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DESIGN OF A DIPLEXING FILTER FOR THE HIGH RESOLUTION IFF ANTENNA OF THE AN/FPS-3 RADAR

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ABSTRACT

A dual high resolution IFF antenna recently designed for the AN/FPS-3 Radar required a diplexing filter to separate transmitted and received signals. Strip transmission line techniques were successfully applied to the design of such a filter which gives adequate separation between the transmitted band (990-1040 mc/s) and the received band (1080-1130 mc/s) in simple and easily fabricated form.

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DESIGN OF A DIPLEXING FILTER FOR THE HIGH RESOLUTION IFF ANTENNA OF THE AN/FPS-3 RADAR

- John H. Craven -

The high resolution IFF antenna used with the AN/FPS-3 Radar consists of two non-resonant slotted waveguide arrays which are fully described in Reference 1. It is required that as little as possible of the transmitted power be allowed to radiate from the receiving array, and that received power picked up by the transmitting antenna should not be allowed to enter the receiver input. These requirements arise because both arrays are designed for relatively wide bandwidth operation and the band separation is small (transmitting 990-1040 mc/s, receiving 1080-1130 mc/s), and also because the squint angles of the two arrays are different, resulting in spurious responses. Originally the first part of the requirement had been met by inserting a high-pass filter with a cutoff frequency of 1060 mc/s in the receiving array feed cable. After discussions with Dr. J.Y. Wong regarding these requirements, it was decided that an attempt should be made to construct a simple diplexing filter utilizing the strip transmission line. Tentative characteristics desired for the filter were: pass band loss 2 db or less; stop band loss to be 15 db or greater at the edge of the opposite pass band, with a rise to at least 40 db.

FILTER DESIGN PROCEDURE

It has been shown by Guillemin [2] that mid-series m-derived high- and low-pass filters may be parallelled by the use of fractional terminations. The first step to be undertaken was the design of a high-pass and low-pass filter of the m-derived type, having the same cutoff frequency (in this case 1060 mc/s midway between the transmitting and receiving bands).

The image parameter method for design of these filters as given by Breeze and Cohn [3, 4] was employed to ascertain if the desired characteristics could be obtained. Differences from filters described in References 3 and 4 which had to be checked were: (a) the two pass bands and the crossover range were much smaller, and (b) it was desirable that only open-circuited stubs be used without any adjustment of stub lengths.

A typical m-derived section is shown in Fig. 1(a) and the half-section used as end-sections in Fig. 1(b). Design equations applicable to the half-section of the low-pass filter with open-circuited stubs are:

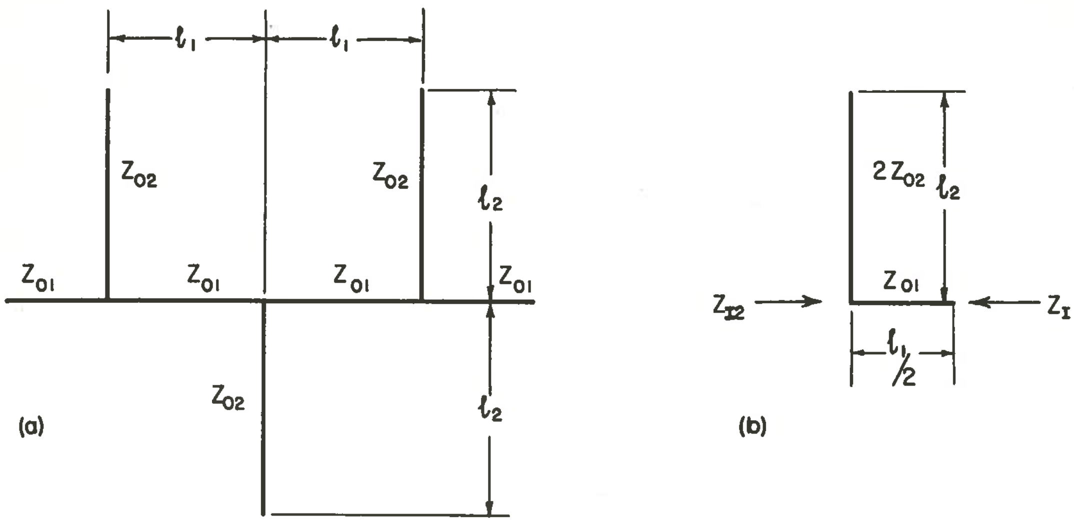

FIG. 1. TYPICAL M-DERIVED FILTER SECTIONS

$$\frac{Z_{I1}}{Z_{01}} = \frac{\left[1 - \frac{n}{2} \tan\left(\frac{f\varphi_{2\infty}}{af_c}\right) \tan\left(\frac{f\varphi_{1c}}{2f_c}\right)\right]^{\frac{1}{2}}}{\left[1 + \frac{n}{2} \tan\left(\frac{f\varphi_{2\infty}}{af_c}\right) \cot\left(\frac{f\varphi_{1c}}{2f_c}\right)\right]^{\frac{1}{2}}},$$

$$\frac{Y_{I2}}{Y_{01}} = \left\{1 + n \tan\left(\frac{f\varphi_{2\infty}}{af_c}\right) \cot\left(\frac{f\varphi_{2c}}{f_c}\right) - \left[\frac{n}{2} \tan\left(\frac{f\varphi_{2\infty}}{af_c}\right)\right]^2\right\}^{\frac{1}{2}},$$

$$\alpha = \cosh^{-1}\left[\cos\left(\frac{f\varphi_{2c}}{f_c}\right) - \frac{n}{2} \tan\left(\frac{f\varphi_{2\infty}}{af_c}\right) \sin\left(\frac{f\varphi_{1c}}{f_c}\right)\right],$$

where $n = \frac{Z_{01}}{Z_{02}} = 2 \cot \frac{\varphi_{2\infty}}{a} \cot \frac{\varphi_{1c}}{2}$,

$$a = \frac{f_\infty}{f_c}.$$

$\varphi_{2\infty}$ is length of shunt stub at frequency of infinite attenuation (90°)
φ_{1c} is length of series line at cutoff frequency (40° to 60° — Charts in Refs. 3 and 4 drawn for 50°)

For a high-pass filter with open-circuited stubs, the equations are the same as above with

φ_{1d} in place of φ_{1c},

f_d in place of f_c,

$$a = \frac{f_\infty}{f_d},$$

$$n = \frac{Z_{01}}{Z_{02}} = -2 \cot \frac{\varphi_{2\infty}}{a} \tan \frac{\varphi_{1d}}{2} .$$

(Charts in Ref. 4 are drawn for $\varphi_{1d} = 120°$)

LOW-PASS FILTER

The nominal cutoff frequency of the low-pass filter was taken as 1060 mc/s and the mid-frequency of the pass band at 1015 or approximately 0.96 f_c. The input impedance of the terminating half-sections should be as flat as possible over the band 0.93 to 0.99 f_c. However, examination of the curves in Reference 4 shows that this is approached only for values of "a" between 1.03 and 1.00. Calculation shows that the shunt stubs would have to be of an impractically high impedance for strip transmission lines. Examination of other possible values of "a" leads to the conclusion that a value of 1.20 is as low as can be reasonably utilized, and if a match is assumed at 0.96 f_c, the normalized input impedance will vary from 1.25 to 0.75 (62.5 to 37.5 ω) across the pass band. As the internal matching of the m-derived sections is very much better than this, this mismatch can be tolerated. Calculations were then carried out for the internal sections using a = 1.10 and a = 1.05, and matching the image impedance at 0.96 f_c. A complete filter made up of one section at a = 1.05, two sections at a = 1.10, and matching half-sections at a = 1.20 was then produced.

The measured response of this filter did not have the required sharp cutoff. A second filter was built with 4 sections of a = 1.05 and terminating half-sections at a = 1.20. The response curve had the desired sharp cutoff and more than adequate rejection in the receiving band (see Fig. 2).

HIGH-PASS FILTER

The high-pass filter was designed in a manner similar to that for the low-pass filter with $\varphi_{1d} = 120°$ and $\varphi_{2\infty} = 90°$. The terminating half-sections were designed with a = 0.84 and the three internal sections with a = 0.92. Impedances were

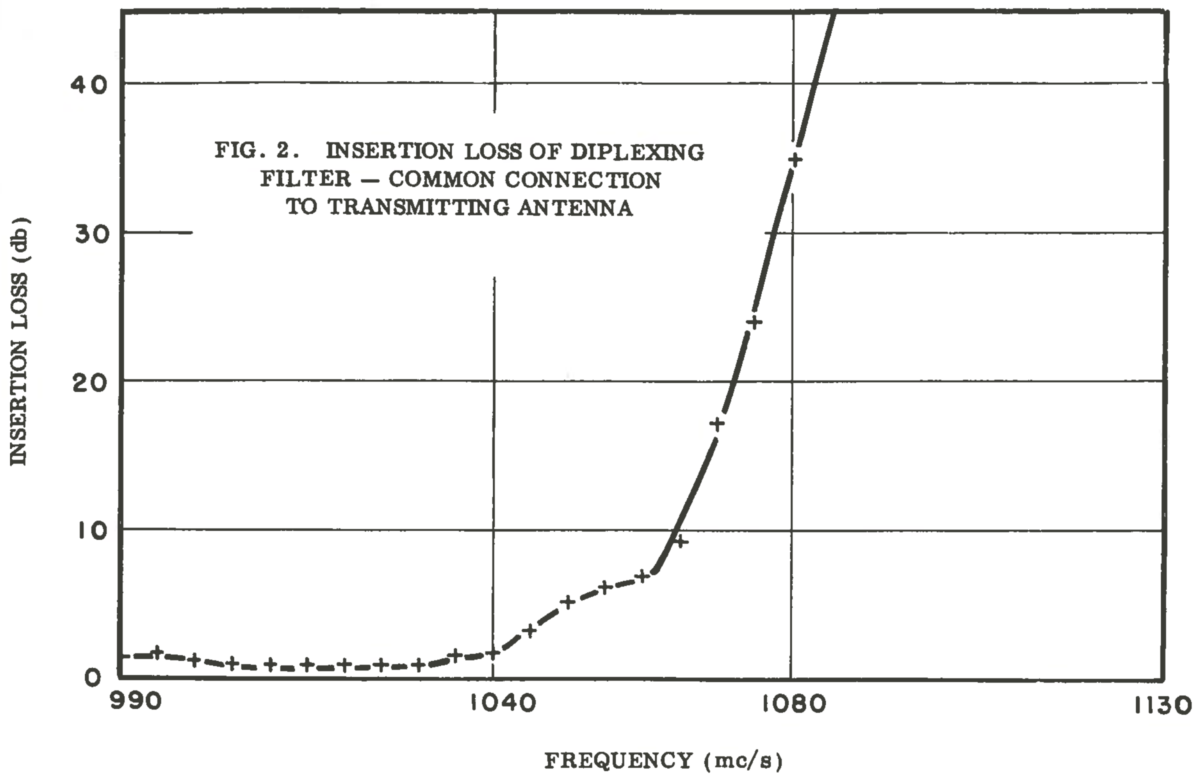

FIG. 2. INSERTION LOSS OF DIPLEXING FILTER — COMMON CONNECTION TO TRANSMITTING ANTENNA

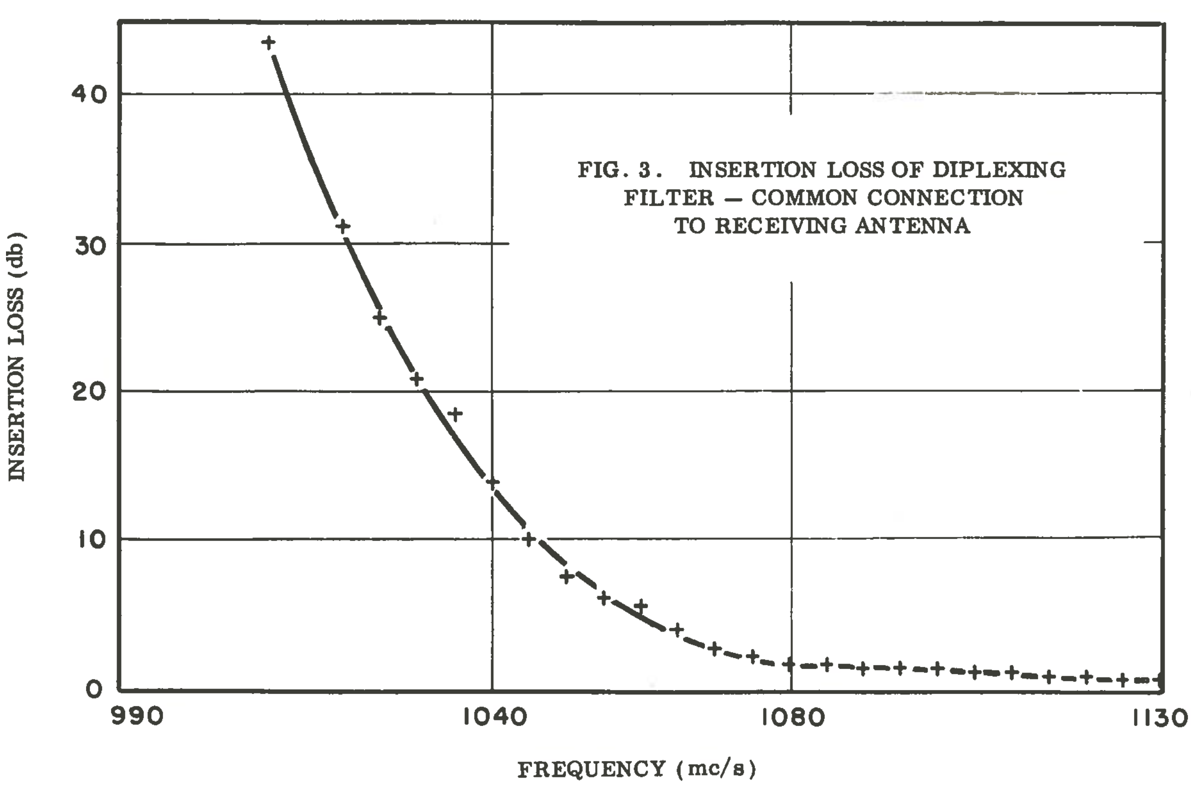

FIG. 3. INSERTION LOSS OF DIPLEXING FILTER — COMMON CONNECTION TO RECEIVING ANTENNA

matched at 1.04 f_c. In the internal sections a maximum value of a = 0.95 would have been better but gave unrealizable impedances. Only 3 internal sections were used in this filter to limit the overall physical size of the complete diplexer. Adequate attenuation was obtained (see Fig. 3).

COMPLETE DIPLEXING FILTER

The final filter consists of a high- and a low-pass filter connected in tandem with the shunt stubs at the junction removed. At the junction a 50-ohm line is attached at right angles to the filters to form the common feed. The response of the composite filter is essentially the same as that of the filters when measured separately (see Figs. 2 and 3). Breeze and Cohn found that some capacitive matching was required in their filters. However, in the present case the best match was obtained with no matching stubs, probably because of the much narrower bandwidths involved. VSWR, as measured at the three coaxial connectors, is shown in Figs. 4, 5, and 6.

TEST RESULTS

As a result of operational tests carried out at RCAF Station Foymount, it was determined that the isolation provided by the filter was adequate for the frequencies used at that time (transmitter at 1030 mc/s, receiver at 1090 mc/s). Spurious responses were completely eliminated by the filter and operation was entirely satisfactory. The filter has been in use at Foymount since its installation in August 1957, and to date (December 1957) is still in operation even though it was not a completely engineered model.

COMMENTS

This diplexing filter is adequate for the frequencies at present in use but it is anticipated that there will be spurious response if the transmitter is operated closer to the upper edge of the allotted band. This is because of insufficient attenuation in the high-pass filter at 1040 mc/s. Improvement could be obtained by provision of a further section of "a" at 0.92 at the expense of adding some $2\frac{1}{2}$ inches to the overall length of the filter.

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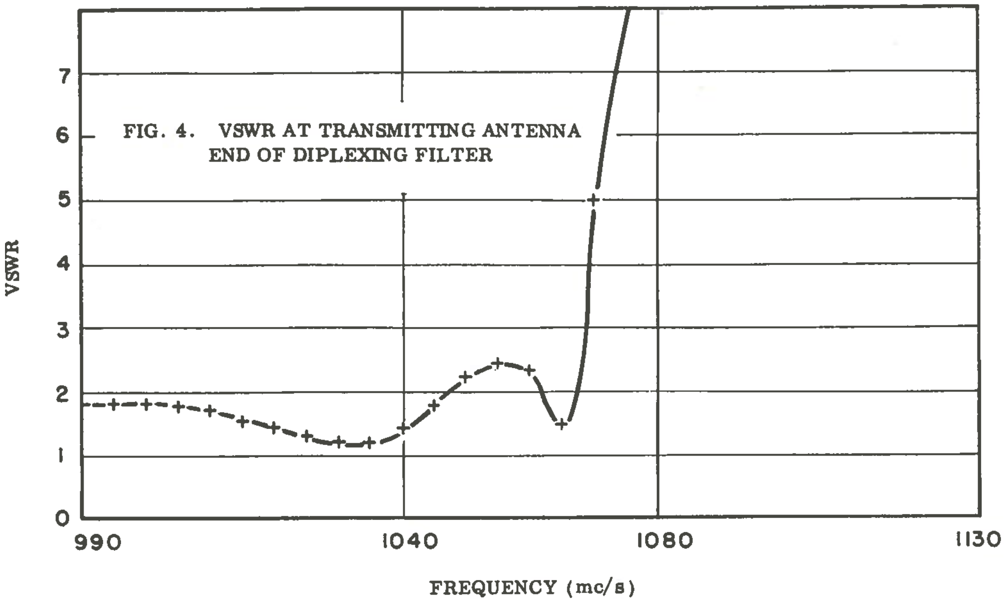
FIG. 4. VSWR AT TRANSMITTING ANTENNA END OF DIPLEXING FILTER
VSWR
0
1
2
3
4
5
6
7
990
1040
1080
1130
FREQUENCY (mc/s)

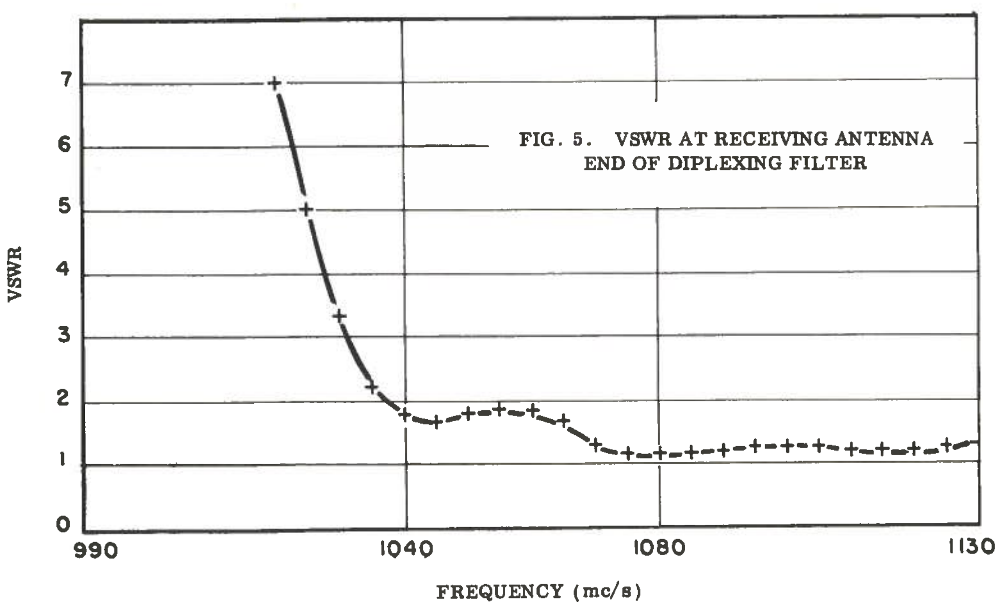
FIG. 5. VSWR AT RECEIVING ANTENNA END OF DIPLEXING FILTER
VSWR
0
1
2
3
4
5
6
7
990
1040
1080
1130
FREQUENCY (mc/s)

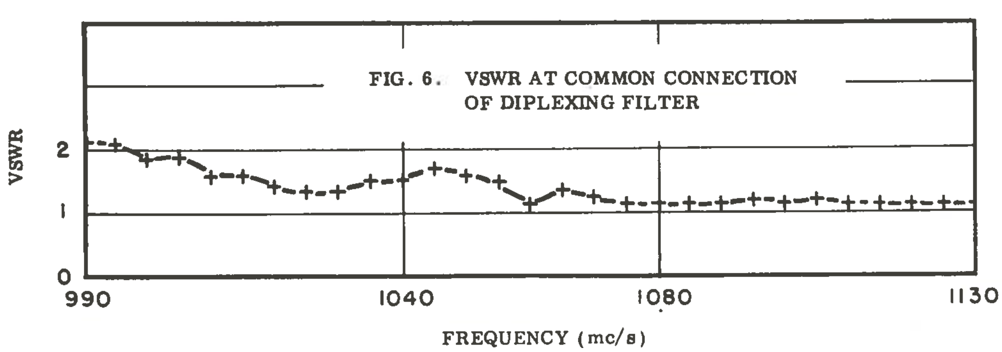
FIG. 6. VSWR AT COMMON CONNECTION OF DIPLEXING FILTER
VSWR
0
1
2
990
1040
1080
1130
FREQUENCY (mc/s)

4. Breeze, M.E. and Cohn, S.B., Final Report on Band Separation Filters, Sperry Gyroscope Co., Contract DA-36-039-sc-5570, 1954

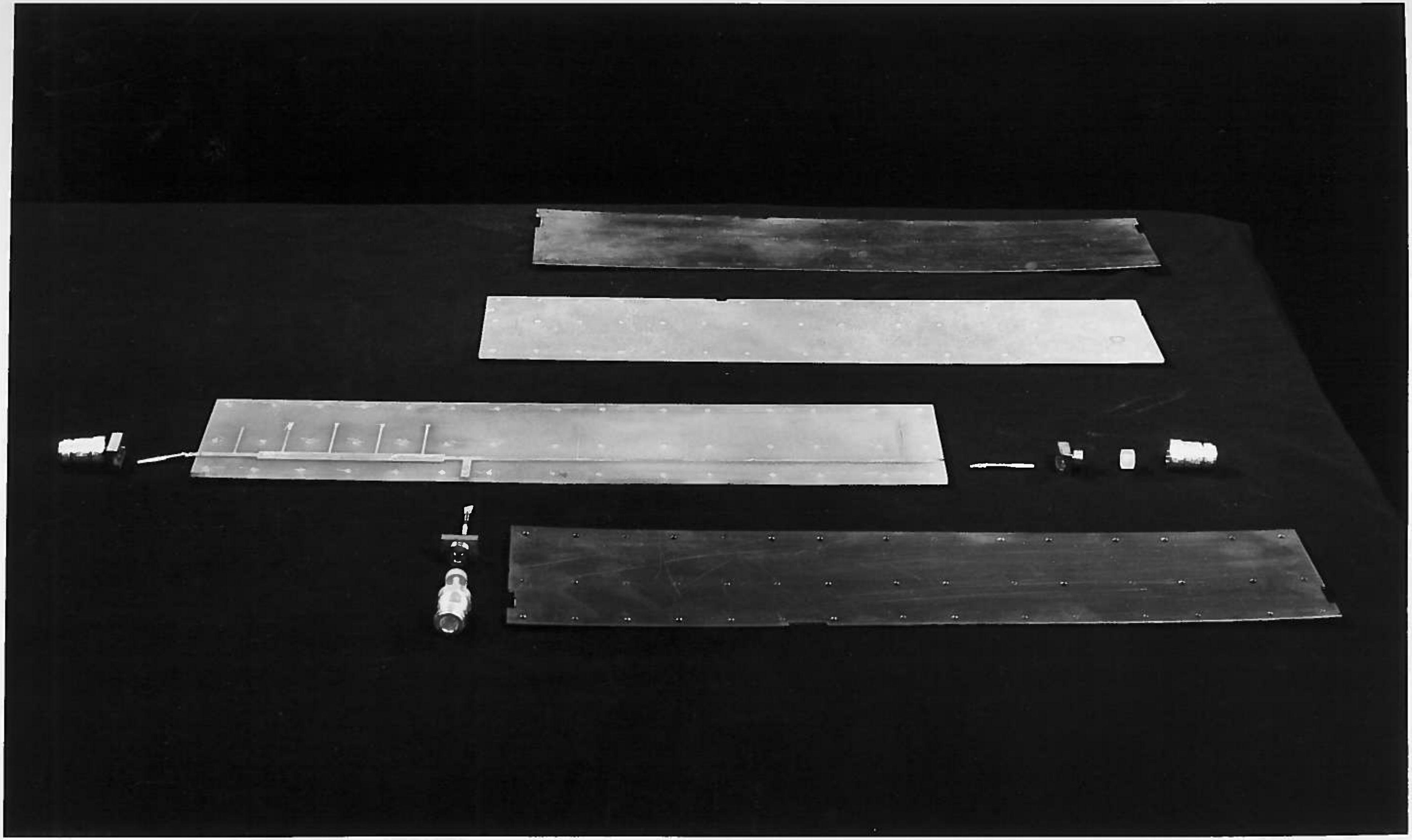

PLATE I DIPLEXING FILTER BEFORE ASSEMBLY

PLATE II DIPLEXING FILTER ASSEMBLED

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