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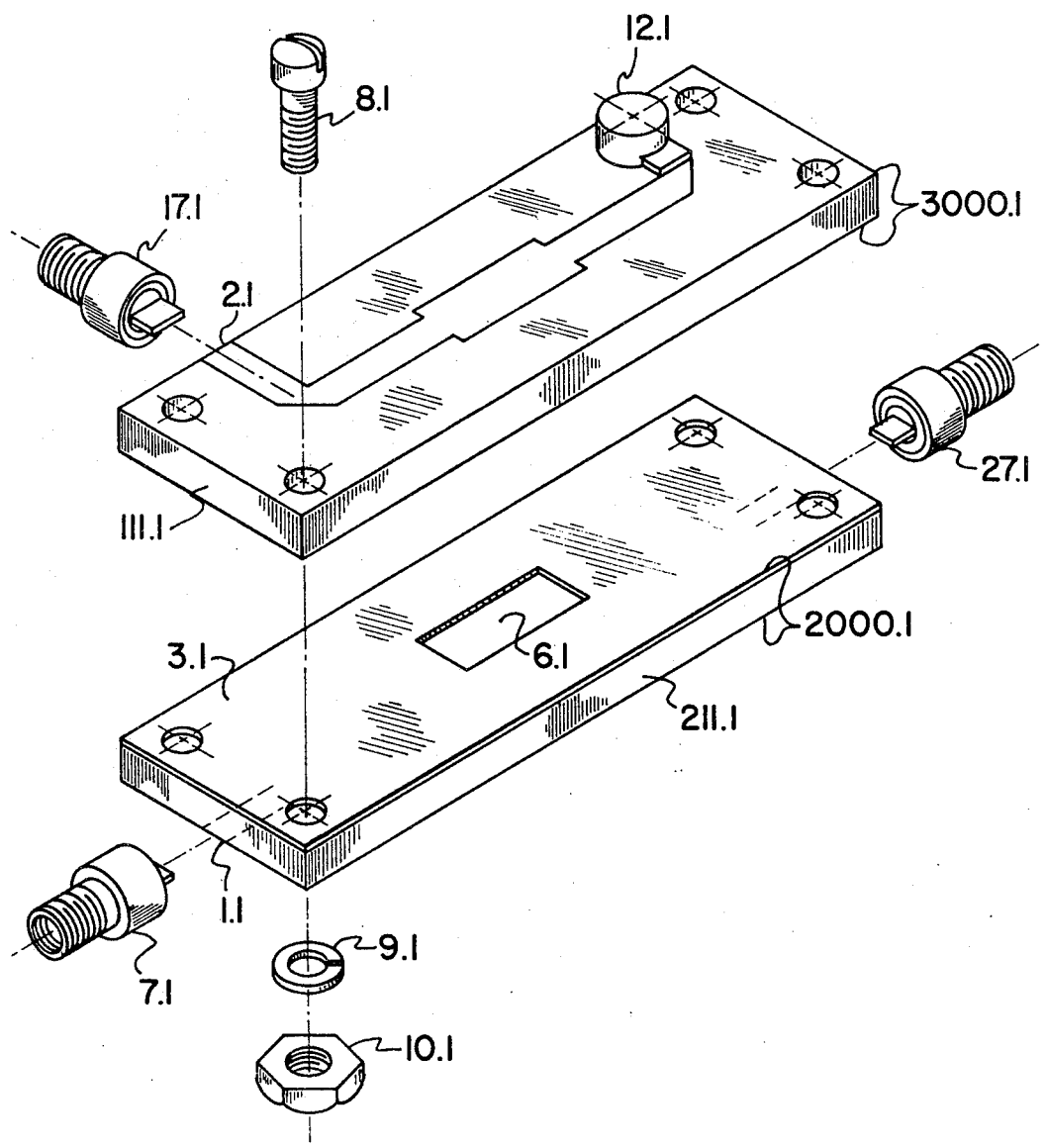
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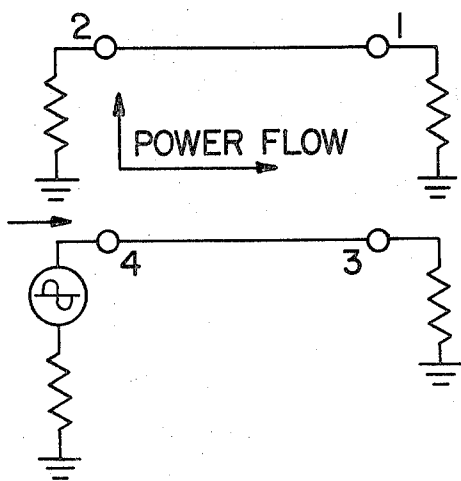
[54] MICROSTRIP IRIS DIRECTIONAL COUPLER
4 Claims, 5 Drawing Figs.

[52]	U.S. Cl.....	333/10, 333/84M
[51]	Int. Cl.....	H01p 5/14
[50]	Field of Search.....	333/10, 84 (M)

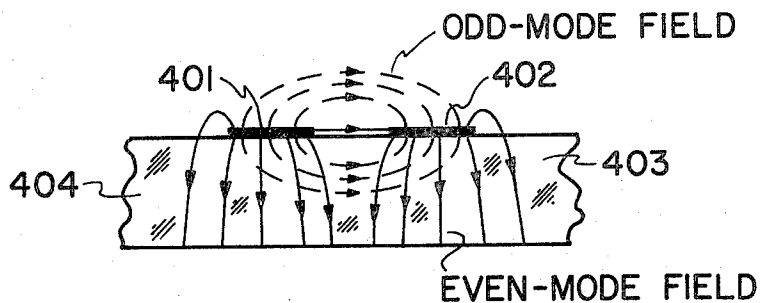
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ABSTRACT: A microwave iris directional coupler on microstrip having high directivity is disclosed. The device is primarily for use in single ground plane microstrip transmission lines of the type commonly used for microwave hybrid integrated circuits. It has an iris between two lines separated by a common ground plane, such that each line forms a separate transmission line with the common ground plane and is completely isolated from each other, beyond the open portion of the iris.





PRIOR ART
FIG 1



PRIOR ART
FIG 2

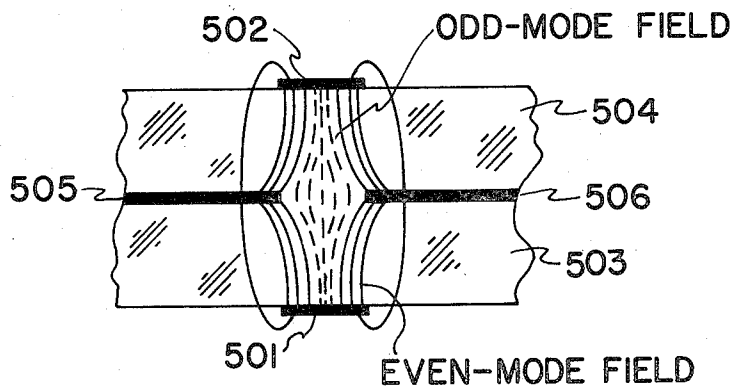
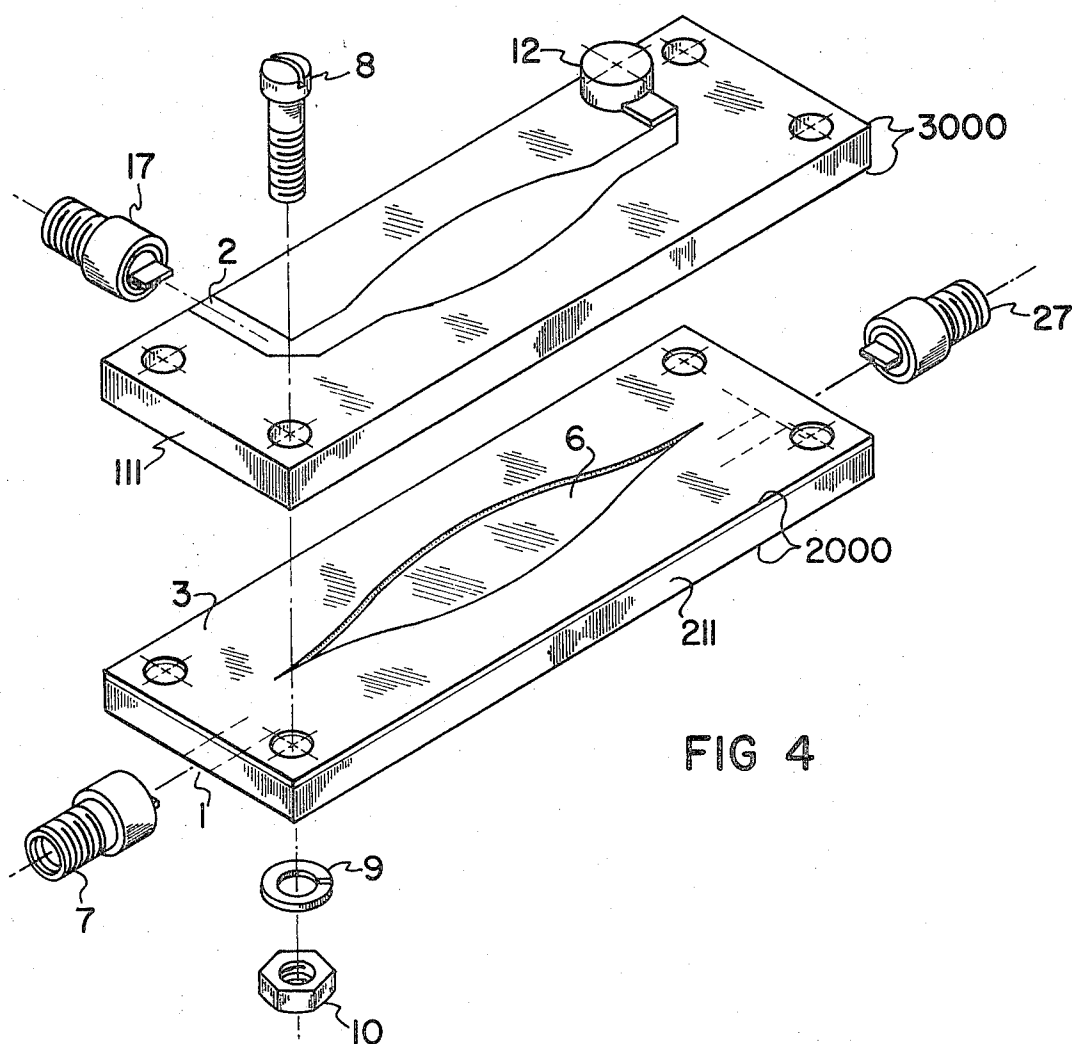


FIG 3

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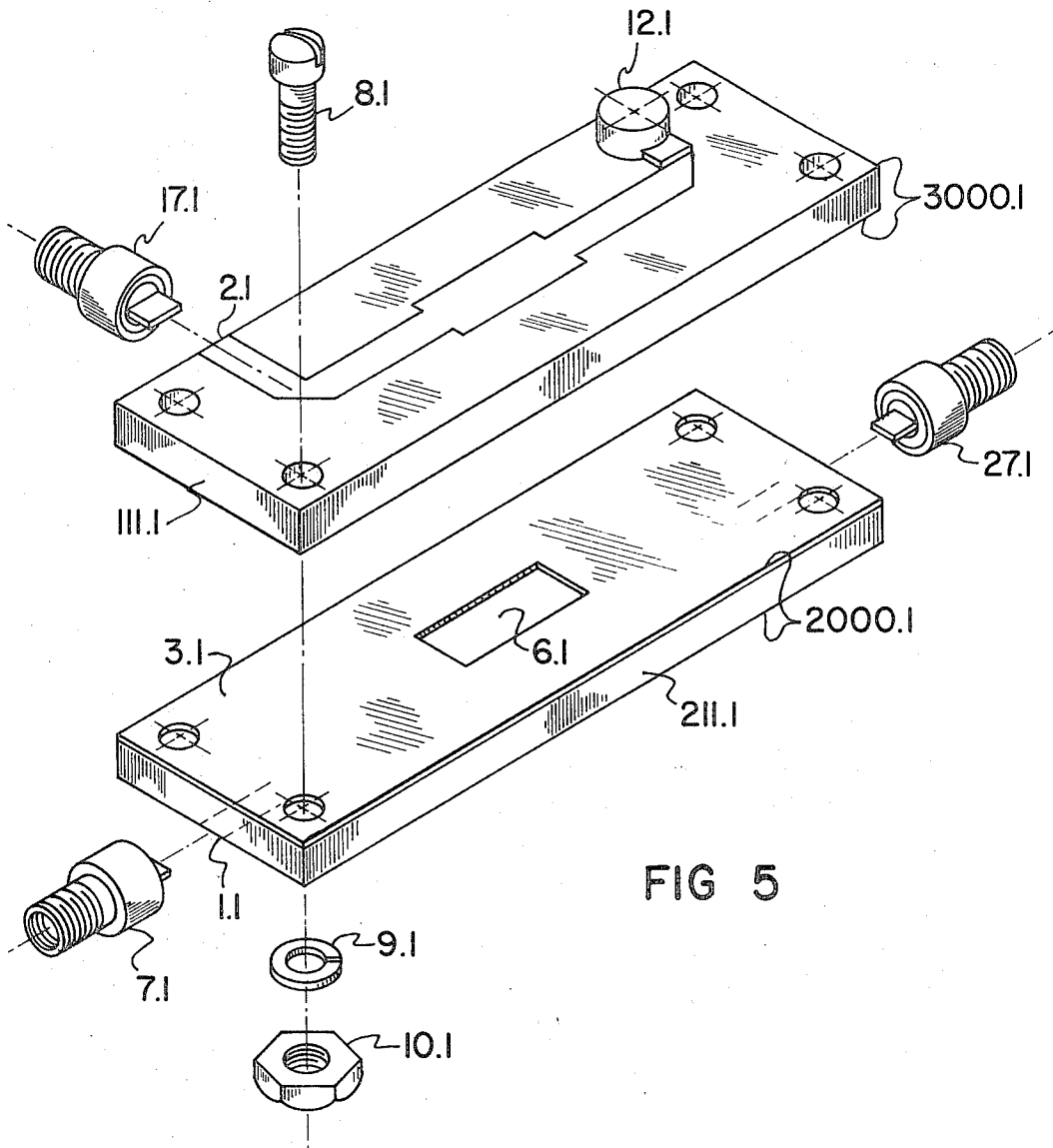


FIG 5

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MICROSTRIP IRIS DIRECTIONAL COUPLER

BACKGROUND OF INVENTION

The field of this invention is generally microwave directional couplers and in particular microstrip 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 microstrip directional coupler when all its ports are terminated in matched loads is exemplified in FIG. 1 labeled "Prior Art." When power is supplied at input port 1, power flows to ports 2 and 3 and no power appears at 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 and high directivity whereas a low performance coupler has low isolation and poor directivity.

It is important that the coupled fields between the conductor as well as the fields between the conductors and the ground plane be balanced electrically and that they have the same propagation velocity. These fields may be described in terms of the even and odd mode impedances of the lines:

$$Z_{oe} = \frac{30\pi}{\sqrt{\epsilon}} \cdot \frac{K(k'_o)}{K(k_o)} \text{ ohms}$$

where Z_{oe} is the even mode impedance

K is the complete elliptic integral of the first kind
 ϵ is the dielectric constant

$$k_o = \tan h \left(\frac{\pi}{2} \cdot \frac{w}{b} \right) \cdot \tan h \left(\frac{\pi}{2} \cdot \frac{w+s}{b} \right)$$

$$k'_o = \sqrt{1 - k_o^2}$$

w is the line width

s is the separation, and

b is the ground plane spacing.

Similarly

$$Z_{oo} = \frac{30\pi}{\epsilon} \cdot \frac{K(k'_o)}{K(k_o)} \text{ ohms}$$

where

Z_{oo} is the odd mode impedance

$$k_o = \tan h \left(\frac{\pi}{2} \cdot \frac{w}{b} \right) \cdot \cot h \left(\frac{\pi}{2} \cdot \frac{w+s}{b} \right)$$

$$k'_o = \sqrt{1 - k_o^2}$$

Further, for two lines coupled together in a fashion which will produce directivity, the following relationships must be met either for the whole coupler in the case of a single section, each section of a multisection, or all points of a nonuniform line distribution

$$Z_o = \sqrt{Z_{oe} Z_{oo}}$$

where Z_o is the characteristic impedance.

Also

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

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

where K_v is the voltage coupling coefficient.

Prior art couplers having the above characteristics have been fabricated in conventional stripline for many years. 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 connectors made between the ends of the coupled conductors and the external terminals. This class of couplers has about one octave of bandwidth and suffers from limited directivity. To improve bandwidth and to some extent, directivity, Cristal and Young (Cristal & Young, "Theory and Tables of Optimum Symmetrical TEM-Mode Coupled-Transmission Line Directional Couplers," MTT-13, No. 5, Sept. 1965, p. 544) added quarter wavelength 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° Couplers Using Nonuniform Line Techniques," MTT-14, 012, Dec. 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, Jan. 1966, p. 7) with a partial overlay coupler sharing common ground planes, and S. Yamamoto et al. (Yamamoto, Osakami, & Itakura, "Slit Coupled Strip Transmission Lines," MTT-14, No. 11, Nov. 1966, p. 542) who introduced the quarter wave rectangular slit coupled overlay coupled 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. Hence, it is known how to couple through a slit on double ground plane stripline. (Stripline is defined as a conductive pattern supported on a dielectric between ground planes.)

All of these techniques are limited, however, when an attempt is made to apply them to single ground plane microstrip because of the unequal dielectric constant between the upper and lower sides of the line which is inherent to microstrip construction. (Microstrip is defined as a conductive pattern supported on a dielectric sheet which has a ground plane on its opposite face). FIG. 2 illustrates the field distribution for conventionally coupled microstrip lines. The even mode field distribution is substantially contained within the dielectric medium 403 between conductors 401 and 402 and the ground plane 404 and is shown in solid lines. The odd-mode field distribution, however, is divided between air and the dielectric 403 between conductors 401 and 402, shown in dotted lines, thereby establishing a second propagation velocity through the air. This difference creates a phase unbalance which limits the directivity of the coupler. (Further discussion on "Shielded Coupled-Strip Transmission Lines" is found in an article by S. B. Cohn having the above title and published in Oct. 1955, IRE Transactions—Microwave Theory and Techniques.)

This invention provides a means of coupling microstrip lines wherein both even and odd mode fields are substantially contained within the dielectric thereby eliminating the phase unbalance common to other types and permitting greater directivity.

SUMMARY OF THE INVENTION

This invention relates to microstrip directional couplers of improved directivity.

An iris of suitable shape on a common ground plane is interposed between two conductive lines such that the lines are in spaced relationship on opposite faces of the common ground plane and having substantially a higher dielectric between conductors and the faces of the common ground plane.

As an example, a device according to this invention will preferably be fabricated on ceramic such as Al_2O_3 , see FIG. 3.

The common ground plane 505 having an iris therein is interposed between ceramic substrates 503 and 504 having conductive lines 501 and 502 on their opposite faces respectively. Both the even and odd mode fields are substantially contained within the dielectric; therefore the phase velocity is substantially the same.

A major feature of this invention is that it provides improved directivity.

Another feature of this invention is that the number of parts are substantially reduced, facilitating fabrication techniques.

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 a schematic side view of conventionally coupled lines on microstrip showing odd and even mode field distribution;

FIG. 3 is a schematic side view representation of the present invention showing even and odd mode field distribution;

FIG. 4 is an exploded view (not to scale) which illustrates an embodiment of this invention having an integrated undulating iris and integrated undulating conductive lines;

FIG. 5 is an exploded view (not to scale) which illustrates another embodiment of this invention having a rectangular iris opening and stepped conductors.

FIG. 3 shows schematically and in side view or elevation the essential elements of this invention and their spatial arrangement. A ground plane 505 with an iris 506 of any desired shape is interposed spatially between electric conductors 501 and 502 such that conductor 501 can "see" conductor 502 through the opening of the iris. A relatively high dielectric material 503 and 504 fills the space between conductors and common ground plane and between conductors through the iris opening. The dielectric material may be ceramic such as alumina or beryllia; or it can be diamond; or even high resistivity semiconductor material such as silicon or gallium arsenide having a dielectric constant greater than 6. Although this invention can function if the dielectric constant of the dielectric material 503 and 504 is greater than 1, the performance of the coupler improves and greater directivity results with substantially higher dielectric constants, with dielectric constant in the 6 to 12 range being preferred in L through X frequency bands.

The electric conductors 501 and 502 can be of aluminum, copper, molybdenum, nickel, silver, gold or other good electrically conductive material such as columbium or niobium. It is not necessary that the conductors 501 and 502 be bonded to the dielectric material 503 and 504, but it is preferred. Any number of techniques well known to the art may be used for placing and bonding the conductors 501 and 502 on the dielectric substrate 503 and 504. Metal can be evaporated and deposited through a mask of desired shape onto the dielectric substrate 503 and 504; or a silk screen technique, well known in prior art, can be used. Subsequent steps of sintering, plating, and sintering well known in the art will produce a conductor integrally bonded to the ceramic dielectric. The common ground plane 505 can be of any conductive material such as copper, aluminum, nickel, molybdenum, silver or gold and can similarly be bonded to either or both of the inner faces of the dielectric 503 and 504, or it may be a separate sheet of conductive material not necessarily bonded to either dielectric. Assembly consists of suitably aligning the individual components and fastening together by any suitable fastening means, not shown in FIG. 3.

FIG. 3 also shows the expected odd-mode and even-mode field distribution of this invention, wherein the odd-mode field is shown dotted between electric conductors 501 and 502 and the even-mode field is shown solid between electric conductors 501 and 502 and the common ground plane 505 respec-

tively. This concept of the field distribution is derived intuitively in observing a similar computer solution ("Microstrip Circuit Designs," H. E. Stinehelfer, Sr., Interim Technical Report No. 1, Jan. 1968, p. 23, Air Force Avionics Laboratory Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio) and from prior knowledge of stripline field distributions ("Shielded Coupled-Strip Transmission Lines," S. B. Cohn, IRE Transactions—MTT, Oct. 1955, p. 30). Note that the even and odd mode field distribution is substantially contained between conductors and common ground plane except for small fringe fields on outermost edge of conductors.

FIG. 4 shows one embodiment of an exploded view, not to scale, of this invention. Referring to FIG. 4, primary electrical conductor 1 is shown dotted on one face of dielectric 211; whereas on the other face of dielectric 211 is the common ground plane 3 in which an integrated iris 6 of an undulating contour has been etched to bound and expose the upper face of the dielectric 211 on which the common ground plane 3 rests. The shape of the curve forming the bounds of the iris in this embodiment is undulating and follows a prescribed mathematical law described later, although any suitable bounds for the iris opening may be used. Although the iris 6 in the embodiment is photoetched in the required pattern on the common ground plane 3 which in turn is integrally bonded to one face of dielectric 211, any suitable process for making the iris such as stamping may be used and the ground plane 3 need not be integrally bonded on the face of dielectric 211. A secondary electrical conductor 2 on the upper face of dielectric material 111 is spaced apart from common ground plane 3 by upper dielectric 111, and is aligned above the iris 6 and the primary electrical conductor 1 so that their planes are parallel and primary conductor 1 "sees" substantially most of secondary electrical conductor 2 through the iris opening 6. (By the word "sees," as used in this context, it is meant that straight lines drawn to connect the primary electrical conductor to the secondary electrical conductor and passing through the iris opening are mutually perpendicular to the planes containing the electrical conductors).

Input power to the primary line is introduced through a standard coaxial-to-microstrip-transformer connector 7 and output power is removed through similar coaxial connectors 17 and 27, where coaxial connector 17 connects to the secondary line 2 and coaxial connector 27 connects to the output of primary line 1.

The secondary electrical conductive line 2 is further terminated by a resistive termination 12 and is matched to line 2. Connection of these elements to their respective lines is by any suitable conventional means such as soldering, welding, thermocompression bonding, etc.

In FIG. 4, the assembly is shown in exploded form. However, in actual assembly the subassemblies 2000 and 3000 are bolted together using bolts 8 and nut 10 with washer 9 in between although other desirable fastening means may be used. Note that subassembly 2000 of this embodiment consists essentially of primary conductor 1 integrally bonded on the lower face of dielectric material 211, common ground plane 3 with an iris 6 therein, said ground plane integrally bonded to the upper face of dielectric material 211, and coax-to-microstrip-connector-transformers 1 and 27; subassembly 3000 consists essentially of secondary conductive line 2 integrally bonded to the upper face of dielectric material 111, coax-to-microstrip-connector-transformer 17, and matched resistive termination 12.

FIG. 5 is similar to FIG. 4 and schematically shows another similar embodiment excepting for the shape of primary and secondary electrical conductors 1.1 and 2.1 respectively, and the shape of the iris 6.1. Whereas in FIG. 4 primary and secondary conductors 1 and 2 respectively and iris 6 are undulating and their shapes follow a prescribed mathematical law to be hereinafter described; in FIG. 5 primary and secondary conductive lines 1.1 and 2.1 respectively and iris 6.1 may be any shape and in this embodiment are shown as rectangular, and

do not follow the hereinafter described mathematical law. Corresponding parts of FIG. 5 to those of FIG. 4 have been numbered similarly except for the addition of 0.1 to corresponding numbers. Hence 1 corresponds to 1.1, 2 to 2.2, 2000 to 2000.1, etc. Therefore, with the exceptions as above noted for FIG. 5, what has been said for embodiment of FIG. 4 applies to embodiment of FIG. 5.

In FIG. 4, the shape of the iris opening 6 and the width of lines 1 and 2 at any given point are critical and to the proper functioning of the embodiment shown on FIG. 4, 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:

$$Z_{oe} = Z_0 \sqrt{\frac{1+K_v}{1-K_v}}$$

$$Z_{oo} = Z_0 \sqrt{\frac{1-K_v}{1+K_v}}$$

where Z_0 is the characteristic impedance of the line and K_v is the voltage coupling coefficient. The stepped coupler must then be described in terms of the

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

domain to establish weighting coefficients to be applied in making a plot of coupling coefficient versus 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

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

This is most conveniently done with the aid of a digital computer with the results being expressed as a curve of Z_{oe} versus distance from the center of the coupler. This plot may then be translated into two plots of iris opening and line width versus distance using the following relations:

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

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

where B = ground plane spacing

W = line width

S = iris width

θ = Jacobian theta function

H = Jacobian eta function

$$a = S_n^{-1} \frac{1}{K} \left[\frac{\sqrt{Z(a)}}{\sqrt{Z(a)S_n^2 a + S_n a \cdot C_n a \cdot d_n a}} \right]$$

$$a = \frac{S}{\beta} K$$

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

S_n, C_n, d_n are Jacobian elliptic functions.

K = complete elliptic integral of the first kind with k as the modulus.

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

The embodiments of the invention which have been described herein are an illustration of the best modes known to practice this invention. Other alternative configurations may be made within the scope of this invention by those skilled in the art. No attempt has 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 three 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 this invention.

I claim:

1. A microwave overlay directional coupler comprising an elongated primary electrical conductor having input and output ends, a secondary electrical conductor being elongated and disposed in vertically spaced longitudinal alignment with said primary electrical conductor, a common ground plane having an iris opening therein, said common ground plane being disposed in spaced relationship between said primary and secondary electrical conductors so that primary conductor, iris opening, and secondary conductor are in spaced longitudinal alignment, and a dielectric material of substantially higher dielectric constant than the surrounding air, said dielectric material separating said primary electrical conductor, said common ground plane with iris opening therein, and said secondary electrical conductor, said iris opening being substantially rectangular with its minor dimension larger than the width of said conductors, each of said conductors having a rectangular portion of similar dimensions to said iris opening in substantial registration with said opening.

2. A microwave overlay directional coupler as recited in claim 1 wherein the dielectric material has a dielectric constant higher than 6.

3. A microwave overlay directional coupler as recited in claim 1 wherein the material of the primary and secondary electrical conductors, and the common ground plane are selected from the group consisting of aluminum, copper, molybdenum, nickel, gold, silver, columbium and niobium.

4. A directional coupler according to claim 1 in which the major dimension of said iris opening is a minor fraction of the length of either of said electrical conductors.