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Group Report

1964-9

**Diplexer
Using Side-Wall Couplers
in One-Half Height
Large X-Guide**

J. A. Kostriza

17 January 1964

Prepared under Electronic Systems Division Contract AF 19(628)-500 by

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LINCOLN LABORATORY

DIPLEXER USING SIDE-WALL COUPLERS
IN ONE-HALF HEIGHT LARGE X-GUIDE

J. A. KOSTRIZA

Group 61

GROUP REPORT 1964-9

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LEXINGTON

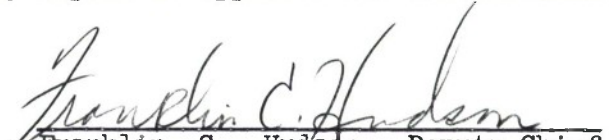
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ABSTRACT

A diplexer in one-half height large X-guide uses side-wall couplers. The analysis is based on the scattering matrix approach.

A compact unit is made possible because of an abrupt 180° E-plane bend.

This technical documentary report is approved for distribution.


Franklin C. Hudson, Deputy Chief
Air Force Lincoln Laboratory Office

DIPLEXER USING SIDE-WALL COUPLERS IN ONE-HALF HEIGHT LARGE X-GUIDE

I. SCATTERING MATRIX OF TWO HYBRIDS IN CASCADE

A schematic of a side-wall coupler is shown in Fig. 1.

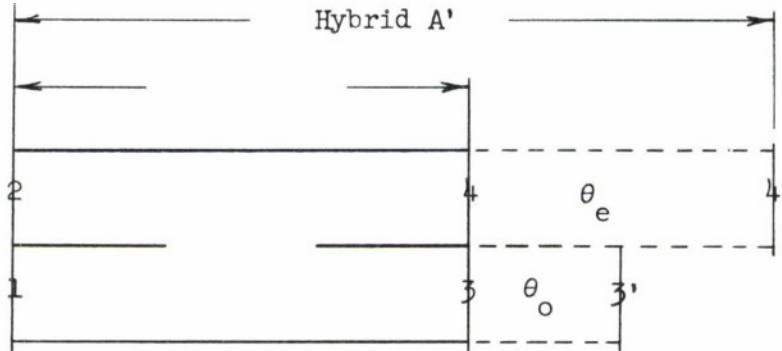


Fig. 1. Side-Wall Coupler Schematic, showing location of reference planes.

The reference planes are labeled 1, 2, 3 and 4. The scattering matrix is given by:

$$S = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 & 0 & 1 & j \\ 0 & 0 & j & 1 \\ 1 & j & 0 & 0 \\ j & 1 & 0 & 0 \end{bmatrix} \quad (1)$$

Now terminal 3 is moved to the right, through θ_o , to 3' and terminal 4 is moved through θ_e , to 4'. The scattering matrix for terminals 1, 2, 3', 4' becomes:

$$S' = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 & 0 & e^{-j\theta_o} & je^{-j\theta_e} \\ 0 & 0 & je^{-j\theta_o} & e^{-j\theta_e} \\ e^{-j\theta_o} & je^{-j\theta_o} & 0 & 0 \\ je^{-j\theta_e} & e^{-j\theta_e} & 0 & 0 \end{bmatrix} \quad (2)$$

Equation (1) holds for hybrid A, whereas Eq. (2) holds for hybrid A'. If the output of A' is joined to a hybrid B whose scattering matrix is the same as that of A, a new four-port device results with terminal planes 1, 2, 3, 4 as shown in Fig. 2.

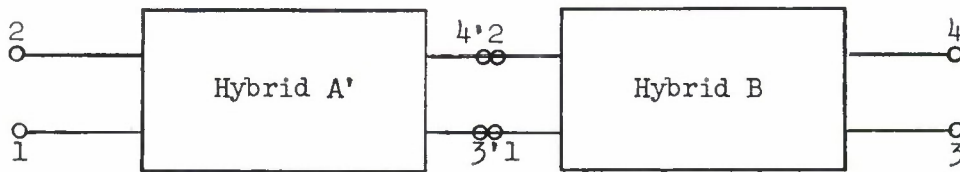


Fig. 2. Four - Port 1, 2, 3, 4 consisting of hybrid A' in cascade with hybrid B.

To join ports 4' with 2, and 3' with 1, the scattering equation $b = Sa$ ($b =$ reflected wave amplitudes, $a =$ incident wave amplitudes) is written for both hybrids:

$$\left. \begin{aligned}
\sqrt{2} b_1 &= e^{-j\theta_o} a_3 + j e^{-\theta_e} a_4, \\
\sqrt{2} b_2 &= j e^{-j\theta_o} a_3 + j e^{-j\theta_e} a_4, \\
\sqrt{2} b_3 &= e^{-j\theta_o} a_1 + j e^{-j\theta_o} a_2, \\
\sqrt{2} b_4 &= j e^{-j\theta_e} a_1 + e^{-j\theta_e} a_2
\end{aligned} \right\} \text{Hybrid A',} \quad (3)$$

$$\left. \begin{aligned}
\sqrt{2} B_1 &= A_3 + jA_4 \\
\sqrt{2} B_2 &= jA_3 + A_4 \\
\sqrt{2} B_3 &= A_1 + jA_2 \\
\sqrt{2} B_4 &= jA_1 + A_2
\end{aligned} \right\} \text{Hybrid B.} \quad (4)$$

To "connect" Eqs. (3) and (4), the wave reflected from port 4' of hybrid A' must equal the wave incident on port 2 of hybrid B, etc., so that the following must hold:

$$\begin{aligned}
b_{4'} &= A_2 & \text{and} & & b_{3'} &= A_1 \\
a_{4'} &= B_2 & & & a_{3'} &= B_1
\end{aligned} \quad (5)$$

Using Eqs. (5), (3) and (4), the composite structure of Fig. 2 may be characterized by Eq. (6) where small case letters are used throughout for reflected and incident wave amplitudes.

$$\begin{aligned}
b_1 &= \frac{a_3}{2} \begin{bmatrix} e^{-j\theta_o} & -e^{-j\theta_e} \end{bmatrix} + j \frac{a_4}{2} \begin{bmatrix} e^{-j\theta_o} + e^{-j\theta_e} \end{bmatrix}, \\
b_2 &= j \frac{a_3}{2} \begin{bmatrix} e^{-j\theta_o} & +e^{-j\theta_e} \end{bmatrix} + \frac{a_4}{2} \begin{bmatrix} -e^{-j\theta_o} + e^{-j\theta_e} \end{bmatrix}, \\
b_3 &= \frac{a_1}{2} \begin{bmatrix} e^{-j\theta_o} & -e^{-j\theta_e} \end{bmatrix} + j \frac{a_2}{2} \begin{bmatrix} e^{-j\theta_o} + e^{-j\theta_e} \end{bmatrix}, \\
b_4 &= j \frac{a_1}{2} \begin{bmatrix} e^{-j\theta_o} & +e^{-j\theta_e} \end{bmatrix} + \frac{a_2}{2} \begin{bmatrix} -e^{-j\theta_o} + e^{-j\theta_e} \end{bmatrix}.
\end{aligned} \tag{6}$$

II. DIPLEXER REQUIREMENTS

To achieve diplexer action, the following conditions must be met:

1. A signal of frequency f_1 , incident at port 1, emerges out of port 3 (or port 4) with negligible coupling to port 4 (or port 3),
and
2. A signal of frequency f_2 , incident at port 2, emerges out of port 3 (or port 4) with negligible coupling to port 4 (or port 3),
and
3. Zero or small coupling between ports 1 and 2.

If the signal f_1 is applied at port 1 (i.e., $a_2 = 0$), then:

$$\begin{aligned}
b_3 \text{ (at } f_1) &= \frac{a_1}{2} \begin{bmatrix} e^{-j\theta_o} & -e^{-j\theta_e} \end{bmatrix}, \\
b_4 \text{ (at } f_1) &= j \frac{a_1}{2} \begin{bmatrix} e^{-j\theta_o} & +e^{-j\theta_e} \end{bmatrix}.
\end{aligned} \tag{7}$$

From the above:

$$\text{when } \theta_o - \theta_e = \pm 2\pi n \text{ (} n = 0, 1, 2\text{---)}, \text{ then } b_3 = 0, \text{ and} \tag{8}$$

$$\text{when } \theta_o - \theta_e = \pm 2\pi \left[m + \frac{1}{2} \right] \text{ (} m = 0, 1, 2\text{---)}, \text{ then } b_4 = 0. \tag{9}$$

If the signal f_2 is applied at port 2 (i.e., $a_1 = 0$), then:

$$b_3 \text{ (at } f_2) = j \frac{a_2}{2} \left[e^{-j\theta_o} + e^{-j\theta_e} \right],$$

$$b_4 \text{ (at } f_2) = \frac{a_2}{2} \left[-e^{-j\theta_o} + e^{-j\theta_e} \right]. \quad (10)$$

From Eq. (10) it follows that:

$$\text{when } \theta_o - \theta_e = \pm 2\pi \left[m + \frac{1}{2} \right] \text{ (} m = 0, 1, 2, \dots \text{), then } b_3 = 0, \text{ and} \quad (11)$$

$$\text{when } \theta_o - \theta_e = \pm 2\pi n \text{ (} n = 0, 1, 2, \dots \text{), then } b_4 = 0. \quad (12)$$

III. COMMON OUTPUT IS PORT 4

Assume that b_4 is of interest at both frequencies f_1 and f_2 . Then Eqs. (8) and (11) must be satisfied.

$$P_{b_3} (f_1) = \frac{1}{2} b_3 b_3^* = \frac{1}{4} (1 - \cos\theta_1), \text{ where } \theta_1 = \theta_o - \theta_e,$$

$b_3^* = b_3$ conjugate, and P_{b_3} = power reflected at port 3.

$$P_{b_4} (f_1) = \frac{1}{4} (1 + \cos\theta_1),$$

$$P_{in} \textcircled{1} (f_1) = \frac{1}{2} a_1 a_1^* = \frac{1}{2}; \quad P_{b_3} + P_{b_4} = \frac{1}{2}.$$

$$I.L. (f_1) = 10 \log \frac{P_{in} \textcircled{1}}{P_{b_4}} = 10 \log \frac{2}{1 + \cos\theta_1}.$$

If $\theta_1 = 2\pi n \pm \delta_1$, $\cos\theta_1 = \cos\delta_1$, and

1. L. J. Ricardi, "A Diplexer Using Hybrid Junctions," Technical Report No. 255 (U), Lincoln Laboratory, M.I.T. (7 February 1962).

$$\text{I.L. } (f_1) = 10 \log \frac{2}{1 + \cos \delta_1}. \quad (13)$$

$$P_{b_3} (f_2) = \frac{1}{4} (1 + \cos \theta_2), \text{ where } \theta_2 = \theta_o - \theta_e,$$

$$P_{b_4} (f_2) = \frac{1}{4} (1 - \cos \theta_2),$$

$$P_{\text{in} \textcircled{2}} (f_2) = \frac{1}{2} a_2 \cdot a_2^* = \frac{1}{2}; \quad P_{b_3} + P_{b_4} = \frac{1}{2}.$$

$$\text{I.L. } (f_2) = 10 \log \frac{P_{\text{in} \textcircled{2}}}{P_{b_4}} = 10 \log \frac{2}{1 - \cos \theta_2}.$$

If $\theta_2 = 2\pi m + \pi \pm \delta_2$, $\cos \theta_2 = -\cos \delta_2$, and

$$\text{I.L. } (f_2) = 10 \log \frac{2}{1 + \cos \delta_2}. \quad (14)$$

Input mismatch at f_1, f_2 .

At f_1 : $a_2 = 0$, $a_3 = \Gamma_3 b_3$, $a_4 = \Gamma_4 b_4$ where Γ is the voltage reflection factor,

From Eq. (6):

$$b_1 = \frac{a_1}{4} \left[\Gamma_3 \left(e^{-j\theta_o} - e^{-j\theta_e} \right)^2 - \Gamma_4 \left(e^{-j\theta_o} + e^{-j\theta_e} \right)^2 \right],$$

$$\Gamma_{\text{in} \textcircled{1}} = \frac{b_1}{a_1} = \frac{e^{-j2\theta_o}}{4} \left[\Gamma_3 (1 - e^{j\theta})^2 - \Gamma_4 (1 + e^{j\theta})^2 \right],$$

with $\theta = \theta_o - \theta_e$.

$$\text{But } \theta_1 = 2\pi n + \delta_1, e^{j\theta_1} = e^{j\delta_1},$$

$$\therefore \Gamma_{in} \textcircled{1} = \frac{e^{-j2\theta_0}}{4} \left[\Gamma_3 \left(1 - e^{j\delta_1} \right)^2 - \Gamma_4 \left(1 + e^{j\delta_1} \right)^2 \right].$$

$$\text{At } f_2: a_1 = 0, a_3 = \Gamma_3 b_3, a_4 = \Gamma_4 b_4.$$

From Eq. (6):

$$b_2 = \frac{a_2}{4} \left[-\Gamma_3 e^{-j2\theta_0} \left(1 + e^{j\theta} \right)^2 + \Gamma_4 e^{-j2\theta_0} \left(-1 + e^{j\theta} \right)^2 \right],$$

$$\text{with } \theta = \theta_0 - \theta_e:$$

$$\Gamma_{in} \textcircled{2} = \frac{b_2}{a_2} = \frac{e^{-j2\theta_0}}{4} \left[-\Gamma_3 \left(1 + e^{j\theta} \right)^2 + \Gamma_4 \left(-1 + e^{j\theta} \right)^2 \right].$$

$$\text{But } \theta_2 = 2\pi m + \pi + \delta_2, e^{j\theta_2} = -e^{j\delta_2},$$

$$\therefore \Gamma_{in} \textcircled{2} = \frac{e^{-j2\theta_0}}{4} \left[-\Gamma_3 \left(1 - e^{j\delta_2} \right)^2 + \Gamma_4 \left(-1 - e^{j\delta_2} \right)^2 \right].$$

IV. COMMON OUTPUT IS PORT 3

$$\text{At } f_1, \text{ from Eq. (9), } \theta_1 = \theta_0 - \theta_e = 2\pi \left[m + \frac{1}{2} \right] \pm \delta_1, \cos\theta_1 = -\cos\delta_1.$$

$$\text{I.L. } (f_1) = 10 \log \frac{P_{in} \textcircled{1}}{P_{b_3}} = 10 \log \frac{2}{1 - \cos\theta_1} = 10 \log \frac{2}{1 + \cos\delta_1}. \quad (15)$$

$$\text{At } f_2, \text{ from Eq. (12), } \theta_2 = \theta_0 - \theta_e = 2\pi n \pm \delta_2, \cos\theta_2 = \cos\delta_2.$$

$$\text{I.L. } (f_2) = 10 \log \frac{P_{\text{in}} \textcircled{2}}{P_{\text{b}_3}} = 10 \log \frac{2}{1 - \cos \theta_2} = 10 \log \frac{2}{1 + \cos \delta_2}. \quad (16)$$

V. SAMPLE DESIGNS

A. Design for $f_1 = 7.75$ Kmc, $f_2 = 8.35$ Kmc, power out of port 4.

$$\text{Set } \theta_1 = \frac{L}{\lambda g_1} \cdot 2\pi = 2\pi n \text{ or } L = n\lambda g_1.$$

$$\text{Set } \theta_2 = \frac{L}{\lambda g_2} \cdot 2\pi = 2\pi \left(m + \frac{1}{2} \right) + \delta_2.$$

In large X-guide, the minimum L comes out 8.28", with I.L. $(f_1) = 0$ and I.L. $(f_2) = .12$ db.

B. Design for $f_1 = 7.75$ Kmc, $f_2 = 8.35$ Kmc, power out of port 3.

$$\text{Set } L = \left(m + \frac{1}{2} \right) \lambda g_1.$$

$$\therefore \theta_2 = \theta_o - \theta_e = \frac{L}{\lambda g_2} \cdot 2\pi = 2\pi n + \delta_2.$$

In large X-guide, the minimum L is 7.245", with I.L. $(f_1) = 0$ db, I.L. $(f_2) = .02$ db.

VI. DIPLEXER IN $\frac{1}{2}$ HEIGHT LARGE X-GUIDE

For satellite applications, to limit weight, it was decided to fabricate the $L = 7.245$ " design. Also, the large X-guide was decreased to $\frac{1}{2}$ height. An MDL large X-guide side-wall coupler was decreased to half height and the capacitive dimple was replaced by a #4-40 screw. With a screw penetration of

approximately 0.120", P_{13} and P_{14} were within 0.1 db at 7750, P_{12} was greater than 30 db, and VSWR was 1.05. At 8350, the corresponding values were 0.1 db, 23 db and 1.12 VSWR.

A second hybrid gave somewhat worse results:

7750 — 0.1 db, > 30 db, 1.05 VSWR;

8350 — 0.4 db, 20 db and 1.09 VSWR.

The screw sensitivity was about 0.5 db/turn w/r P_{13} and P_{14} , with a measurable but small effect on input VSWR's.

In Fig. 2, imagine that hybrid B, being pivoted at ports 1, 2 is lifted upward through 180° and then is slid over until it lies exactly over hybrid A. Ports 4' and 2, and 3' and 1 are now connected by an abrupt 180° bend as illustrated in Fig. 3.

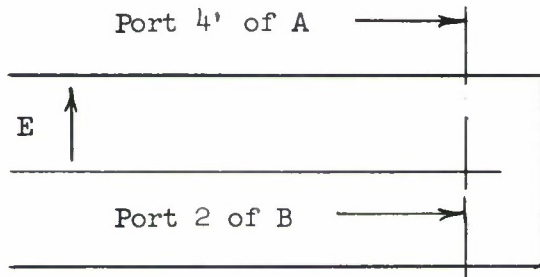


Fig. 3: 180° E-Plane Bend in $\frac{1}{2}$ Height Large X-Guide.

The VSWR characteristics of the bend in Fig. 3 are:

7750 - 1.05

8050 - 1.02

8350 - 1.02

The complete diplexer appears in Figs. 4 and 5. Because of soldering difficulties, it was not possible to align each $\frac{1}{2}$ height hybrid for optimum behavior prior to joining. Therefore, each hybrid has a tuning screw for power-split trimming (where the dimple had been) and a "shorting" screw in the line

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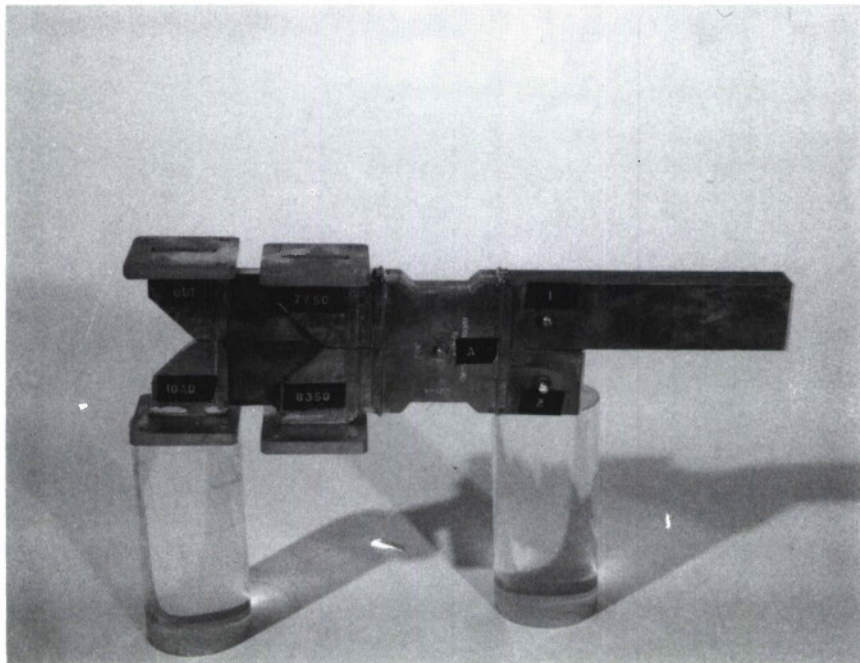


Fig. 4: Photograph of Completed Diplexer

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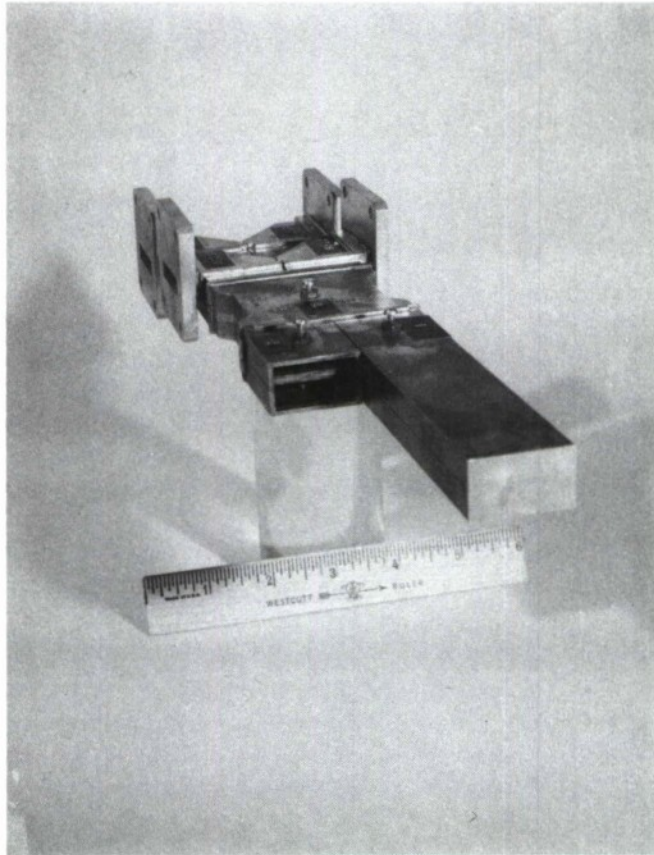


Fig. 5: Photograph of Diplexer
with Inside View of 180° Bend

past ports 3 and 4. It was hoped that with the shorting screw in position, it would be possible to set the power-split screw for minimum VSWR and so balance each hybrid.

Circuit A was found to be somewhat worse than that experienced on the two preliminary $\frac{1}{2}$ height hybrids, giving VSWR's of 1.12 at 7750 and 1.21 at 8350. Circuit B gave VSWR's of 1.38. The reason for such inferior performance of B is not known.

In view of the poor performance of hybrid B, all four shorting screws were used as tuning elements, in addition to the two power-split screws. By a converging process, the diplexer was tuned to the following characteristics:

<u>7750</u>	<u>8350</u>
I.L. = 0.3 db (= P_{13})	I.L. = 0.5 db (= P_{23})
P_{12} = 32 db	P_{21} = 27 db
P_{14} = 30 db	P_{24} = 22 db
VSWR 1 \approx 1.3	VSWR 2 = 1.28

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