considerably too large and the slots were somewhat tapered: The "average width" of a slot (i.e., average of the width near the top and the width near the bottom of the slot) varied from 2.9 to 4.2 mils. All but two of the 20 slots measured were wider near the top. The taper varied from 1.5 mils wider at the top to 0.2 mils wider at the bottom. Slot spacing (between center-lines of slots in the same half-block), nominally 16.0 mils, varied from 15.2 to 17.1 mils, with an average value of 16.2 mils. Misalignment between corresponding slots in opposite block-halves varied from -0.1 to +0.9 mil with an average value of 0.5 mil.

Results for the two aluminum couplers, summarized in Tables IV and V, were much better. We requested that coupler #1 be made to the nominal dimensions, while coupler #2 should have the smallest possible slots. In #1 the "average slot widths" were well within 0.2 mils of the nominal 2.0 mils. The slots in #2 were actually about 0.4 mils wider than in #1; this was because at first attempt the thinner EDM tool curled in use and a second cut with another tool was necessary. The slots were much less tapered in aluminum than in copper -- from 0.4 mils wider at the top to 0.2 mils wider at the bottom. Slot spacing, nominally 16.0 mils, varied from 15.6 to 16.3 mils. Misalignment between corresponding slots in opposite block-halves varied from 0.0 to 1.2 mils.

Conclusions

Based on these tests, it appears that in brass and copper the EDM process may be quite useful for making short waveguide sections where tolerances of ± 0.001" are acceptable. For blind waveguides (e.g., mixer backshort disks) it may be necessary to machine pieces after EDM to adjust the depth. Blind waveguides of height 0.005" are likely to have rounded ends. In brass or copper EDM does not appear sufficiently precise for waveguides less than about 0.005" high.

Results using aluminum were considerably better, and it appears that EDM is practical for waveguides down to 0.002" high with a tolerance of ± 0.0002". For our WR-4 directional couplers EDM appears to give better results than we have been able to achieve otherwise.

The superiority of aluminum over copper for EDM work is a result of the much lower tool wear in aluminum. It was possible to machine each slot in our aluminum couplers with a single tool, while in copper (and brass) an initial roughing cut was necessary, followed by a final cut with a fresh tool. Maintaining sub-mil tolerances in a process requiring a tool change is very difficult.

For high-Q applications (e.g., resonators in waveguide filters) it will be necessary to know the loss of the EDM'ed waveguide before its usefulness can be established.

Material & Quantity:

4 Brass
4 ETP Copper

T - Values:

0.0100"
0.1000"
Through (0.250")

Pilot hole P: 0.040" dia.

Tolerances:

X.XXX ±0.001
X.XXXX ±0.0002

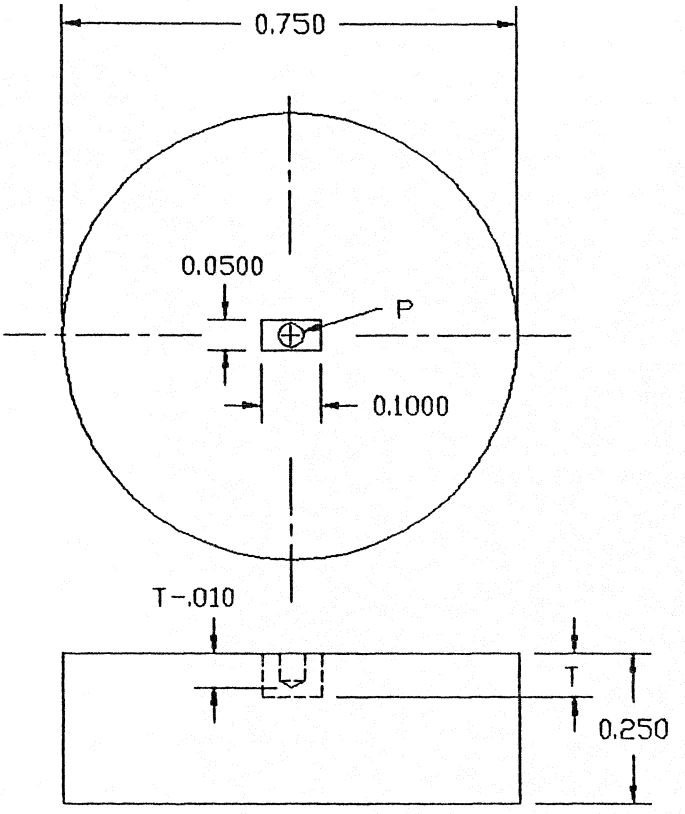


Fig. 1 Specification of 0.100" x 0.050" waveguides.

Material & Quantity:

4 Brass
4 ETP Copper

T - Values:

0.0100"
0.1000"
Through (0.250")

Tolerances:

X.XXX ±0.001
X.XXXX ±0.0002

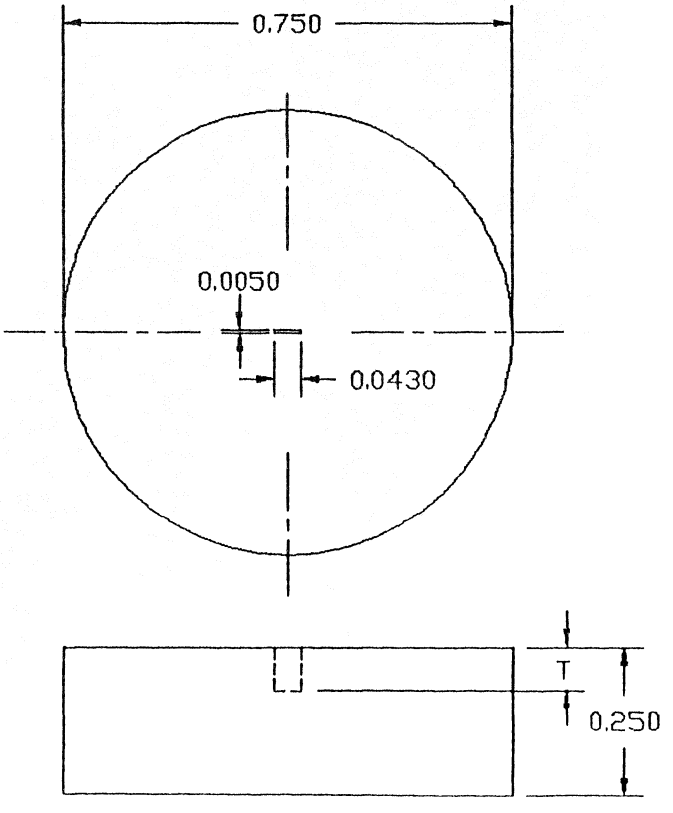
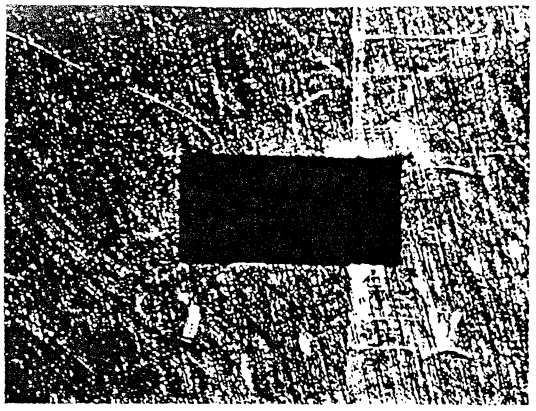


Fig. 2 Specification of 0.043" x 0.005" waveguides.



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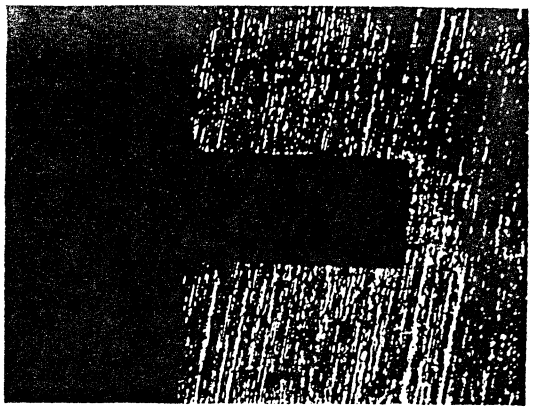

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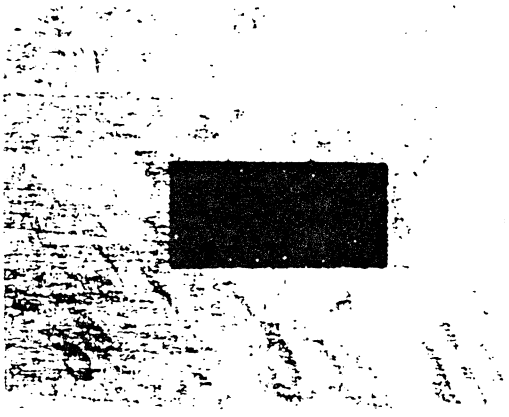

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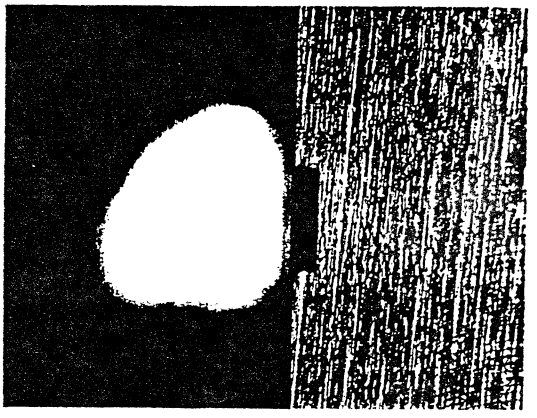

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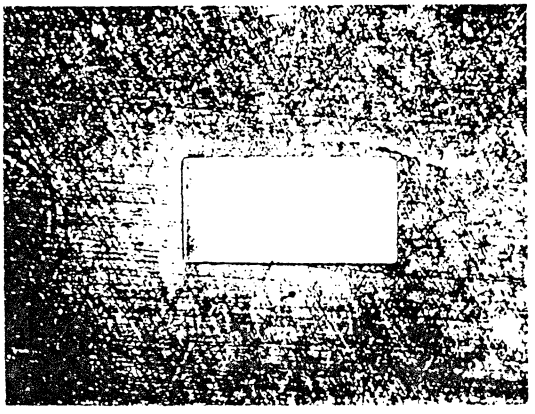

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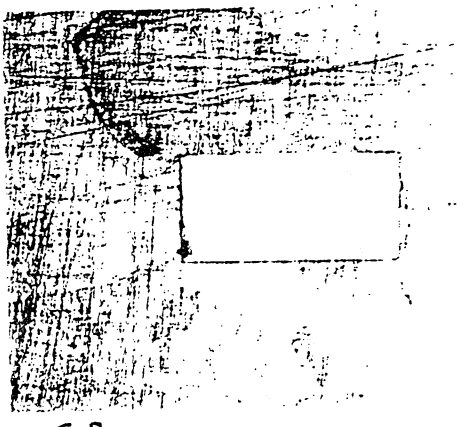

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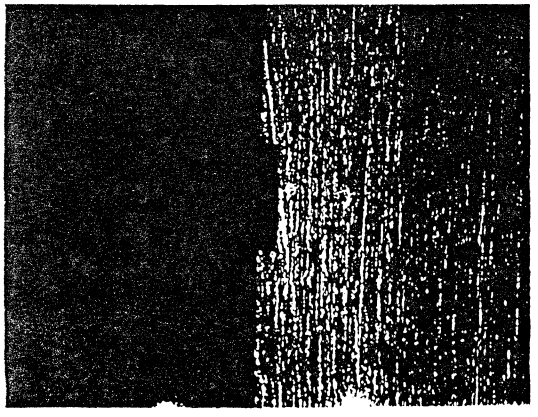

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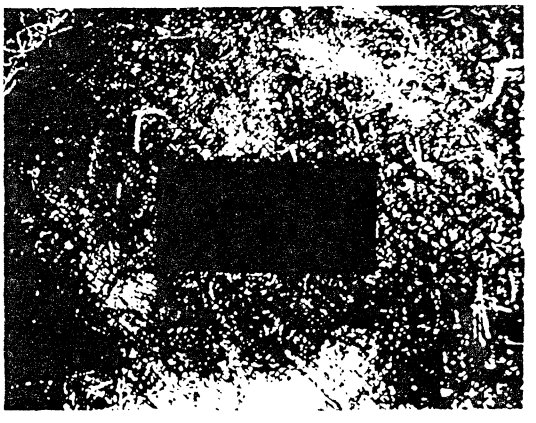
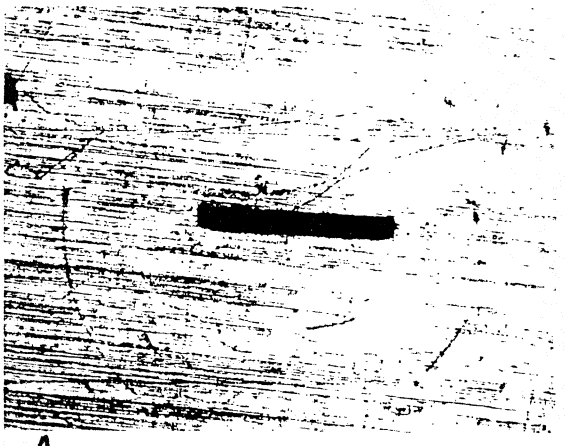


I

Fig. 3 Photographs of 0.100" x 0.050" waveguides.



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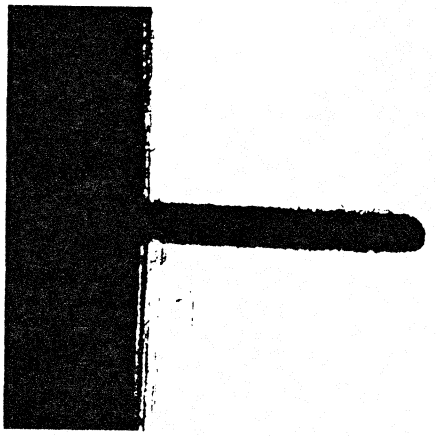

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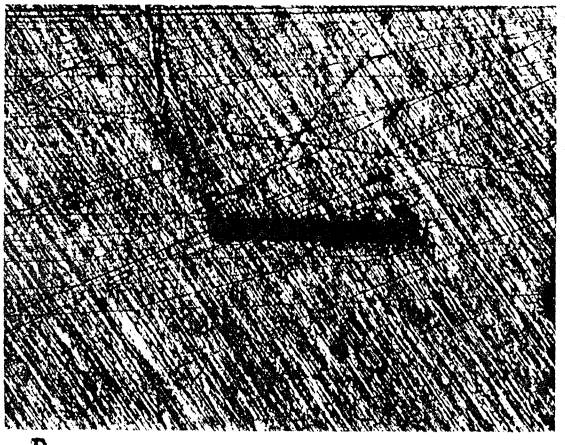

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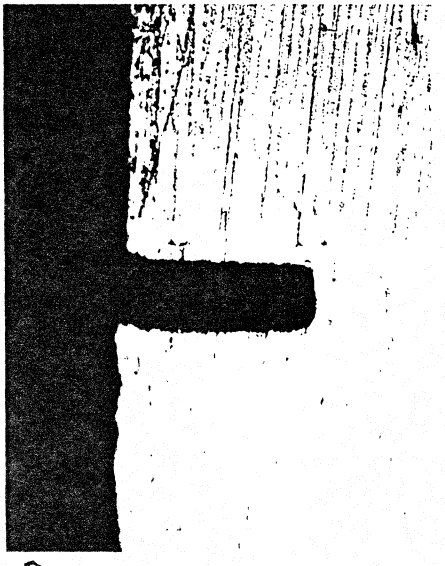
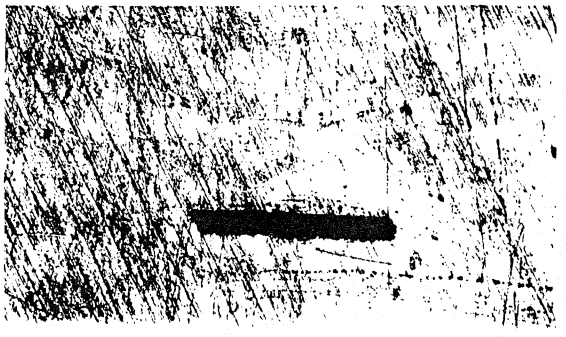
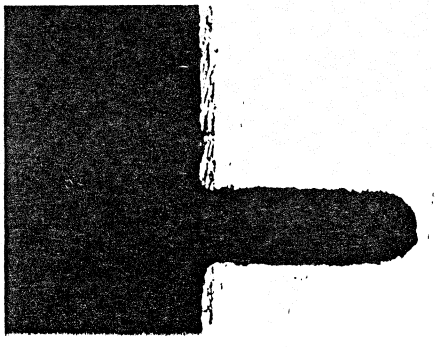


B CROSS-SECTION



C



C CROSS-SECTION

Fig. 4 Photographs of 0.043" x 0.005" waveguides.

RESULTS OF EDM TESTS BY R. ALBINSKY ARK 13 Nov 87

0.050 x 0.100" SAMPLES Dimensions in mils.

Sample #	Material	Height /error	Width /error	End Ht. /error	End Wdth. /error	Depth /error
F	Cu	51.3	100.7			100.2
		1.3	0.7			0.2
G	Cu	50.0	100.8	50.0	99.3	250.0
		0.0	0.8	0.0	-0.7	Thru.
H	Cu	51.0	100.5	50.1	99.5	250.0
		1.0	0.5	0.1	-0.5	Thru.
D	Brass	50.9	101.0			101.8
		0.9	1.0			1.8
E	Brass	50.2	100.3			13.0
		0.2	0.3			3.0
I	Brass	50.0	100.5			10.6
		0.0	0.5			0.6

0.005 x 0.043" SAMPLES Dimensions in mils.

Sample #	Material	Height /error	Width /error	Depth /error
C	Cu	4.8	42.3	11.7
		-0.2	-0.7	1.7
J	Cu	4.9		31.2
		-0.1		1.2
A	Brass	5.3	42.9	31.1
		0.3	-0.1	1.1
B	Brass	4.6	42.5	10.2
		-0.4	-0.5	0.2

Table I Measurements on 0.100" x 0.050" and 0.043" x 0.005" copper and brass waveguides fabricated by EDM.

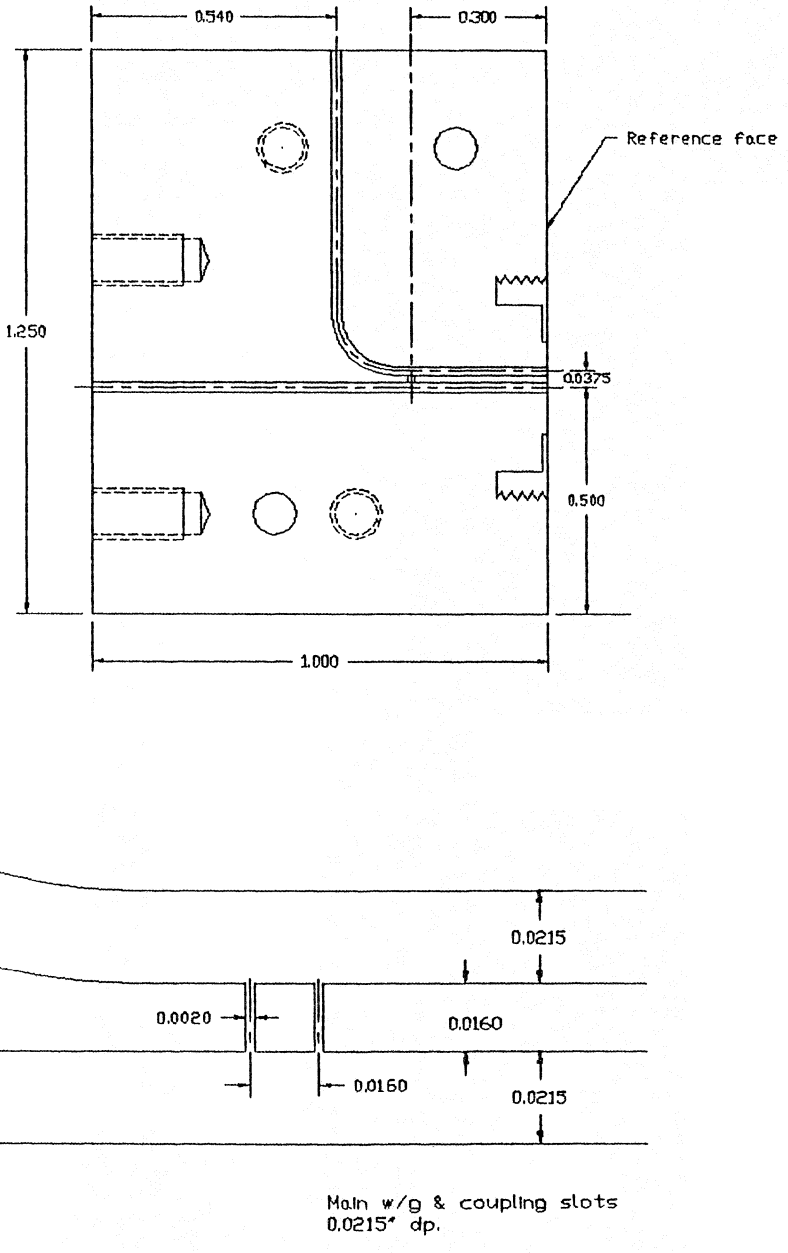


Fig. 5 Drawing of the WR-4 branch-line coupler. The coupler is fabricated as two mirror-image half-blocks (one shown). Detail shows 0.002" wide coupling slots.

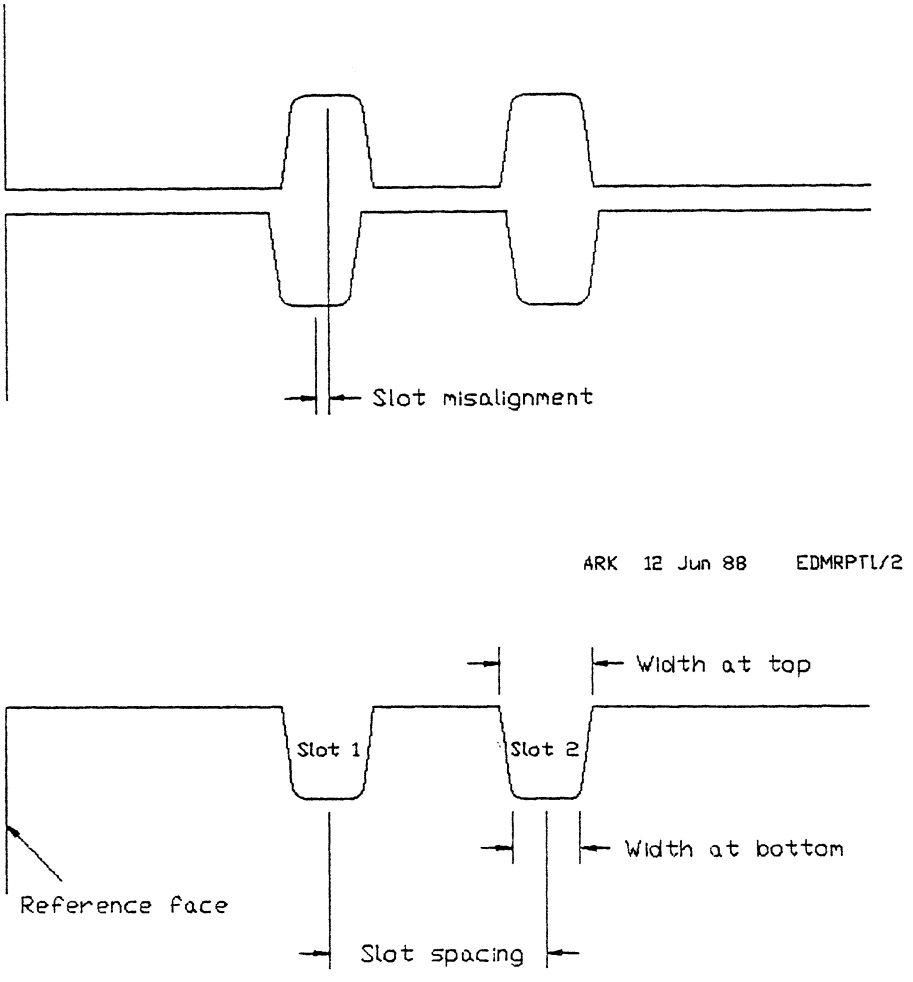


Fig. 6 Sketch of directional coupler cross-section defining terms used in Tables II-V.

COUPLER NO.	LOWER HALF slot 1	LOWER HALF slot 2	UPPER HALF slot 1	UPPER HALF slot 2	
			Width at top		
spec.	2.00	2.00	2.00	2.00	Max
1	3.82	4.06	4.76	3.74	4.76
2	4.06	3.27	3.78	3.43	Min
3	4.06	3.27	3.86	3.54	3.27
4	3.96	3.74	3.39	4.61	Average
5	4.09	4.17	4.69	4.69	3.95
			Width at bottom		
spec.	2.00	2.00	2.00	2.00	Max
1	3.19	2.99	3.23	3.43	4.26
2	3.19	3.23	3.31	3.50	Min
3	3.07	2.60	2.91	2.83	2.60
4	2.99	2.60	3.15	3.86	Average
5	4.26	3.41	3.54	3.66	3.25
			Average width		
spec.	2.00	2.00	2.00	2.00	Max
1	3.51	3.53	4.00	3.59	4.24
2	3.63	3.25	3.55	3.47	Min
3	3.57	2.94	3.39	3.19	2.94
4	3.48	3.17	3.27	4.24	Average
5	4.18	3.79	4.12	4.18	3.60
			Average width error		
spec.	0.00	0.00	0.00	0.00	Max
1	1.51	1.53	2.00	1.59	2.24
2	1.63	1.25	1.55	1.47	Min
3	1.57	0.94	1.39	1.19	0.94
4	1.48	1.17	1.27	2.24	Average
5	2.18	1.79	2.12	2.18	1.60
			Taper		
spec.	0.00	0.00	0.00	0.00	Max
1	0.63	1.07	1.53	0.31	1.53
2	0.87	0.04	0.47	-0.07	Min
3	0.99	0.67	0.95	0.71	-0.17
4	0.97	1.14	0.24	0.75	Average
5	-0.17	0.76	1.15	1.03	0.70

Table II Measurements of the coupling slots fabricated by EDM in the copper couplers.

COUPLER NO.	LOWER HALF	UPPER HALF	
	Slot spacing		
spec.	16.0	16.0	Max
1	15.4	15.3	17.1
2	16.8	17.1	Min
3	16.6	16.6	15.3
4	16.2	16.5	Average
5	15.8	15.6	16.2

COUPLER NO.	FIRST PAIR	SECOND PAIR	
	Slot misalignment		
spec.	0.0	0.0	Max
1	0.2	0.4	0.9
2	0.9	0.6	Min
3	0.9	0.9	-0.1
4	0.7	0.4	Average
5	-0.1	0.1	0.5

Table III Measured spacing and alignment between the coupling slots in the copper couplers.

COUPLER NO.	LOWER HALF slot 1	LOWER HALF slot 2	UPPER HALF slot 1	UPPER HALF slot 2
		Width at top		
spec.	2.00	2.00	2.00	2.00
1	1.97	2.05	2.09	2.01
2	2.64	2.24	2.40	2.40
		Width at bottom		
spec.	2.00	2.00	2.00	2.00
1	1.98	1.97	1.70	1.73
2	2.20	2.40	2.50	2.48
		Average width		
spec.	2.00	2.00	2.00	2.00
1	1.98	2.01	1.90	1.87
2	2.42	2.32	2.45	2.44
		Average width error		
spec.	0.00	0.00	0.00	0.00
1	-0.02	0.01	-0.10	-0.13
2	0.42	0.32	0.45	0.44
		Taper		
spec.	0.00	0.00	0.00	0.00
1	-0.01	0.08	0.39	0.28
2	0.44	-0.16	-0.10	-0.08

Table IV Measurements of the coupling slots fabricated by EDM in the aluminum couplers.

COUPLER NO.	LOWER HALF	UPPER HALF	
	Slot spacing		
spec.	16.0	16.0	Max
1	15.9	15.6	16.3
2	16.3	16.2	Min
			15.6
			Average
			16.0

COUPLER NO.	FIRST PAIR	SECOND PAIR	
	Slot misalignment		
spec.	0.0	0.0	Max
1	-1.2	-0.9	-0.0
2	-0.1	-0.0	Min
			-1.2
			Average
			-0.5

Table V Measured spacing and alignment between the coupling slots in the aluminum couplers.