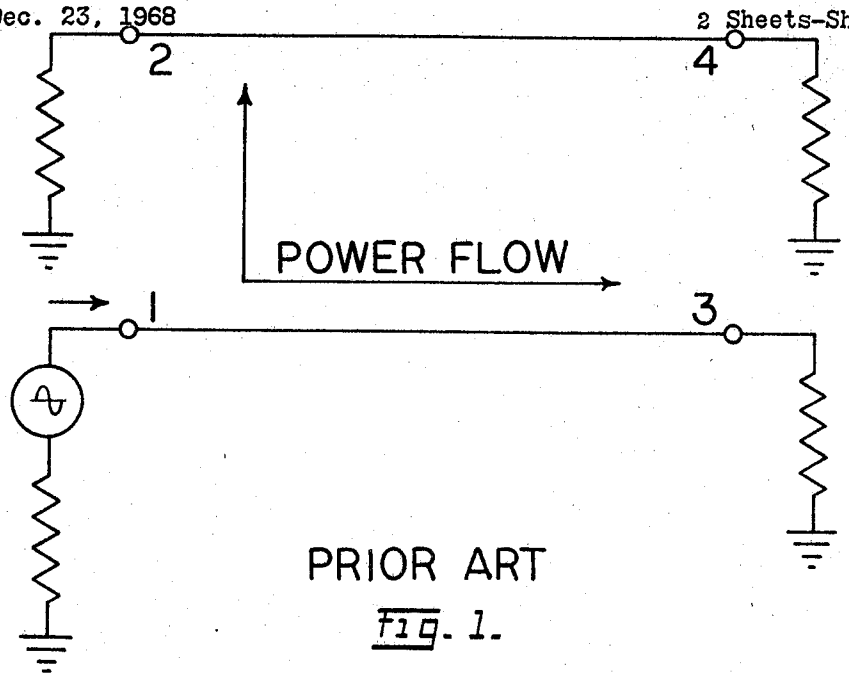
May 19, 1970 H. HOWE, JR 3,513,414

INTEGRATED IRIS COUPLER

Filed Dec. 23, 1968 2 Sheets-Sheet 1



PRIOR ART

Fig. 1.

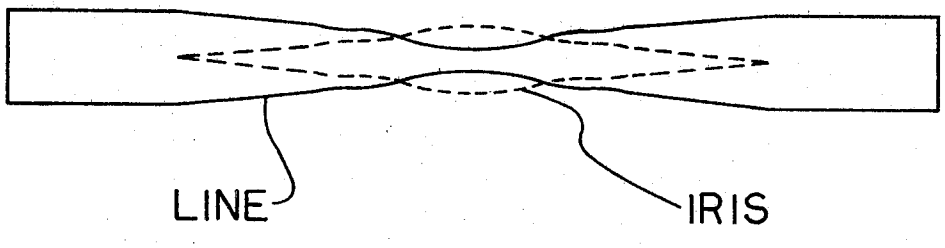


Fig. 3.

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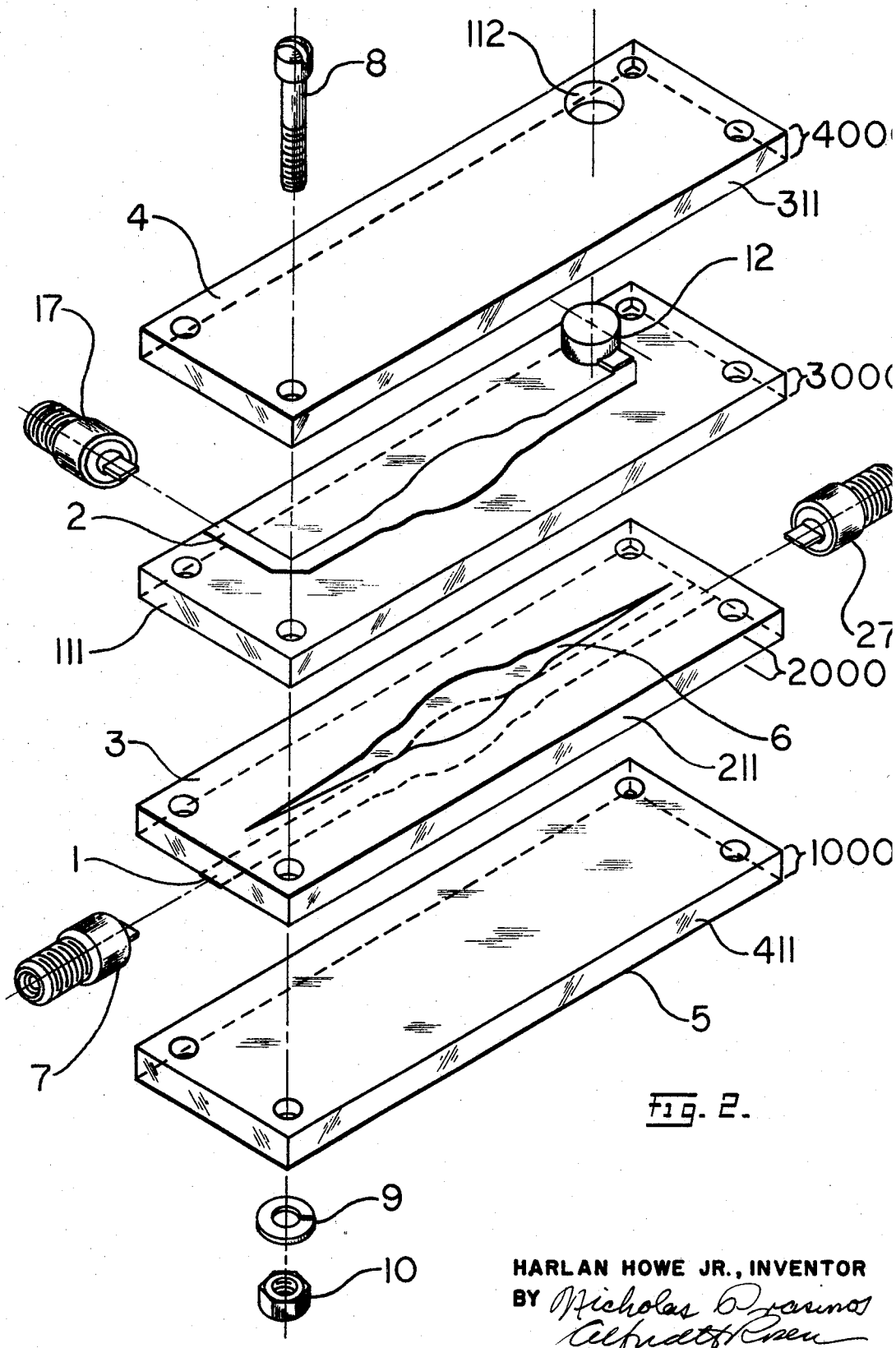

Fig. 2.

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3,513,414

INTEGRATED IRIS COUPLER

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U.S. Cl. 333—10 9 Claims

ABSTRACT OF THE DISCLOSURE

A microwave integrated directional coupler of broad bandwidth and high directivity is disclosed. An integrated line approach is used which generates a smoothly varying iris between two lines separated by a common ground plane, such that when the iris is closed each line has its own pair of ground planes and is completely isolated from the other.

BACKGROUND OF THE INVENTION

The field of this invention is generally microwave directional couplers and in particular stripline microwave directional couplers. The basic elements of such a coupler comprise two conductors coupled together electrically and magnetically. Directional couplers are generally four port devices wherein power is selectively coupled between ports. The flow of power in an ideal stripline directional coupler when all its ports are terminated in matched loads is exemplified in FIG. 1; when power is supplied at input port **1**, power flows to ports **2** and **3**; no power appears at output port **4**. In practice, however, some power will appear at port **4**. The ratio of the power input to the coupler at a given port to the power appearing at another port where power is not expected is called the isolation of the device. The isolation is a measure of the imperfection of the device. The directivity of the device is equal to the isolation minus the coupling and is in essence a quality factor. A perfect coupler has an infinitely large isolation or high directivity whereas a low performance coupler has low isolation or poor directivity.

The simplest prior art coupler consists of a single quarter wave section of coupled conductors sharing one side of a common ground plane, where power input and output is effected by connections made between the ends of the coupled conductors and the external terminals. This class of couplers has about one octave bandwidth and suffers from limited directivity. To improve bandwidth and, to some extent, directivity Cristal and Young (Cristal and Young, "Theory and Tables of Optimum Symmetrical TEM-Mode Coupled-Transmission Line Directional Couplers," MTT–13, No. 5, September 1965, p. 544) added quarter wave length sections in symmetrical discrete steps in such a manner that separation between conductors increased with each quarter wavelength of conductor addition. However, interstage discontinuities limited directivity and in an effort to overcome this deficiency C. P. Tresselt (Tresselt, "The Design and Construction of Broadband High-Directivity, 90-Degree Couplers Using Non-Uniform Line Techniques," MTT–14, #12, December 1966, p. 647) modified this type coupler by using a continuously tapered coupling coefficient which resulted in multielement undulating branches. These type couplers were all of the side coupled variety sharing one side of a common ground plane. Further improvements were made by Shelton (Shelton, "Impedances of Offset Parallel Coupled Strip Transmission Lines," MTT–14, No. 1, January 1966, p. 7) with a partial overlay coupler sharing common ground planes, and S. Yamamoto et al. (Yamamoto, Ozakami, and Itakura, "Slit Coupled Strip Transmission Lines," MTT–14, No. 11, November 1966, p. 542) who introduced the quarter wave rectangular

slit coupled overlay coupler such that input and output lines had separate ground planes. Although directivity improved somewhat with this type coupler, the bandwidth was limited to one octave, and also because the abrupt slot created internal discontinuities it limited the directivity of the device.

It is the object of this invention to increase bandwidth by several octaves, and substantially improve directivity.

SUMMARY OF THE INVENTION

This invention relates in general to stripline microwave directional couplers and in particular to stripline microwave directional couplers of broad bandwidth and high directivity. A smoothly undulating iris on a common ground plane tapering symmetrically from the center line toward each end is interposed between two lines such that each line has its own pair of ground planes on the closed portion of the iris.

The employment of a smoothly undulating coupling iris will improve the performance of this class of directional couplers.

Another feature of the invention is that the lines can be tapered corresponding to the iris or opposite to the taper of the iris. Embodiments of both constructions are illustrated below.

DESCRIPTION OF THE INVENTION

Exemplary embodiments of the invention and methods to make them are described with reference to the accompanying drawings, in which:

FIG. 1 illustrates schematically the essential elements of prior art devices;

FIG. 2 is an exploded view (not to scale) which illustrates the elements of one embodiment of this invention and their assembly;

FIG. 3 is a schematic plan view showing the shape and relative position of the lines and iris, of another embodiment of this invention.

Referring to FIG. 2, **1** is the primary electrical conductor (shown in dotted line) and **2** is the secondary of a directional coupler electrical conductor; these conductors may be discrete electrically conductive elements or they may be an integral part of the dielectric formed by standard photoetch techniques well konwn to the printed circuits technology. In the present embodiment, **2** and **1** are photo-etched to shape on one face of copper clad dielectrics, **111** and **211** respectively. The iris **6** is photoetched in a required pattern (to be described in detail below) on the common ground plane **3** which in turn is integrally bonded to one face of dielectric **211**. Upper ground plane **4** is integrally bonded on one face of dielectric **311** whereas lower ground plane **5** is integrally bonded to one face (the lower face—not shown) of dielectric **411**. Ground planes may be any electrically conductive material such as copper, silver, gold molybdenum, nickel, etc. and the dielectric may be any suitable dielectric such as "Rexolite", polyoefin, polyphenylene or "Teflon" (tetrafluorethylene polymer) fiber glass. For the present embodiment, copper clad dielectrics of "Rexolite" (polystrene plastics) are preferred. One end of secondary line **2** is terminated by a resistive termination **12** matched to the line **2**. Input power to the primary line **1** is introduced through a standard coaxial-to-stripline-transformer connector **7** and power output is removed through similar coaxial connectors **17** and **27**. The elements are spatially superimposed as shown in the exploded view of FIG. 2 and bolted together so as to have all elements stacked one on top of another with at least one face of each element contiguous and in physical contact to the element above it. Hence lower ground plane **5** is at the bottom of the stack with dielectric **411**, which, in this case is integrally bonded to the lower ground plane

5, is next on the stack; primary conductor **1** is the next on the pile making physical contact with dielectric **411** below it and dielectric **211** above it; next in sequence is dielectric **211**, which is not only integrally bonded to primary conductor **1** below it but also to common ground plane **3** above it; common ground plane **3** integrally a part and on top of dielectric **211** has the iris **6** photo-etched in a given pattern so that dielectric **211** is exposed through the aperture (note that the iris is placed in spatial relationship over primary line **1** so as to "see" primary line **1** in its aperture through the dielectric **211**); still higher in this multilayer sandwich is dielectric **111** its bottom face in physical contact with common ground plane **3** and iris **6**; on the upper face of dielectric **111** is secondary line **2** which may be a discrete element but in this embodiment is an integral part of dielectric **111** formed by photo-etching techniques on its upper face (note that secondary line **2** is spatially positioned above iris **6** and primary conductor **1** so that it "sees" through dielectrics **111** and **211** and iris **6**, to primary conductor **1**); next in the vertical spatial stack are resistive termination **12** (although the termination could be replaced by a connector so that the isolated port can be externally monitored or terminated), and dielectric **311**, a hole **112** being provided in dielectric **311** to accomodate resistive termination **12**; finally at the top of the stack is upper ground plane **4** which in this embodiment is integrally bonded to dielectric **311**. In this embodiment dielectric **411** and lower ground plane **5** form integral structure **1000**; primary conductor **1**, dielectric **211** and common ground plane **3** with iris **6** form integral structure **2000**; dielectric **111** and secondary line **2** form integral structure **3000**; whereas dielectric **311** and upper ground plane **4** form integral structure **4000**.

The shape of the iris opening **6** and the width of the lines **1** and **2** at any given point are critical to the proper functioning of this invention and are determined by the required even and odd mode impedances at that point. The design technique makes use of the exact design of a stepped impedance prototype. For each section of the prototype, the even and odd mode impedances may be expressed as:

$$Z_{oe}=Z_o\sqrt{\frac{1+K}{1-K}}$$

$$Z_{oo}=Z_o\sqrt{\frac{1-K}{1+K}}$$

where Z_o is the characteristic impedance of the line and K is the voltage coupling coefficient. The stepped coupler must then be described in terms of the

$$P(U)=\tfrac{1}{2}\frac{d}{du}\ln Z_{oe}(u)$$

domain to establish weighting coefficients to be applied in making a plot of coupling coefficient vs. distance. This is achieved by integrating the weighted function

$$\frac{\sin^2 u/2}{u/2}$$

using the cosine integral function

$$C(a)=\int_0^a\frac{(1-\cos u)}{u}\,du$$

and equating it to

$$P(u)\tfrac{1}{2}\frac{d}{du}\ln Z_{oe}(u)$$

This is most conveniently done with the aid of a digital computer with the results being expressed as a curve of Z_{oe} vs. distance from the center of the coupler. This plot may

then be translated into two plots of iris opening and line width vs. distance using the following relations:

$$W=\frac{B}{\pi}\log\frac{\theta(\alpha+a)}{\theta(\alpha-a)}$$

$$S=\frac{B}{\pi}\log\frac{H(\beta+a)}{H(\beta-a)}$$

where: B=outside ground plane spacing
W=conductor width
S=iris width
θ=Jacobian theta function
H=Jacobian eta function

$$\alpha=S_n^{-1}\left[\frac{1}{k}\frac{\sqrt{Z(a)}}{\sqrt{Z(a)S_n^2a+S_na.C_nad_na}}\right]$$

$$a=\frac{s}{B}K$$

$$\beta=S_n^{-1}(k_e/k_o,k)$$

S_n, C_n, d_n are Jacobian elliptic functions.
K=complete elliptic integral of the first kind with k as the modulus
s=primary to secondary conductor spacing,
k_e=modulus for even mode impedance,
k_o=modulus for odd mode impedance,
Z=Jacobian zeta function.

The final dimensional plots are then used as artwork for the fabrication process of the iris.

The embodiment of the invention which has been illustrated and described herein is an illustration of the best mode now known to practice this invention. Other alternative configurations may be made within the scope of this invention by those skilled in the art. No attempts have been made to illustrate all possible embodiments of the invention, but rather to illustrate its principles and best manner to practice it. Therefore, while only two embodiments have been described as illustrative of the invention, such other forms as would occur to one skilled in this art on a reading of the foregoing specification are also within the spirit and scope of the invention.

What is claimed is:

1. An overlay directional coupler for use at microwave frequencies comprising ribbon-like primary and secondary conductors, said primary and secondary conductors being disposed in spaced lateral face to face alignment, a common ground plane of width greater than that of said primary and secondary conductors having a single iris opening for coupling microwave energy between said primary and secondary conductors, said iris opening being defined by smoothly undulating curves therein according to a prescribed coupling relationship, said common ground plane being disposed in spaced face to face relationship between said primary and secondary conductors so that primary conductor, iris, and secondary conductor are in spaced lateral alignment, said common ground plane with iris opening, and said primary and secondary conductor being separated respectively by dielectric material extending uniformly between them.

2. An overlay directional coupler as recited in claim **1** wherein the primary and secondary conductors are shaped to correspond substantially to said iris.

3. An overlay directional coupler is recited in claim **1** wherein primary and secondary conductors are shaped substantially inversely to said iris.

4. A directional coupler as recited in claim **1** wherein the primary and secondary conductors are of the undulating type having a continuously tapered coupling coefficient.

5. A directional coupler as recited in claim **2** wherein the iris opening on the common ground plane is defined by a pair of symmetrical undulating curves having laterally corresponding 180° spaced pairs of points whose loci generate said pair of undulating curves tapering in a

longitudinal direction from a maximum lateral opening to intersect at two points equidistant from a centerline of said maximum separation.

6. An overlay directional coupler for use at microwave frequencies as recited in claim 1 including a upper and lower ground plane of width greater than that of said primary and secondary conductors, said upper and lower ground planes being disposed in spaced lateral face to face alignment, and including therein between said primary conductor, common ground plane with iris opening, and said secondary conductor, said upper ground plane, primary conductor, common ground plane with iris opening, secondary conductor and lower ground plane being separated by dielectric material extending uniformly between them.

7. An overlay directional coupler for use at microwave frequencies as recited in claim 1 wherein one end of said secondary conductor is terminated by matched impedance means.

8. An overlay directional coupler for use at microwave frequencies as recited in claim 6 wherein the iris opening progressing longitudinally is defined by the following relationship:

$$S=\frac{B}{\pi}\log\frac{H(\beta+a)}{H(\beta-a)}$$

where:

B=upper to lower ground plane spacing
S=iris width
H=Jacobian eta function
$\beta=S_n^{-1}(k_e/k_o, k)$
k_e=modulus for even mode impedance
k_o=modulus for odd mode impedance
S_n=Jacobian elliptic function
k=modulus of K which is the complete elliptic integral of the first kind
s=primary to secondary conductor spacing.

9. A directional coupler as recited in claim 6 wherein the shape of the primary and secondary conductors progressing in a longitudinal direction is defined by the following relationship:

$$W=\frac{B}{\pi}\log\frac{\theta(\alpha+a)}{\theta(\alpha-a)}$$

where:

θ=Jacobian theta function

$$\alpha=S_n^{-1}\left[\frac{1}{k}\frac{\sqrt{Z(a)}}{\sqrt{Z(a)S_n^2a+S_na.C_na.d_na}}\right]$$

B=upper to lower ground plane spacing

$$a=\frac{s}{B}K$$

s=primary to secondary conductor spacing
Z=Jacobian zeta function
S_n,C_n, d_n are Jacobian elliptic function and
K=complete elliptic integral of the first kind with k as the modulus.

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U.S. Cl. X.R.

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