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Mosko et al.

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[45] May 27, 1975

[54] WIDEBAND, MATCHED THREE PORT POWER DIVIDER

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[73] Assignee: **The United States of America as represented by the Secretary of the Navy,** Washington, D.C.

[22] Filed: **July 22, 1974**

[21] Appl. No.: **490,433**

[52] **U.S. Cl.** .... **333/9;** 333/10; 333/84 M

[51] **Int. Cl.** **H01p 5/12**

[58] **Field of Search** .... 333/6, 8, 9, 10, 11, 84 M

[56] **References Cited**

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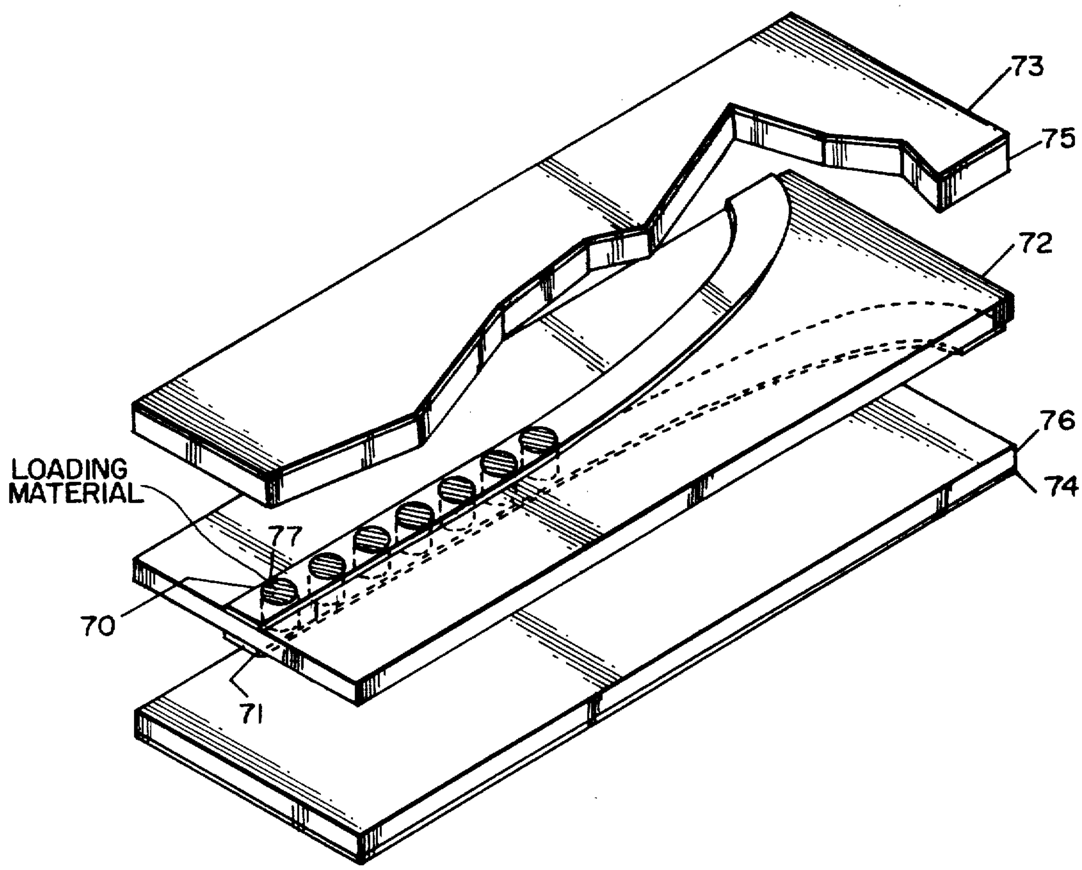
[57] **ABSTRACT**

A power divider having coupled lines comprising striplines wherein the divider is loaded only in the overlapping region of the striplines.

6 Claims, 9 Drawing Figures



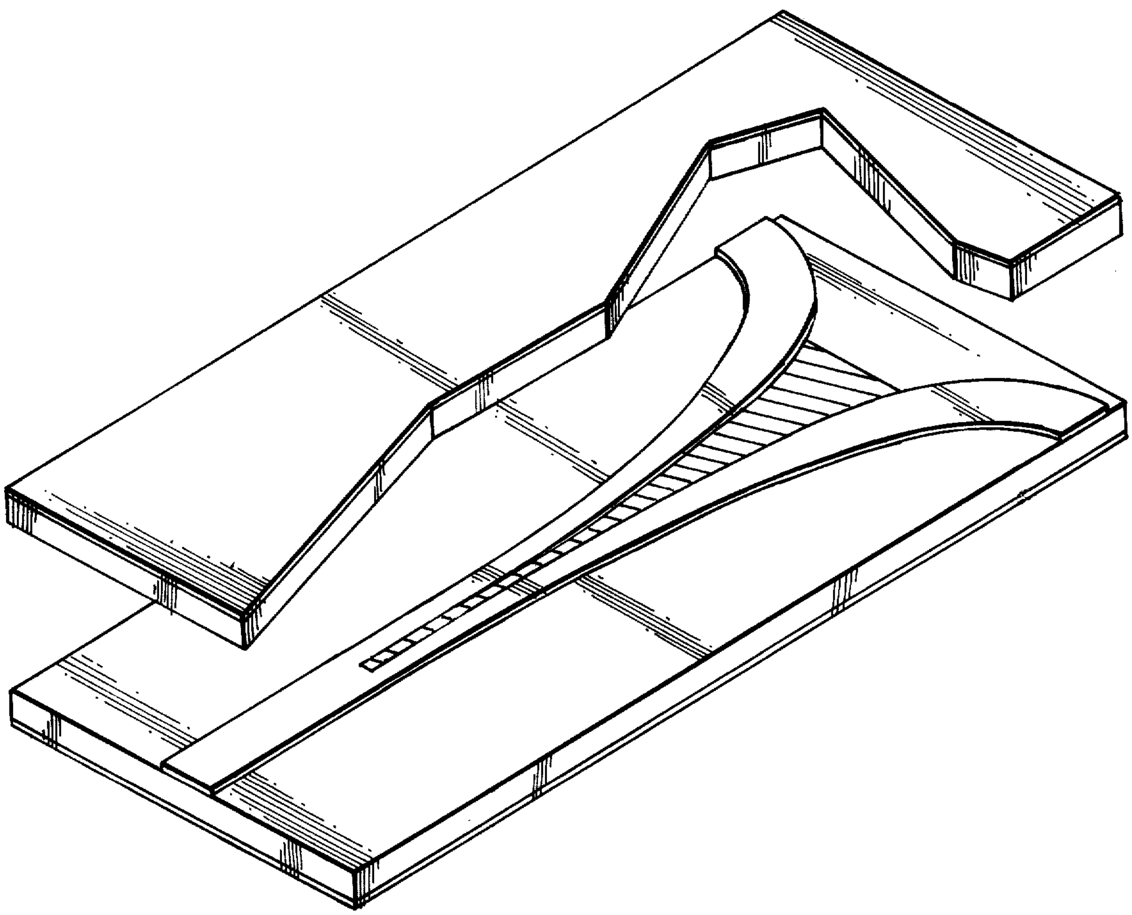


Fig. 1
Prior Art

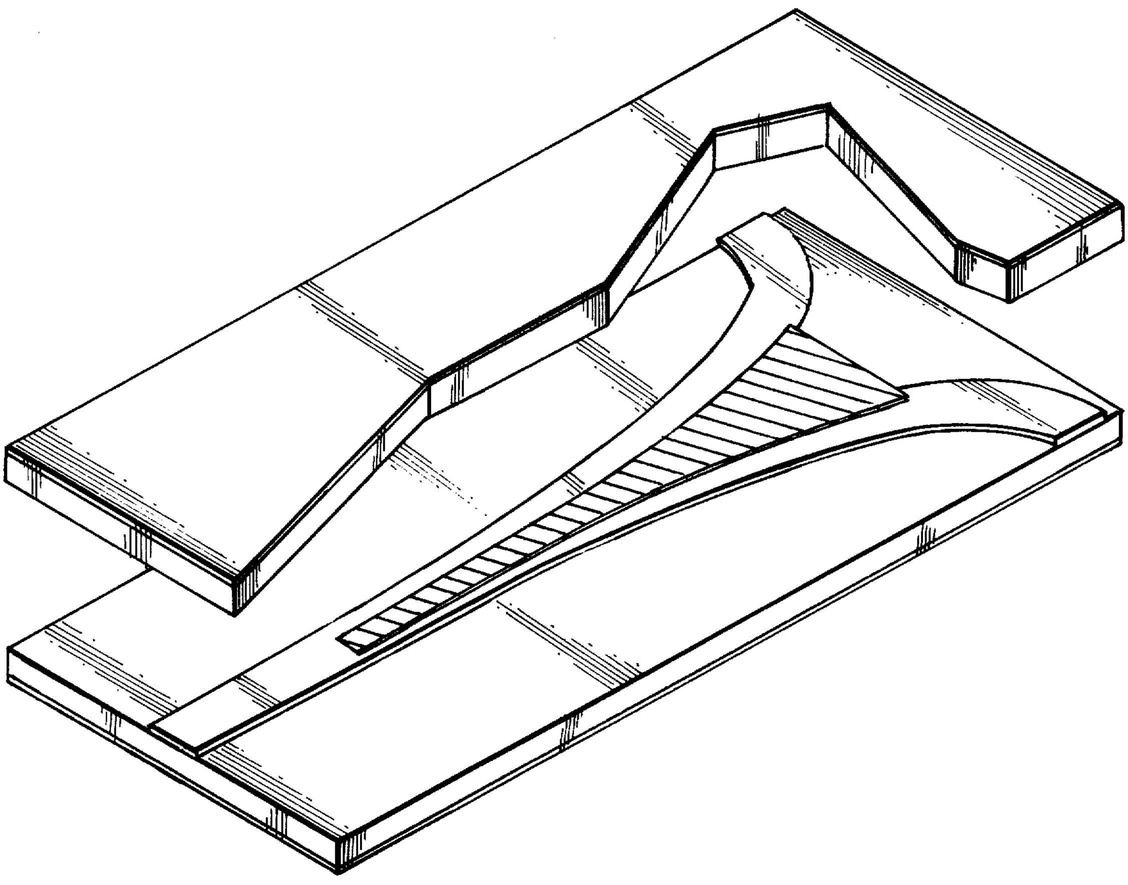


Fig. 2
Prior Art

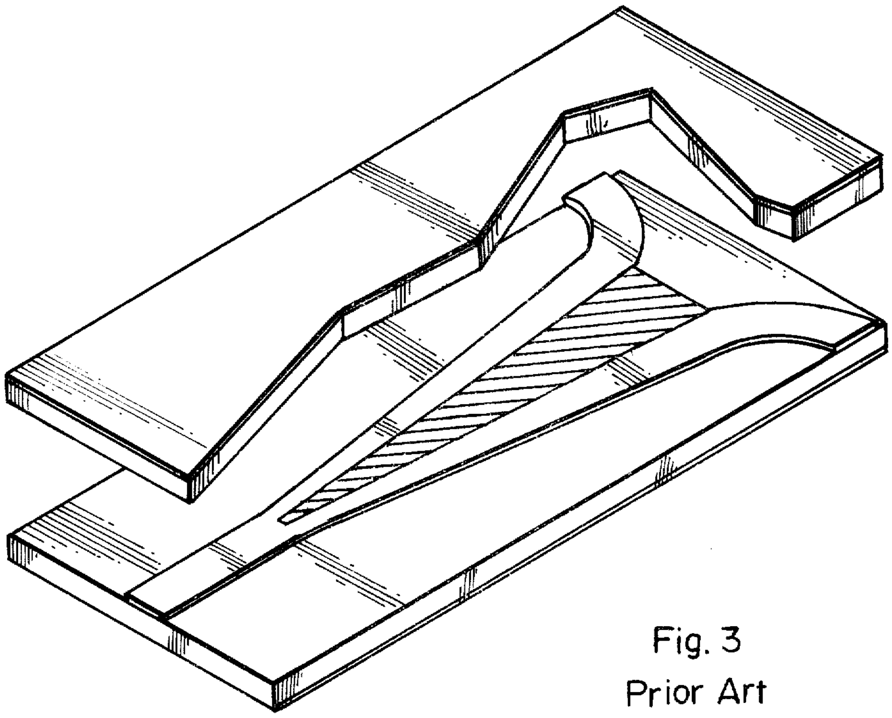


Fig. 3
Prior Art

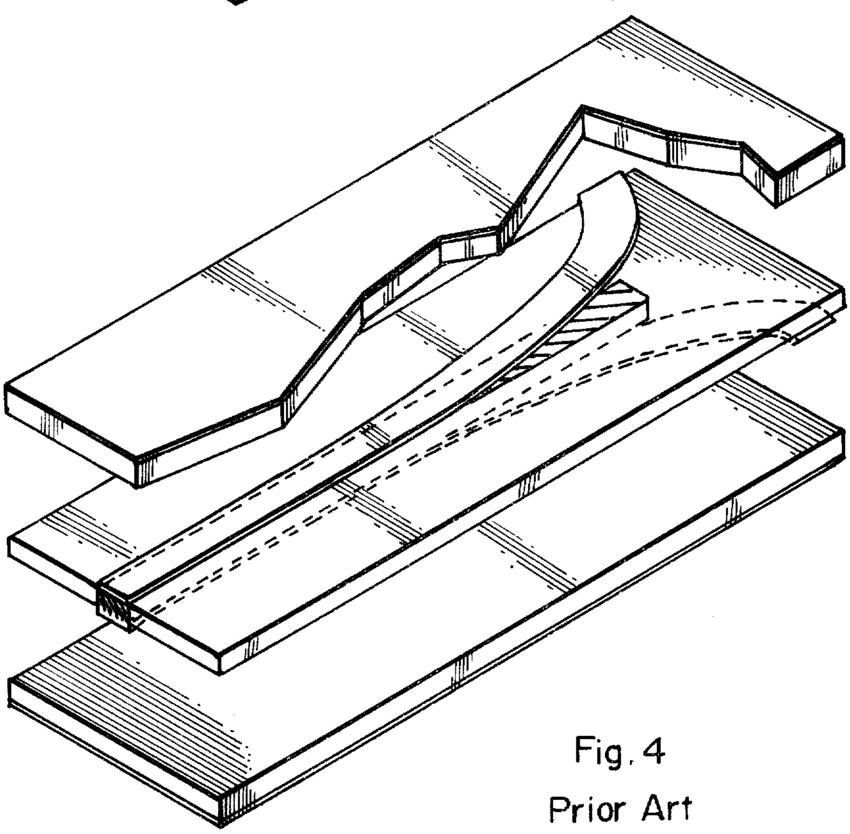


Fig. 4
Prior Art

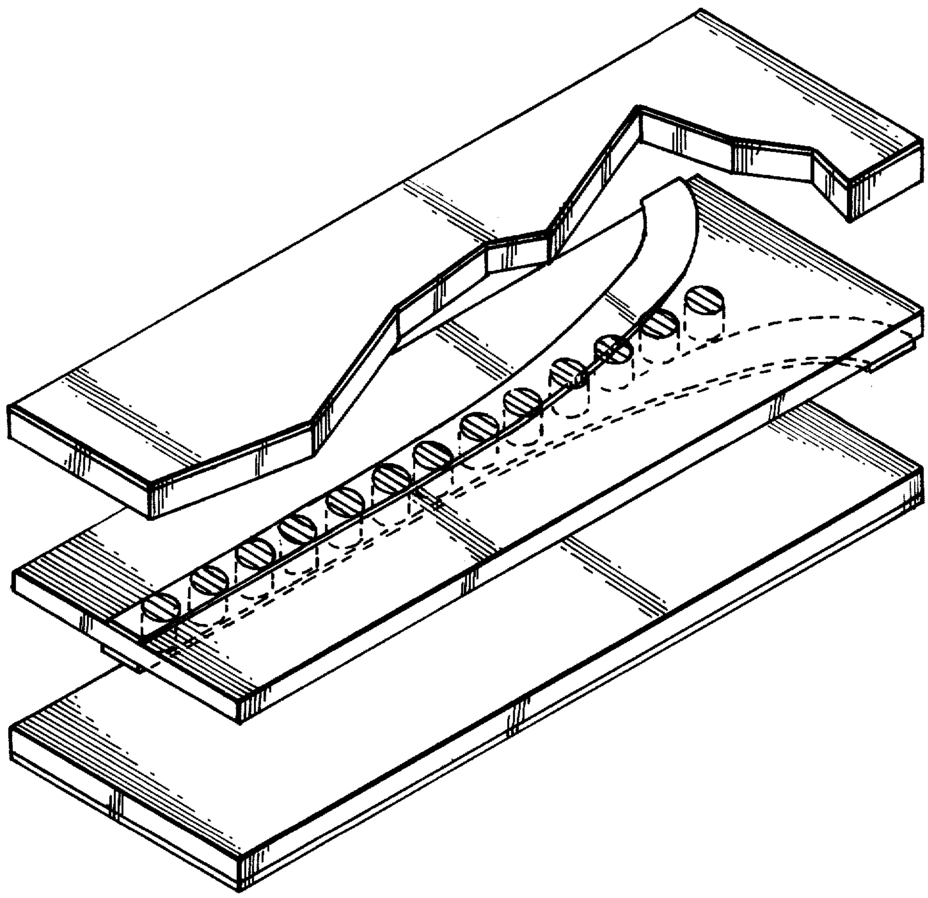


Fig. 5
Prior Art

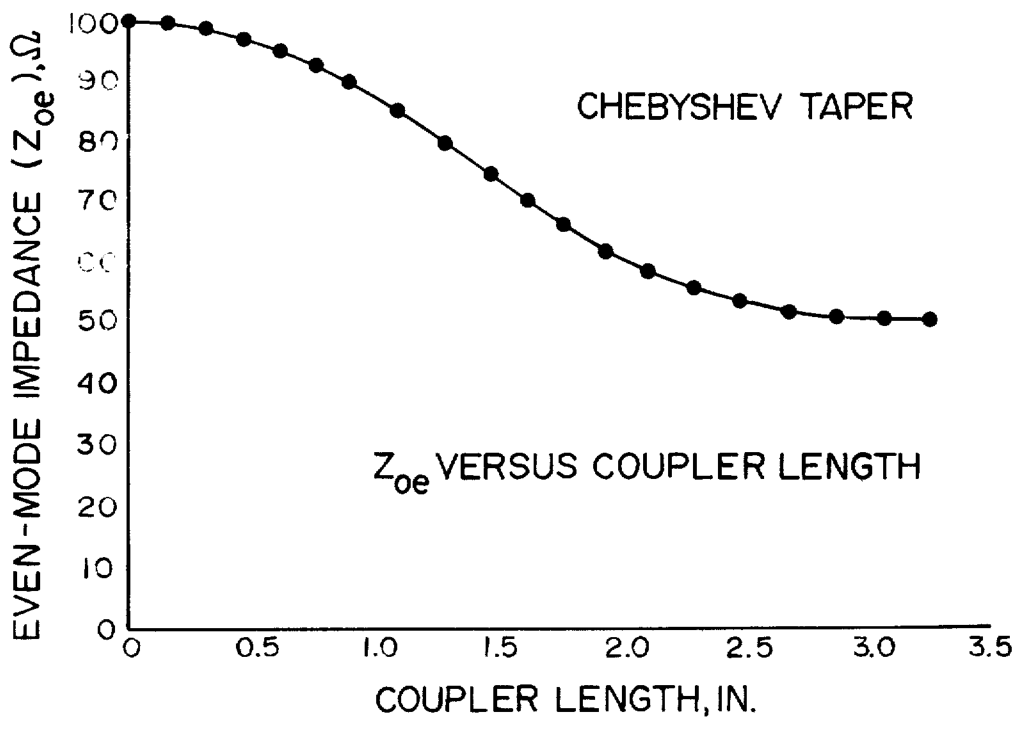

100
90
80
70
60
50
40
30
20
10
0
EVEN-MODE IMPEDANCE (Z_{oe}),Ω
CHEBYSHEV TAPER
Z_{oe} VERSUS COUPLER LENGTH
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
COUPLER LENGTH, IN.

Fig. 6

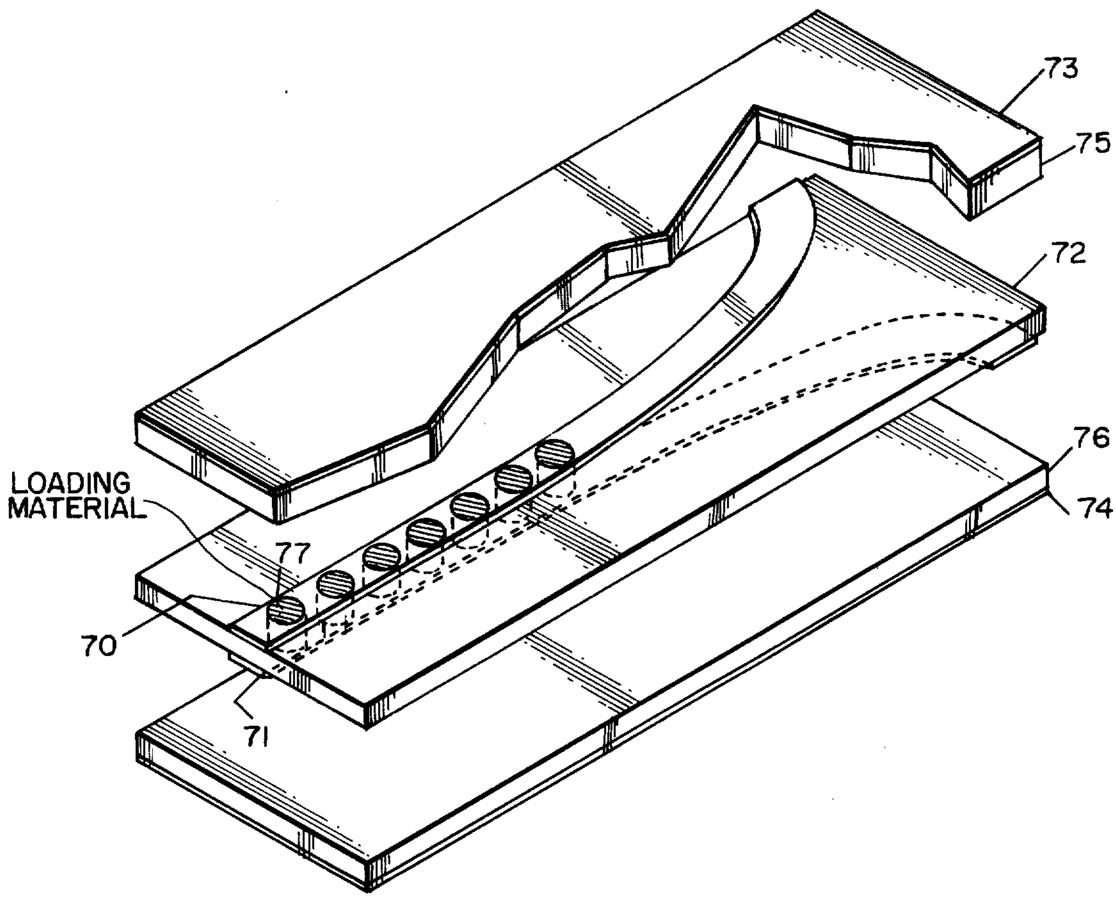


Fig. 7

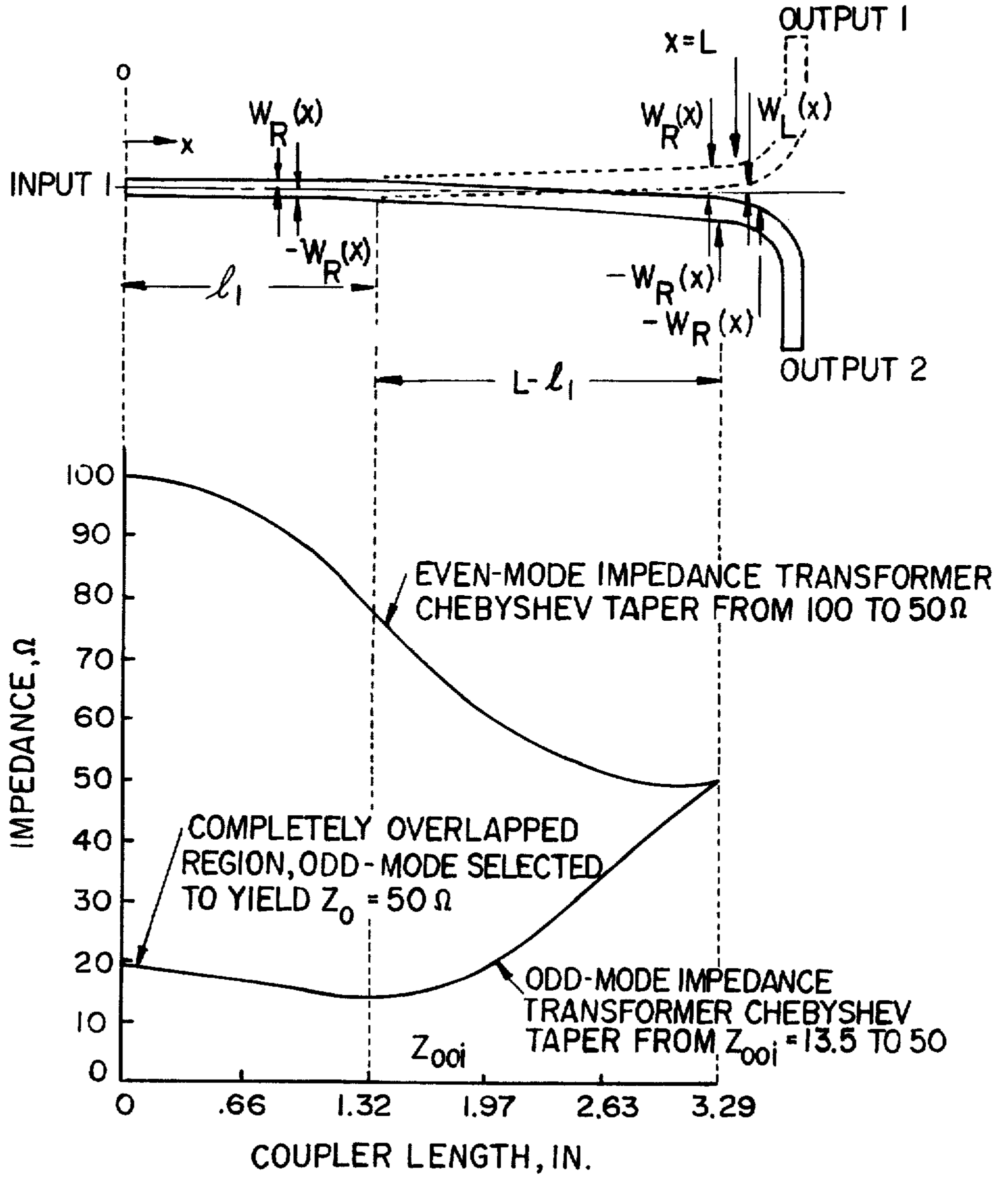
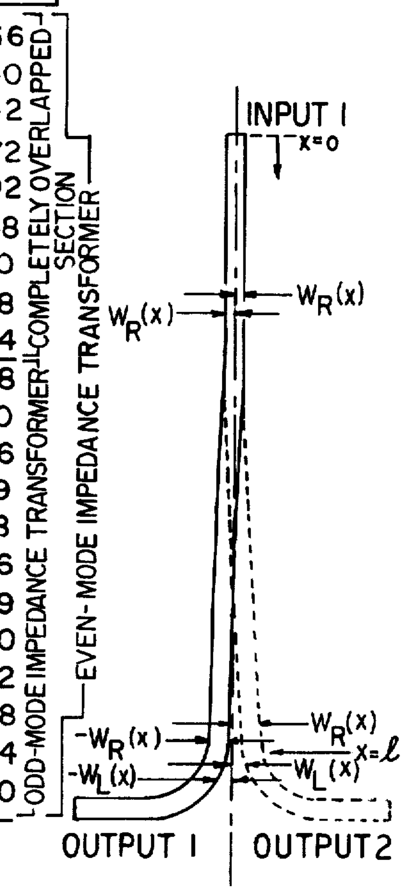

OUTPUT 1
x=L
o
$W_R(x)$
$W_R(x)$
$W_L(x)$
x
INPUT 1
$-W_R(x)$
$-W_R(x)$
$-W_R(x)$
ℓ_1
OUTPUT 2
$L-\ell_1$
100
90
80
70
60
50
40
30
20
10
0
IMPEDANCE, Ω
EVEN-MODE IMPEDANCE TRANSFORMER CHEBYSHEV TAPER FROM 100 TO 50Ω
COMPLETELY OVERLAPPED REGION, ODD-MODE SELECTED TO YIELD Z_0 = 50 Ω
ODD-MODE IMPEDANCE TRANSFORMER CHEBYSHEV TAPER FROM Z_{00i} = 13.5 TO 50
Z_{00i}
0
.66
1.32
1.97
2.63
3.29
COUPLER LENGTH, IN.

Fig. 8

Data point	Z (x),Ω	Z (x),Ω	x, in	W_L(x), in	W_R(x), in	W(x), in
1	100.00	18.72	0.000	-.0368	.0368	.0736
2	99.65	18.62	0.164	-.0370	.0370	.0740
3	98.88	18.39	0.329	-.0376	.0376	.0752
4	97.53	18.00	0.493	-.0386	.0386	.0772
5	95.47	17.41	0.657	-.0401	.0401	.0802
6	92.65	16.63	0.822	-.0424	.0424	.0848
7	89.08	15.67	0.986	-.0455	.0455	.0910
8	84.88	14.59	1.150	-.0494	.0494	.0988
9	80.26	13.46	1.315	-.0542	.0542	.1084
10	75.45	14.45	1.479	-.0425	.0673	.1098
11	70.71	15.55	1.643	-.0360	.0760	.1120
12	66.27	17.17	1.808	-.0288	.0848	.1136
13	62.30	19.41	1.972	-.0213	.0936	.1199
14	58.91	22.33	2.136	-.0139	.1019	.1158
15	56.13	25.94	2.301	-.0072	.1094	.1166
16	53.97	30.13	2.465	-.0010	.1159	.1169
17	52.37	34.67	2.630	-.0054	.1214	.1160
18	51.27	33.19	2.794	-.0138	.1270	.1132
19	50.57	43.28	2.958	-.0256	.1344	.1088
20	50.17	46.57	3.123	-.0420	.1464	.1044
21	50.00	50.00	3.287	...	...	.1000



NOTE: E = 2.54, relative dielectric constant
S = 0.016 inch
b = 0.1362 inch
b' = 0.0601 inch
F_{low} = 1.9 gigahertz
W = 0.100 inch for uncoupled line width
SLL_e = 40.0 decibels
SLL_0 = 19.3 decibels

Fig.9

WIDEBAND, MATCHED THREE PORT POWER DIVIDER

BACKGROUND OF THE INVENTION

1. Field of the Invention

Power dividers and combiners have a countless number of applications in various microwave systems. Thus, there are narrowband, wideband, stepped impedance, tapered line, coaxial line, and stripline-type of three-port power dividers, just to name a few. However, none of these designs have been realizable in stripline with the following characteristics over 10 to 1 and greater bandwidths with upper frequency limits in the I and J band regions.

1. Reproducibility at low cost
2. Power balance or tracking (at outputs) better than 0.1 decibel over frequency range
3. Negligible insertion loss (over what is due to that length of stripline)
4. Directivity of device 20-decibel minimum (directivity is defined as the difference between the output-port-isolation 5. Minimum length of the power divider for a given degree of match at each of the three terminals

The isolation requirement basically rules out from consideration any heretofore known design employing stepped impedance lines or discrete loading between the two coupled lines. It also rules out any design that does not consider the two lines of the device to be coupled lines. The coupling exists due to the required proximity of the two lines.

2. Description of the Prior Art

The minimum length (therefore minimum total insertion loss) requirement of the device for a given degree of match dictates that the transformer be a Chebyshev-type, not simply a linear or other type of taper. Therefore, this leaves only three implementations of the power divider for consideration. One design is set forth in FIG. 1, wherein the slot between the coupled lines, which contains a lossy film attenuator, varies nonlinearly with length because of a constant odd-mode impedance of 50 ohms. To cut the lossy material and insert it into the slot without getting significant attenuation of the even mode is extremely difficult from a practical standpoint.

FIG. 2 illustrates a coplanar power divider with continuous overlapping load. In this embodiment it was found that the slightest overlap of the lossy film with the stripline induced several decibels of loss for the even mode. This, then, makes the accurate tracking or power balance virtually impossible to achieve with this design due to the critical alignment of the lossy film material with the stripline conductors.

FIG. 3 comprises an attempt to alleviate this problem and illustrates a coplanar power divider with a triangular-shaped load. The power divider is similar to that of FIG. 2 except that the odd-mode impedance is chosen so that the slot between the coupled lines becomes a triangular wedge, facilitating accurate cutting of the lossy film material. This allows considerably simpler alignment of the lossy film with the stripline conductors without excessive overlap, as opposed to the configuration of FIG. 2. Unfortunately, it is still very difficult to insert the lossy film in such a way that the insertion loss is low, the balance is good, and yet maintain high isolation.

FIG. 4 illustrates a broadside power divider with loaded center spacer. This design was based on the assumption that a film between two coplanar strips is too critical for placement. In the design, the constraint on the odd-mode for a Chebyshev-tapered device was that the unloaded impedance $\sqrt{Z_{oo} Z_{oe}} = 50$ ohms, as in conventional quadrature couplers. Therefore, the odd-mode impedance was reduced below the theoretical value in the loaded region, thus slightly degrading that match as seen from the "output" terminals. Therefore, it was possible to drill and resistively load the dielectric spacer separating the offset-parallel-coupled striplines and keep the loading material reasonable well confined between the coupled conductors as shown in FIG. 5. Again, it was very difficult to attain good power division and isolation with low insertion loss in the device: this failure was, in part, because the conductor edges of the coupled line were severed by the drill when loading the dielectric spacer and later could not be sufficiently well repaired. It was also noted that the power-handling capability of the broadside-coupled line configuration was superior to the coplanar edge-coupled configuration.

SUMMARY OF THE INVENTION

The invention comprises a broadside power divider with a center spacer loaded by drilling only in the overlapping region of the stripline coupler.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a coplanar power divider with continuously varying load;

FIG. 2 is a coplanar power divider with continuous overlapping load;

FIG. 3 is a coplanar power divider with triangular-shaped load;

FIG. 4 is a broadside power divider with loaded center spacer;

FIG. 5 is a broadside power divider with center spacer loaded by drilling;

FIG. 6 is a graph of a sample design of even-mode impedance profile;

FIG. 7 is a broadside power divider with center spacer loaded by drilling only in the completely overlapping region;

FIG. 8 is a complete impedance profile sample design; and

FIG. 9 is a three-port power divider sample design.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the invention, the even-mode impedance of the coupled stripline is selected to taper from 100 to 50 ohms (for a 50-ohm input impedance at all three terminals) as a Chebyshev-transformer. The design is set forth in FIG. 6. This will guarantee an optimum match for a given length of taper, L, at the input port.

Throughout the discussion, the following nomenclature will be used:

Z_{oo} Odd-mode characteristic impedance

Z_{oe} Even-mode characteristic impedance

S Distance between the planes containing the two coupled strips

b Shortest distance between the plane containing a coupled strip and a ground plane

b Ground plane spacing (i.e., $b = 2b' + S$)

L Length of the power divider

l_1 Length of the lossy (odd mode) transmission line in the power divider; length of completely overlapped coupled striplines

Z_{ooi} Nominal odd-mode input impedance of the lossy line of length l_1

E_r Relative dielectric constant of stripline material

$Z_{oe(x)}$ Local even-mode impedance of coupled strips at the point x

$Z_{oo(x)}$ Local odd-mode impedance of coupled strips at the point x

$W_{(x)}$ Width of coupled striplines at point x

$W_{L(x)}$ Distance from centerline of power divider to left edge of coupled stripline at point x

$W_{R(x)}$ Distance from centerline of power divider to right edge of coupled stripline at point x

SLL_e Even-mode impedance taper sidelobe level

SLL_o Odd-mode impedance taper sidelobe level

TEM Transverse electromagnetic waves or wave propagation

FIG. 7 is one embodiment of the present invention wherein stripline material **70** and **71** is separated by a dielectric spacer **72.** Ground planes **73** and **74** are spaced from the stripline by dielectric material **75** and **76.** In the completely overlapping region of the stripline coupler, suitable microwave loading material is inserted in the spacer **72** by drilling holes as at **77.** The holes are loaded with a suitable loading material which is commercially available from the Filmohm Corporation or Emerson and Cumming. Castable microwave absorbant known as "Filmohm-F" was used in the present invention, however, as stated previously, any suitable loading material may be used. The holes are covered over after loading by covering on both sides with 0.0005-inch thick (0.5 mill) aluminum sensing tape such as is used on magnetic tape. The tape is not shown in FIG. **7.**

Over a suitable part of the total length of the device, the odd-mode impedance is required to be sufficiently low so that the coupled lines are exactly overlapped (the S/b ratio was previously selected for compatibility with other stripline components etched on the same stripline sandwich and interconnected with the power divider). This allows loading the volume between the coupled lines (in the so-called S spacer) with suitable load material in order to absorb/attenuate the odd mode. This is easily accomplished, since any drilling, milling, etc., can be done without severing the outside edges of the coupled lines. Also, the -even-mode electric field lines are virtually nonexistent between the coupled lines, thereby guaranteeing least loss for the even mode. Thus, a highly symmetrical and effective lossy transmission line for the odd mode and simultaneously, lossless even-mode line can be realized.

Next, the odd-mode input impedance at the point l_1 is determined as defined in FIG. **8.** Note that this lossy transmission line is shorted at one end by the input to the power divider. This odd-mode impedance will be specified as Z_{ooi}.

Finally, over the length of L - l_1, the odd-mode impedance of 50 ohms is matched to that of Z_{ooi} utilizing, again, an optimum (i.e., Chebyshev) transformer; this odd-mode impedance constraint, along with the previously determined even-mode impedance, now defines a Shelton line pair. The power divider is now completely characterized and the complete impedance profile is shown in FIG. **8.**

Other possibilities exist as to the design of power dividers utilizing the present invention. One other example is mentioned to further illustrate the concept.

In the example, the constraint that the two coupled lines must be completely overlapped is relaxed. Instead, allow the lines to be only as much overlapped as is found convenient. For instance, over the length l_1, assume that the two strips have strip overlaps that are a constant. This would still allow relatively easy loading of the line while producing considerably higher Z values along the line of length l_1. Obviously, the closer the Z_{oo} values are to 50 ohms, the easier it is for the second Chebyshev-transformer to match the odd-mode Z_{ooi} value to 50 ohms.

The transformers are basically high-pass structures, therefore, the power dividers will work equally well at any frequency above the low-frequency cutoff. The highest actual frequency of operation is determined by such things as connectors to the device, ground-plane spacings which allow undesirable parallel plate mode propagation, etc., and not by any limits inherent with the theory of the device.

A requirement for a specific power divider is set forth below:

Frequency of operation, GHz . . . 1.9 to 12.0

Match at input . . . 50 dB return loss (i.e., VSWR = 1.0064)

S = 0.016 inch, stripline spacer thickness

b' = 0.0601 inch, stripline dielectric thickness (i.e., $b = 2b' + S = 0.1362$ inch, the groundplane spacing)

E_r = 2.54 relative dielectric constant of material

It is assumed that the "completely overlapped" design previously described will be used, which has the important feature that the odd-mode loading is easiest to achieve.

To achieve the input port match of 50 decibels return loss, a 40-decibel sidelobe transformer is required. That taper is 0.843-wavelength-long at the lowest frequency of operation, or about 3.287 inches long.

The even-mode impedance profile $Z_{oe(x)}$ is found and is listed in FIG. **9.** For the upper segment of the device (where the strips are forced to overlap), strip widths and odd-mode impedances obtained are shown in Data Points **1** through **9.** Note that the odd-mode impedance varies from 18.72 ohms at its "shorted end" to 13.46 ohms near the center of the device. A uniform resistive load of length, $l_1 = 1.315$ inches, would appear to be tapered in its effect and thus, quite promising for absorbing the odd-mode energy.

This leaves 3.287 − 1.315 = 1.972 inches length on the right half to match the odd mode of 50 ohms to the Z_{ooi} value (input impedance of loaded Z_{oo} line with short at input to power divider). For example, assume that Z_{ooi} = 13.4 ohms over the operating band of frequencies; then a 50— to 13.4-ohm Chebyshev-transformer (19.3—decibel sidelobe level requires a 1.972-inch length taper) would complete the specification of the device. Calculation of the expected directivity is as follows: The 50 to 13.46 ohms, 19.3—decibel sidelobe transformer has a peak reflection coefficient in the passband of [(50.0 − 13.46)/(50.0 + 13.46)] (0.109) = 0.063. For a 1.0-volt input at one of the output ports, this results in (½) (0.063) = 0.0315 volt at the other output port (neglecting the virtually zero contribution due to the even mode). This, consequently, would provide an isolation of 30 decibels, or a directivity of 27 decibels for the sample design.

The described design was fabricated and tested. The loading consisted of a single row of **32** uniformly spaced holes 0.035 inch in diameter. They were loaded (filled) with Solitron/Microwave, Filmohn Division, castable microwave absorbent "Filmohn-F." The holes were covered over after loading by covering on both sides with 0.0005-inch-thick (0.5 mil) aluminum sensing tape such as is used for splicing magnetic tape. The insertion loss from input **1** to output **1** tracked the insertion loss from input **1** to output **2** quite well, the maximum unbalance being on the order of 0.2 decibel at all frequencies up to the maximum 12-gigahertz test frequency. Additionally it is noted, as predicted, that the insertion loss is quite low, on the order of 0.5 decibel at 12 gigahertz. This is nearly all attributable to dielectric and copper losses. The isolation (insertion loss from output **1** to output **2**) is also quite good, averaging 20 decibels across the band except for a slight ripple at 2.5 gigahertz. This could probably be improved on by experimenting with different load materials, number and distribution of loading holes, hole diameter, etc. The return loss of the input port was better than −24 decibels from 2 to 9 gigahertz and better than −18 decibels from 9 to 12 gigahertz. The return loss measurements on the output ports tracked very well, again demonstrating the superior symmetry of the device, and measured better than −15 decibels from 2 to 8 gigahertz and better than −20 decibels from 8 to 12 gigahertz. All return loss measurements included the effects of the OSM coax connector to stripline transitions and conventional OSM 50-ohm coax loads. The return loss, like the isolation between output ports, could probably be slightly improved by experimenting with the type and layout of the loading material. Performance is quite good, however, and easily achieved as long as symmetry of the etched lines is maintained.

A new synthesis procedure has been set forth which appears to yield stripline power dividers of state-of-the-art performance. The new design is clearly superior to deal with from a mechanical and reproducibility standpoint. The continuously tapered striplines and the tapered loading make it the best contender for very high microwave frequency applications. The longer the device, the better the performance. Having employed Chebyshev-type tapers where appropriate, best performance for a specific length device is guaranteed.

This synthesis technique also duly rewards a skillful microwave designer in the following sense: The designer, capable of providing very short length broadband loads, is thereby allowed to match the odd mode over the greatest length in the device (resulting in better isolation). Similarly, the designer and builder capable of inserting the load symmetrically and without effect on the even mode, would select an odd-mode impedance level closer to 50 ohms (than the 10 ohms in the sample design) at which the load would attenuate; this also results in better isolation since the odd-mode impedance transformation is less severe. The higher odd-mode impedance is achieved by greater offset of the Shelton line pair.

Based on commercially available microwave load materials, the loading of the odd mode (as in 1.315-inch length of line for the example) is indeed very feasible and practical. Attenuations of 90 dB/in for TEM-mode applications are claimed, which is more than required in this example.

A perhaps obvious variation of the above disclosed power divider is to first design a desired transformer for a particular case corresponding to the L-*l*, region of FIG. **8.** Then one would provide isolation by adding exterior loading at the input end by providing a completely overlapping region where in the loading is done in that region.

However, a drawback of this technique is that the overall length of the resulting power divider would be physically longer than that of the equivalent of FIG. **8.**

What is claimed is:

1. A power divider comprising;

electrically conducting coupling lines;

an electrically insulating material separating said coupling lines;

said coupling lines being mutually overlapping over a portion of the total length of the lines; and

microwave loading means in said insulation material in the portion thereof only in the mutually overlapping region, defined by said coupling lines.

2. A power divider, as set forth in claim **1** wherein;

said coupling lines are completely overlapping over a portion of the total length thereof;

wherein;

said microwave loading means is placed in said insulation material only in the completely overlapping region defined by said coupling lines.

3. A power divider as set forth in claim **1** wherein;

said electrically insulating material is a dielectric.

4. A power divider as set forth in claim **1** and further including;

ground planes on either side of said coupling lines and spaced therefrom; and

other electrically insulating means between each of said ground planes.

5. A power divider as set forth in claim **2** wherein;

said electrically insulating material is a dielectric.

6. A power divider as set forth in claim **2** and further including;

ground planes on either side of said coupling lines and spaced therefrom; and

other electrically insulating means between each of said coupling lines and each of said ground planes.

* * * * *