United States Patent [19]

Stinehelfer, Sr.

[11] **3,904,997**

[45] **Sept. 9, 1975**

[54] **TRAPPED-RADIATION MICROWAVE TRANSMISSION LINE**

[75] Inventor: **Harold Eugene Stinehelfer, Sr.**, Burlington, Mass.

[73] Assignee: **Microwave Associates, Inc.**, Burlington, Mass.

[22] Filed: **Sept. 13, 1973**

[21] Appl. No.: **397,156**

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

[51] **Int. Cl.** **H01p 3/08**

[58] **Field of Search** .... 333/84 M, 84 R, 96, 12

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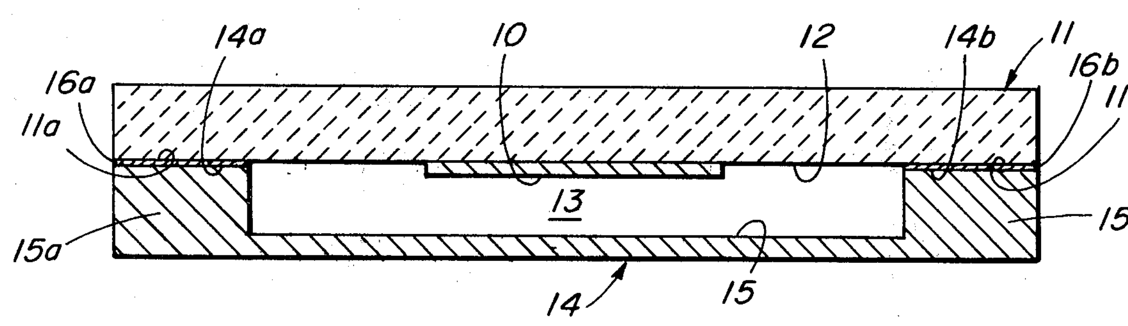
Primary Examiner—Alfred E. Smith
Assistant Examiner—Wm. H. Punter
Attorney, Agent, or Firm—Alfred H. Rosen; Frank A. Steinhilper

[57] **ABSTRACT**

A novel microwave transmission line is described, in which a conductor strip is supported on one side of a high-dielectric substrate body, the other side of which is not backed by a ground-plane conductor. The side of the dielectric body with the conductor strip is faced toward and spaced a distance from a ground plane conductor. A channel is provided in the ground plane conductor, and the dielectric body is in contact with the conductive material of the ground plane conductor along two paths at the sides of the channel. The conductor strip is enclosed in the channel, between the side paths, "suspended" or spaced from the ground plane body. Radiation from the conductor strip is minimized by trapping in the channel and in the dielectric body.

15 Claims, 21 Drawing Figures



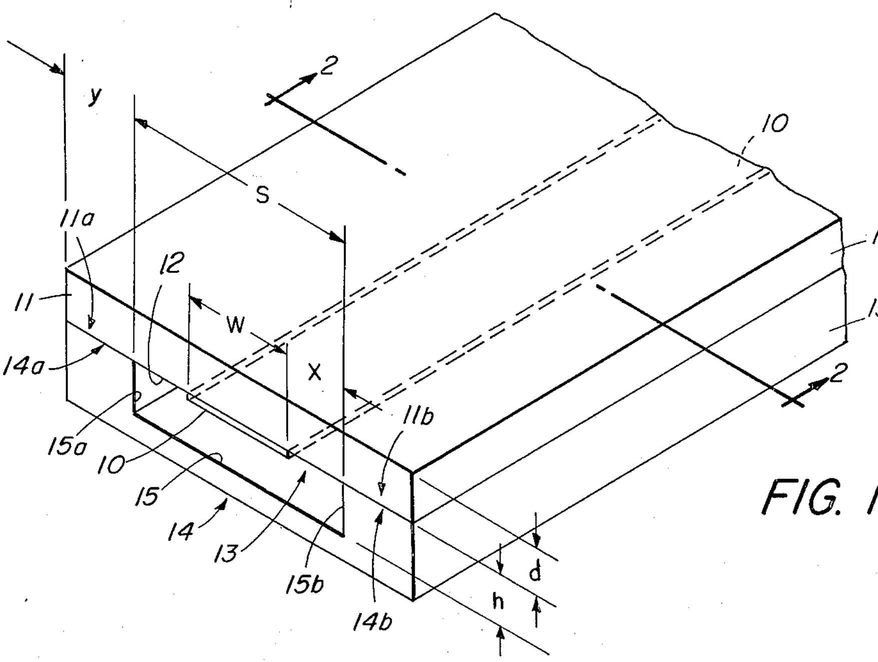


FIG. 1

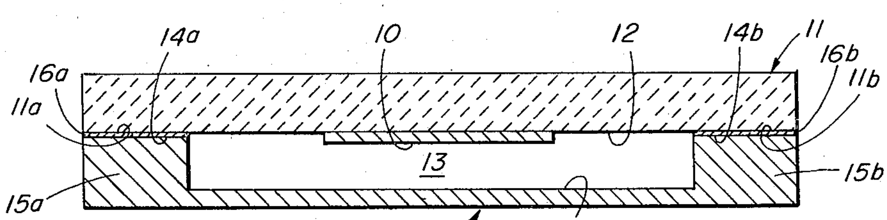


FIG. 2

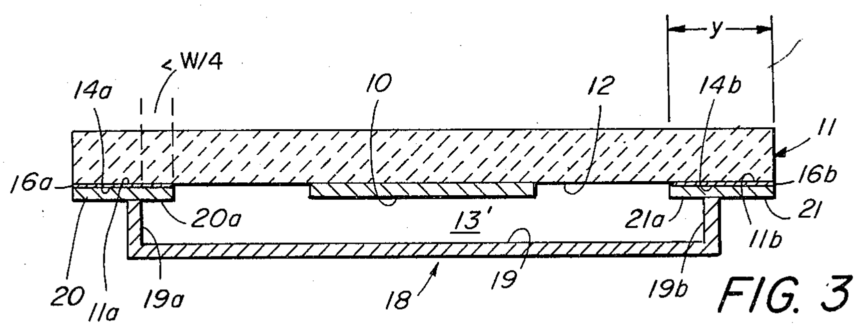


FIG. 3

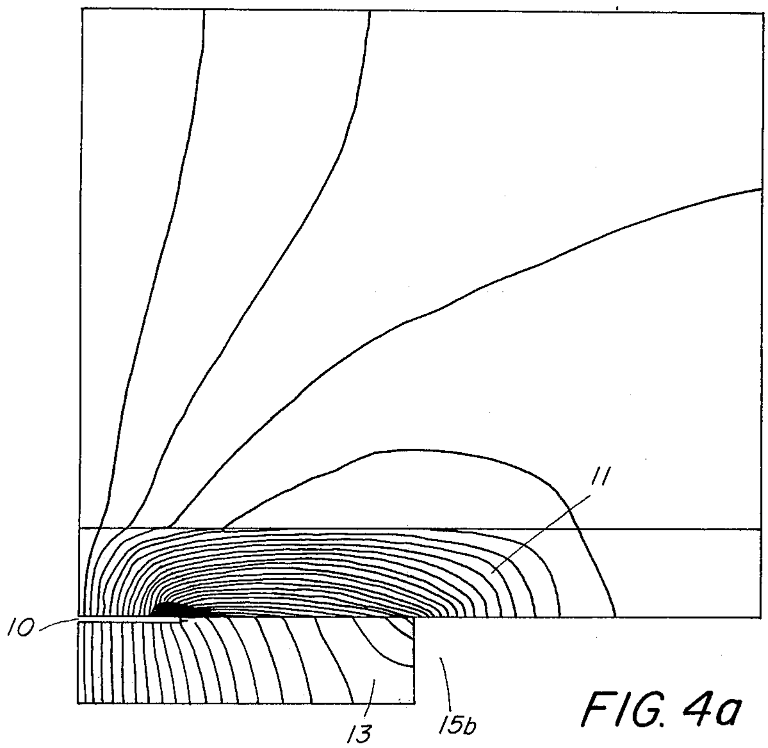


FIG. 4a

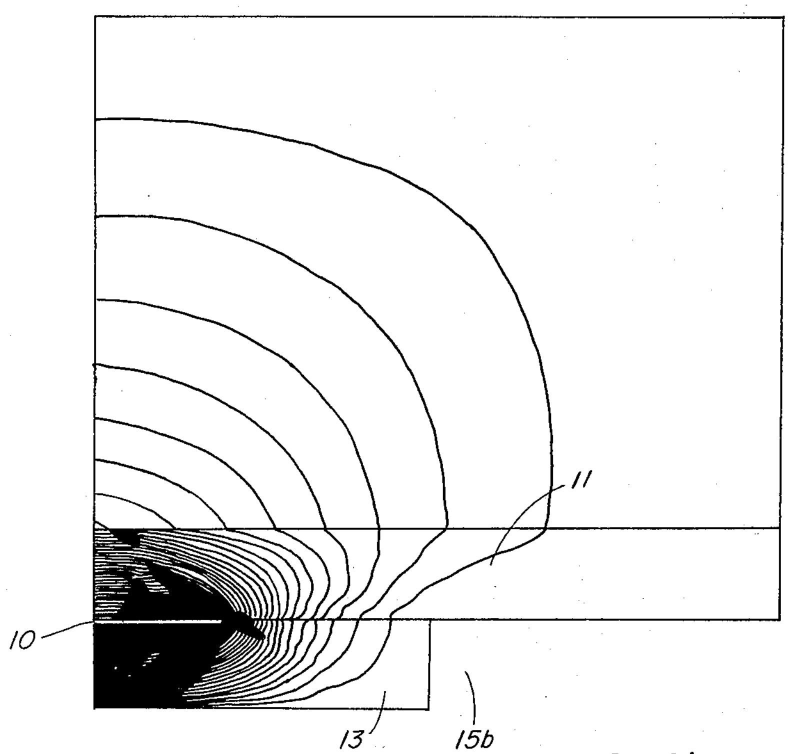


FIG. 4b

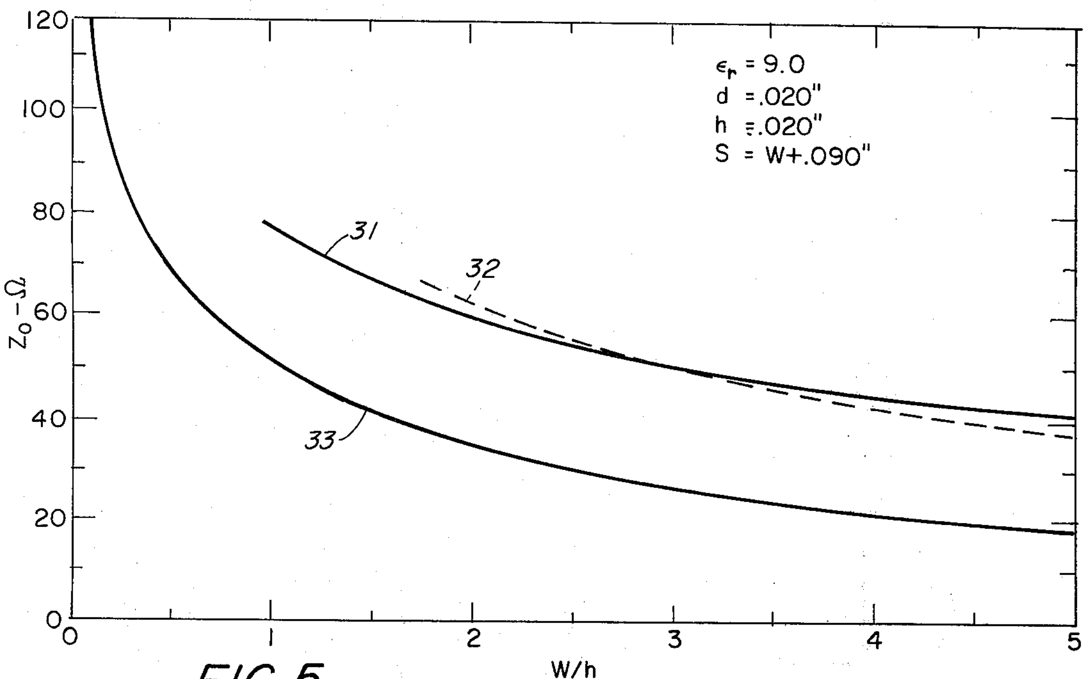

120
100
80
60
40
20
0
$Z_0 - \Omega$
0
1
2
3
4
5
W/h
ϵ_r = 9.0
d = .020"
h = .020"
S = W+.090"
31
32
33

FIG. 5

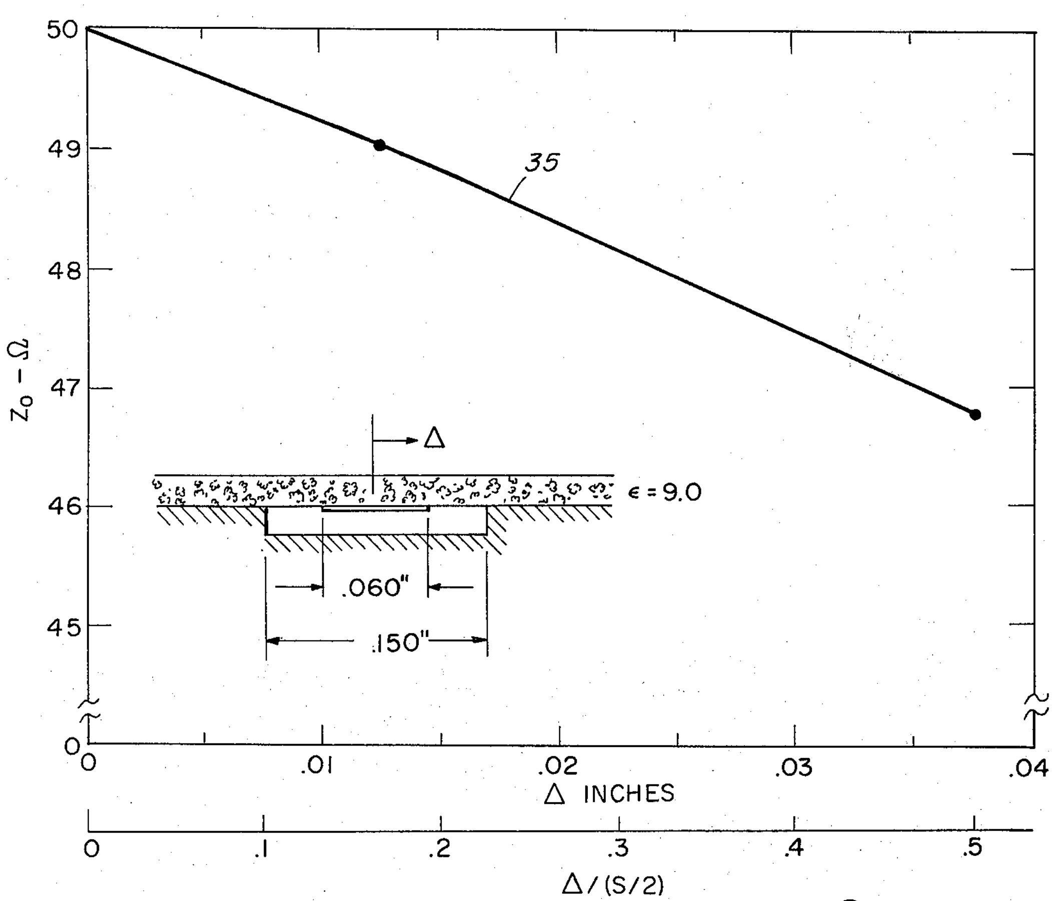

50
49
48
47
46
45
0
$Z_0 - \Omega$
0
.01
.02
.03
.04
Δ INCHES
0
.1
.2
.3
.4
.5
Δ/(S/2)
35
Δ
ε = 9.0
.060"
.150"

FIG. 6

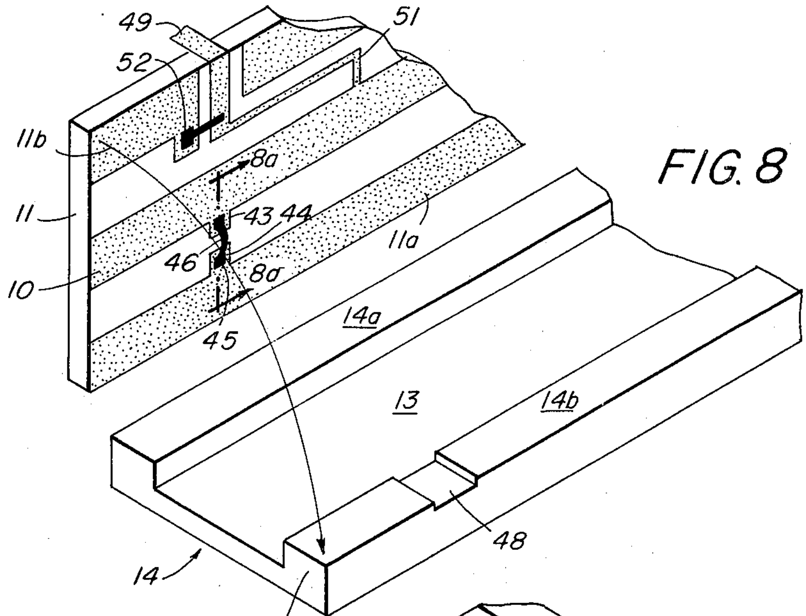


FIG. 8

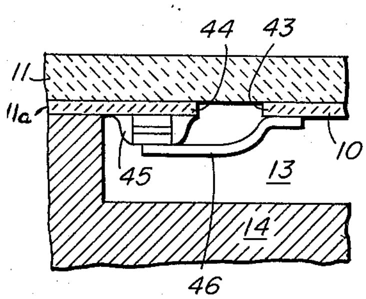


FIG. 8a

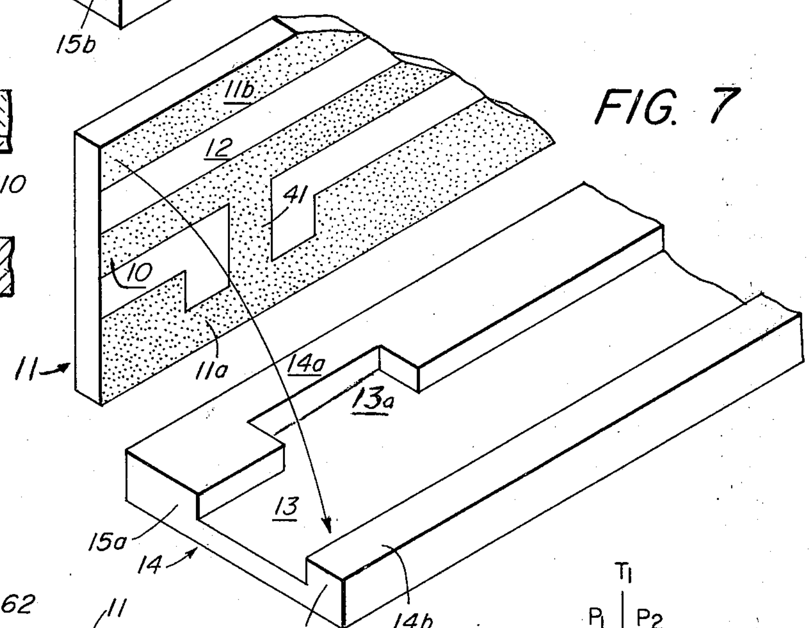


FIG. 7

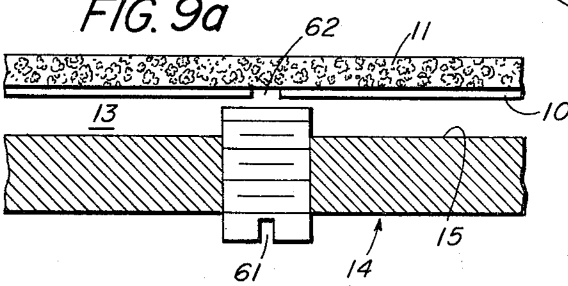


FIG. 9a

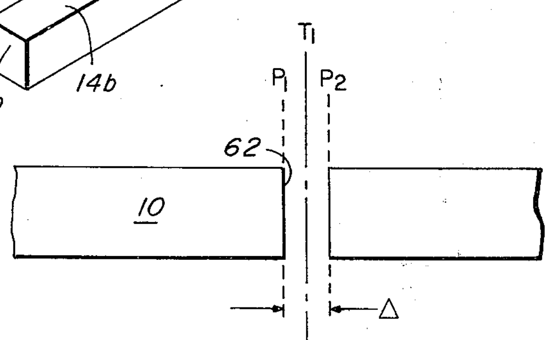


FIG. 9b

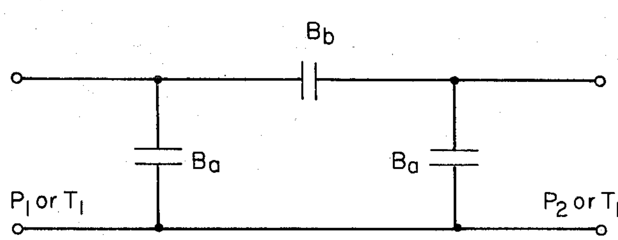


FIG. 9c

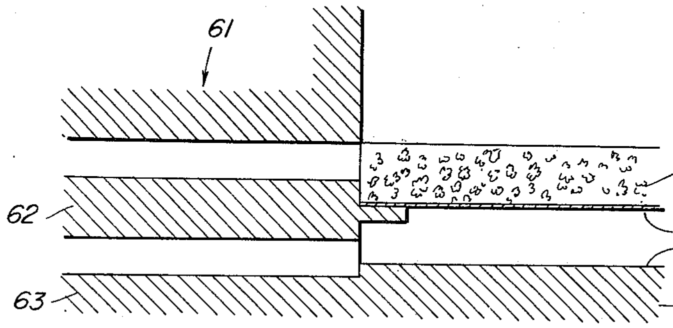
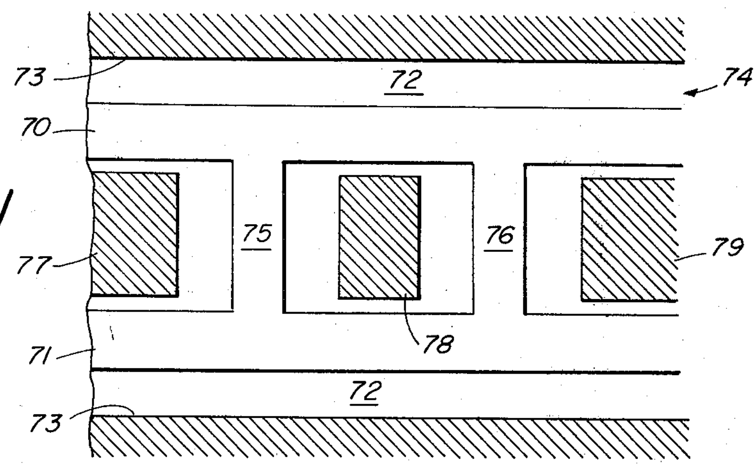


FIG. 10

FIG. 11



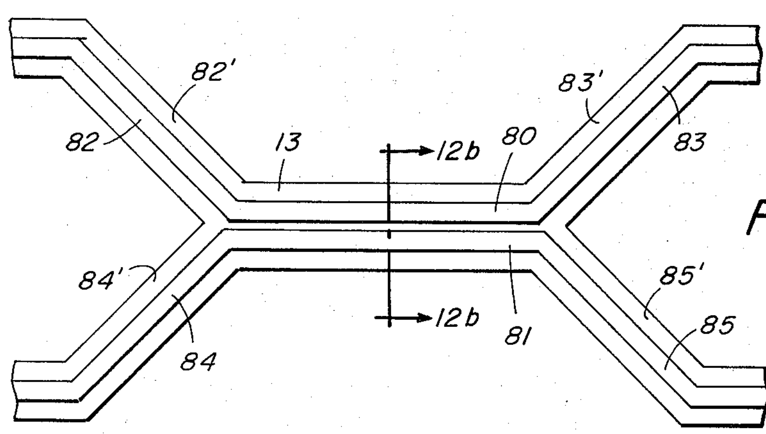
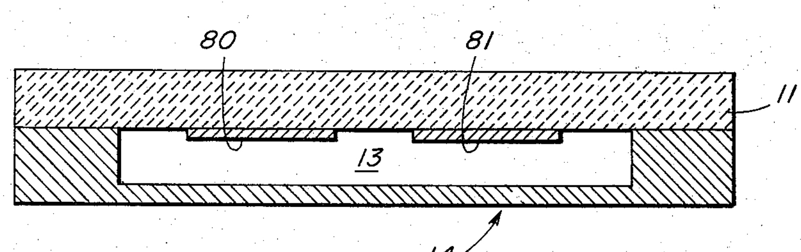


FIG. 12a

FIG. 12b



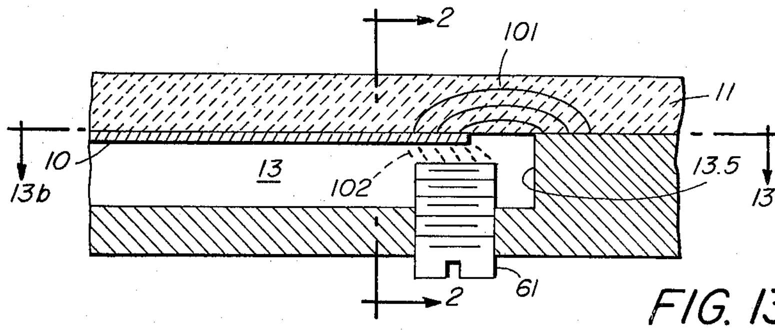


FIG. 13a

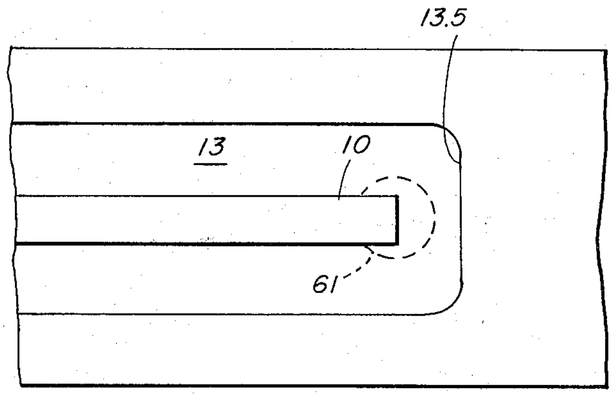


FIG. 13b

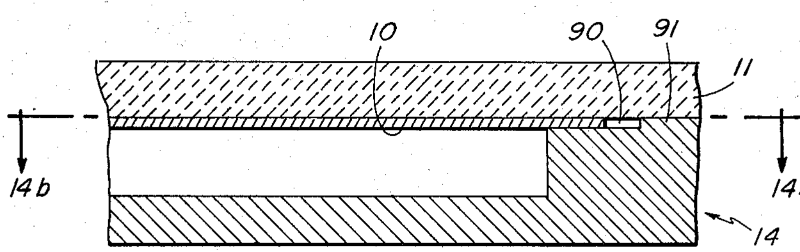


FIG. 14a

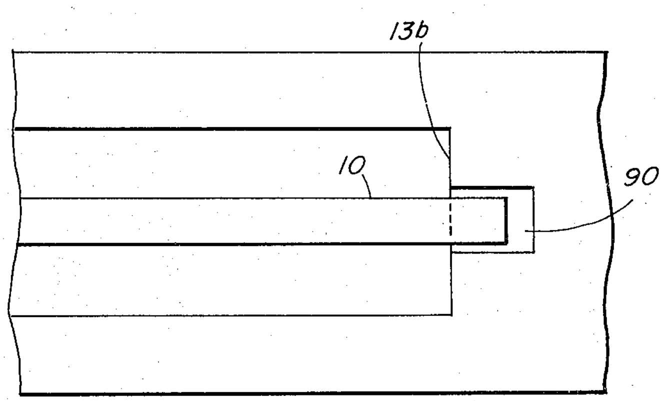


FIG. 14b

TRAPPED-RADIATION MICROWAVE TRANSMISSION LINE

BACKGROUND OF THE INVENTION

The use of microstrip transmission line, generally in the form of an electrical conductor formed, as by etching on high dielectric permittivity substrate material, has become widely recognized in the design of microwave transmission circuits and integrated circuits, subassemblies and components. A basic or common microstrip structure consists of a conductor strip or other circuit pattern supported on one side of a dielectric substrate backed on the other side by an electrically-conductive ground plane. The dielectric substrate is usually alumina ceramic because of its high dielectric constant and low loss tangent although other dielectric materials are also used. Often the microstrip circuits are completely enclosed and sealed in an electrically-conductive enclosure. Various forms of microstrip, strip line, and other transmission lines are illustrated in FIG. 1 of the article of E. G. Cristal et al., "MICRO-GUIDE - A NEW INTEGRATED CIRCUIT TRANSMISSION LINE" - GMTT May 1972 pages 212–214.

The features of ceramic-based microstrip which led to its popularity in microwave integrated circuit (MIC) applications are:

1. its fairly high effective dielectric constant and the consequent miniaturization of microwave circuits;
2. the ease, reproducibility and economy of producing circuits by photo etching methods;
3. the ease of mounting unpackaged semiconductor devices directly on the deposited conductors; and
4. its "open" construction which permits probing and adjustment of the circuit while it is operating.

Microstrip does have a couple of drawbacks, however, which limit its applicability. First, its attenuation is relatively high, compared to coaxial line or stripline. Second, microstrip has a tendency to radiate RF energy at discontinuities.

The high loss is a consequence of the high effective dielectric constant. (The effective dielectric constant is a weighted average of the air and ceramic dielectric constants, which properly accounts for the decrease in wave phase velocity and line impedance from the values in air). The high dielectric constant concentrates the electric energy within the dielectric, enhancing the dielectric loss, while the small size of the conductor strip raises the current density, enhancing the "copper" losses.

Because of its open, unbalanced configuration, microstrip tends to radiate RF power from discontinuities where higher order modes are excited. Open circuits and high-Q resonators are particularly troublesome. The radiation can be reduced by increasing the dielectric constant, which better confines the fields to the dielectric, but this is done at the cost of increased attenuation. Radiation into free space can, of course, be eliminated by enclosing the microstrip in a shielded box, as is common practice. Nevertheless, the excitation of higher order modes by discontinuities is not changed by the shielding, and the tendency toward radiation becomes manifested as increased coupling or crosstalk among the various circuit elements in the enclosure. Furthermore, the transverse dimensions of the enclosure should be less than a half wavelength long to avoid the excitation of box resonances. Since most circuit

functions require circuits somewhat greater than a quarter wavelength on a side, it is often difficult to satisfy this criterion without resorting to elaborately shaped enclosures and circuit substrates.

Suspended substrate microstrip line was introduced as aa way of decreasing the effective dielectric constant and, thereby, the loss. Suspended substrate (SS) has a thin strip of conductor deposited on a dielectric substrate, as in microstrip, but the substrate is placed or "suspended" nearly equidistant between two ground planes. The strip may be on either side of the dielectric. SS has relatively little electric energy stored in the dielectric compared to microstrip; it thus has a lower dielectric loss and wider, lower loss strips for a given impedance level. Also, because of the reduced effect of the dielectric on the wave propagation in SS lines, the tolerance on the dielectric material properties — its thickness, dielectric constant, uniformity and surface finish — which are rather critical in microstrip, are considerably relaxed.

Of course, SS line does not alleviate the radiation and box resonance problems of microstrip. In fact, because of the lower effective dielectric constant, SS line has an even greater tendency to radiate and a shielded, narrow enclosure is essentially mandatory.

GENERAL NATURE OF THE INVENTION

The present invention provides a novel transmission line having a channel between a dielectric body and a ground plane conductor body that are spaced a distance apart, there being a conductor strip supported on that surface of the dielectric body which faces the ground plane conductor body, the conductor strip being thereby suspended a distance from the ground plane conductor. The remaining surface of the dielectric body, outside the channel, is not backed by a ground plane conductor. The channel is provided in the ground plane conductor, and the dielectric body is in contact with the conductive material of the ground plane conductor along two paths at the sides of the channel which paths are generally parallel to and spaced from the conductor strip. The width of each path of contact is related to the width of the conductor strip such that radiation from the transmission line, e.g.: from discontinuities, is minimized by trapping the electric fields in the channel and in the dielectric material. For convenience, this novel transmission line may be referred to as trapped-radiation microstrip transmission line.

The invention improves upon the radiative properties of ordinary microstrip without paying the loss penalty associated with a higher effective dielectric constant. A line according to the invention will have a dielectric constant between those characterizing the equivalent microstrip and suspended substrate lines. Like a suspended substrate line, it will have low loss and relaxed tolerances to dielectric material properties. On the other hand, the fields will be largely confined to the channel region adjacent the conductor strip by virtue of the high dielectric constant in the fringing field zone. This "trapping" of the fields in the channel reduces the coupling to the free space outside the channel or "above" the substrate, significantly reducing the excitation of radiation or box resonances by circuit discontinuities. The fact that a wave propagating in this line gets trapped in the channel causes the wave to propagate in a uniform manner over longer distances than in the case of microstrip or suspended substrate lines.

In addition to maintaining simultaneously low radiation and low loss, the transmission line according to the invention possesses several other advantages and useful features, some of which will be described in detail. It is an attractive transmission line medium for use in microwave integrated circuit technology, for example.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an isometric sketch of a preferred embodiment of the invention;

FIG. 2 is a section line 2—2 of FIG. 1;

FIG. 3 is a section of another embodiment of the invention;

FIG. 4*a* is a representation of a typical electric field pattern in the embodiment illustrated in FIG. 2;

FIG. 4*b* is a representation of a typical magnetic field pattern in the embodiment illustrated in FIG. 2;

FIG. 5 is a set of graphs showing typical characteristic impedance of microstrip and suspended-substrate transmission lines, and a trapped-radiation transmission line according to the invention.

FIG. 6 is a graphic illustration of the impedance of a transmission line according to FIGS. 1 and 2 as a function of eccentricity of the strip conductor therein;

FIG. 7 illustrates a shorted stub in a transmission line according to FIGS. 1 and 2;

FIG. 8 illustrates structure for incorporating shunt-mounted devices and bias feed-through conductors in a transmission line according to FIGS. 1 and 2;

FIG. 8*a* is an enlarged partial cross-section taken along line 8A—8A in FIG. 8 with the parts 14 and 11 closed on each other;

FIG. 9*a* illustrates the incorporation of a capacitive tuning screw in a transmission line according to FIGS. 1 and 2;

FIG. 9*b* illustrates a series capacitive gap in the strip conductor of a transmission line of the invention;

FIG. 9*c* is the equivalent circuit of FIG. 9*b*;

FIG. 10 illustrates a structure for launching wave energy from a coaxial line into a trapped-radiation transmission line of the invention;

FIG. 11 is a longitudinal top-section through an embodiment of the invention which incorporates in one structure a branch-line hybrid with off-center conductors;

FIG. 12*a* is a longitudinal top-section through a coupled-strip coupler employing trapped-radiation transmission line according to the invention;

FIG. 12*b* is a section on line 12*b*—12*b* FIG. 12*a*;

FIG. 13*a* is a longitudinal side-section through an open stub end of a transmission line according to FIGS. 1 and 2;

FIG. 13*b* is a top view on line 13*b*—13*b* of FIG. 13*a*;

FIG. 14*a* is a longitudinal side-section through a "shorted" stub end of a transmission line according to FIGS. 1 and 2; and

FIG. 14*b* is a top view on line 14*b*—14*b* of FIG. 14*a*.

DETAILED DESCRIPTION OF THE DRAWINGS

In FIGS. 1 and 2, a strip 10 of electrical conductor is supported on a surface 12 of a dielectric substrate body 11, in the same manner as in a microstrip transmission line. The dielectric body 11 is affixed in paths 11*a* and 11*b* along the edges of the surface 12 to confronting surfaces 14*a* and 14*b* respectively of an electrical ground-plane conductor 14. The ground plane conductor 14 has a channel 13 in it, bounded at its bottom by a bottom wall 15 and at its sides by walls 15*a*, 15*b* extending to the surfaces 14*a* and 14*b*, respectively. The channel 13 is an elongated passage of rectangular cross-section, bounded on the bottom and two sides by electrical conductor walls 15, 15*a* and 15*b*, and on the top by the surface 12 of the dielectric body 11. The strip conductor 10 is suspended from the dielectric surface 12 spaced from the bottom wall 15 of the channel 13.

The relative dimensions of the components in FIGS. 1 and 2 are as follows:

width of conductor 10	= W
width of paths 11a–14a and 11b–14b	= W/2 (approx.)
width of space between each side-wall (inner) of sides 15a, 15b and the nearer longitudinal edge of conductor 10	= X
width of channel 13 (W + 2X)	= S
thickness of dielectric body 11	= d
thickness of channel 13	= h

In a practical transmission line having $Z_o = 50$ ohms $d > W/3$; $W/h = 3$ (approx.); $S < \lambda/2$ at fmax; and $X = 2.2h$ (approx.)

FIG. 3 is a modification of FIG. 2 in which the dielectric body 11 and strip conductor 10 are the same, but the ground plane member 18 is structurally different, being made of a thin metal channel having a bottom wall 19 and up-standing thin sidewalls 19*a* and 19*b*. At the top edge of each sidewall 19*a*, 19*b* is a flat electrically conductive plate 20, 21, respectively, of width Y on each of which the meeting path surface 14*a*, 14*b*, respectively, for the dielectric member 11 is formed. The portion 20*a*, 21*a* of each plate 20, 21, respectively, that extends inward from the sidewalls 19*a*, 19*b*, respectively, should preferably be less than W/4 in width. The channel 13′ is bounded by the electrically conductive walls 19, 19*a* and 19*b*, and the surface 12 of the dielectric body 11.

The dielectric body and the ground plane body may be joined together in any fashion known to the art, now or hereafter. For example, metalized strips (16*a*, 16*b*) like the conductor 10 can be laid down on the dielectric member in the paths 11*a*, 11*b*.

FIGS. 4*a* and 4*b* illustrate typical field patterns of trapped-radiation transmission lines according to the invention. These are, respectively, computer-generator plots of the electric and magnetic fields in a line according to FIGS. 1 and 2 but, the lines being symmetrical about a longitudinal centrally-located plane between the side walls of the channel, these figures show only one half of the transmission line, each being bisected along the axis of symmetry. The magnetic field pattern (FIG. 4*b*) is equivalent to the electric equipotential pattern, and similarly the electric field pattern (FIG. 4*a*) is equivalent to the magnetic equipotential pattern. The patterns were computed by the finite element program for solving the two-dimensional LaPlace's equation developed by Sylvester and coworkers at McGill University, (Z. Csendes and P. Sylvester, "Dielectric Loaded Waveguide Analysis Program", IEEE Trans. Microwave Theory and Techniques, Volume MTT-19, p. 789, Sept. 1971; and Z. Csendes and P. Sylvester, "A Finite-Element Field-Plotting Program", IEEE Trans. MTT, Vol. MTT-20, p. 294, April 1972). It will be seen that the electric field lines in FIG.

4*a* and the magnetic field lines in FIG. 4*b* exhibit a high degree of trapping in the channel **13** and in the dielectric **11**, particularly in the portion adjacent the coupling path **11***b*– **14***b* at the side wall **15***b*.

Comparison with similarly-derived field patterns for micro-strip line and suspended substrate line, all three lines being in the same-size enclosure, and employing dielectrics having the same dielectric constant and physical thickness, and strip conductor widths chosen to correspond to substantially the same line impedance, demonstrates that field trapping in lines according to the invention is greater, and therefore radiation is more greatly restricted than in the prior lines mentioned. Thus, it is found that in all three kinds of transmission line most of the electric field is concentrated in the dielectric. This proportion is greaten in micro-strip, less in suspended substrate, and intermediate in the trapped-radiation line of FIGS. **1** and **2.** However, when one considers the electric field above the dielectric substrate (i.e.: at the side opposite the side bearing the strip conductor **10**) the trapped-radiation line of the present invention has the weakest fields. The difference is dramatic relative to micro-strip, and less marked but still significant relative to suspended substrate. The suspended substrate field in this region is only slightly greater than in the line according to FIGS. **1** and **2,** but it falls off less rapidly as one moves off the center line. Thus can be seen, at least qualitatively, the reduced penetration of electric fields into the air above the substrate, for example, the substrate **11** in FIG. **2.** Lateral confinement of the fields by the channel **13** is quite dramatic, there being no equivalent structure in either of the microstrip or suspended substrate lines. The invention attains drastic lateral confinement in the channel **13** even though the effective dielectric constant may be only about half that of microstrip line.

In addition to reducing the lateral extension of fields, the trapped-radiation line channel (**13, 13'**), together with the dielectric interface, i.e., outer surface of the body **11**, above the line deflect the fields back to the channel edges, effectively eliminating or greatly reducing the radiative coupling to the region above, or outside, the dielectric substrate. It is possible to increase the effective dielectric constant of the trapped-radiation lines of the invention, e.g.: to 4 or 5, by increasing the substrate thickness or its dielectric constant, and thereby further reduce the radiation while keeping the loss below that of microstrip.

In FIG. **5**, curve **31** shows the measured characteristic impedance Z_o of a set of trapped-radiation transmission lines according to FIGS. **1** and **2**, in which the strip conductor **10** and widths W as follows:

0.020 inch
0.040 inch
0.060 inch
0.080 inch, and
0.100 inch

In each case the conductor was on a dielectric substrate **11** of alumina having thickness $d = 0.020$ inch and dielectric constant $\epsilon_r = 9.0$; and the depth h of the channel **13** was 0.020 inch. Each channel had width S that was 0.090 greater than W. Except for channel width S, the geometry corresponds to that of FIGS. **4***a* and **4***b*, where W was 0.050, and S was 0.150 inch. In FIG. **5**, Z_o is plotted as a function of the ratio W/*h*, and the characteristic impedance is seen to fall between 80 ohms and 40 ohms, being 50 ohms when $W/h = 3$ (approx.).

Curve **32** (in dashed-line) shows for comparison the impedance of suspended substrate line on the same dielectric, as estimated from the curves of H. E. Brenner "Use a Computer to Design Suspended Substrate IC's", Microwaves, Vol. 7, No. 9, p. 38, Sept. 1968. FIG. **5** illustrates that the characteristic impedance for these two lines is closely similar.

Curve **33** shows for comparison the characteristic impedance of microstrip line, as calculated from Wheeler's formulas, (See M. V. Schneider, "Microstrip Lines for Microwave Integrated Circuits", Bell Sys. Tech. Journal, Vol. 48, p. 1421, May–June 1969).

Trapped-radiation lines according to the invention have four impedance-determining parameters, as is apparent from FIG. **5.** These are:

$$W/h;\ d/h;\ S/h;\ \text{and}\ \epsilon_r$$

By contrast, suspended substrate has only three such parameters, and microstrip has only two. These additional variable parameters make it possible to develop transmission lines having a wide variety of specifications. The channel width S can be increased until the trapping effect is lost, or decreased until the width W of the strip conductor **10** must be so narrow that losses are unacceptably high and mechanical tolerances become unacceptably close. The dielectric can be made thinner to the point where leakage flux and radiation become unacceptably high, or thicker to the point where effective dielectric constant and consequent loss become unacceptably high and the possibility of box resonance entirely within the dielectric is introduced or becomes unacceptable. In general, acceptable ranges of dimensisons have been indicated above, in connection with FIGS. **1** and **2,** and FIG. **5,** for frequencies up to 18 GHz.

Since there is no inherent reason for the strip conductor **10** to run along the center line of the channel **13**, the offset, or eccentricity, Δ of this conductor is a variable parameter which offers one more degree of freedom in designing transmission lines according to the invention. FIG. **6** shows the measured effect of offsetting a 50 ohm strip conductor up to half the channel width. The characteristic impedance is plotted as a function of the offset Δ, and curve **35** shows that Z_o can be varied, essentially linearly, from 50 ohms to less than 47 ohms. FIG. **6** illustrates the comparatively relaxed tolerances that are possible in trapped-radiation lines of the invention. For typical channels, that is, those which have width S about 2 to 3 times the width W of the strip conductor **10,** the lateral positioning tolerance of the conductor is not critical; a 15% offset causes only a one-ohm error in a 50 ohm line. Similarly, the channel width itself is not critical. The strip conductor having width $W = 0.060$ inch was 50 ohms in a channel having width $S = 0.150$ inch, and approximately 49 ohms in a channel having width $S = 0.130$ inch.

Trapped-radiation lines according to the invention have many advantages over microstrip and suspended substrate lines. For example, short-circuited stubs are rarely used in microstrip because they are inconvenient to make. In order to return the open end of a stub to ground, either it must be positioned at the edge of the dielectric board (or substrate), or a hole must be provided through the board and a separate grounding connection must be made. On suspended substrate, one does not have even the option to drill a hole through the board to the ground plane. By contrast, a short circuit in lines according to the invention can be simply printed (e.g.: etched out) with the rest of the circuit, as is illustrated in FIG. 7, where parts correspond to parts in FIG. 2 have the same reference characters. The stub conductor **41** runs from the main line conductor **10** to the edge of the channel **13**, which is widened in the region **13**a in the vicinity of the stub to accommodate its length. The contact paths **11**a and **11**b of the dielectric body **11** are metallized in the same manner as the conductor **10**, in a common printing or etching operation, for ease in making fixed electrical contact to the meeting path surfaces **14***a*, **14***b* of the ground plane member **14**. Since shorted stubs in microstrip are usually simulated by an extra quarter wavelength of open stub, they do not have the same frequency response of true shorted stubs, and they radiate. By contrast, a shorted stub as shown in FIG. 7 has none of these deficiencies, giving it a clear advantage in such circuit applications as interdigital and comb-line filters. This shorted stub also offers the possibility of a sliding short by filling the widened channel region **13**a with a movable metal block (not shown).

The advantage of the invention that makes it an easy matter to fabricate shorted stubs also makes it easy to shunt-mount discrete circuit elements, such as semiconductors, resistors, capacitors, directly on the dielectric substrate **11**. FIG. **8** (and FIG. **8***a*) illustrates several possible arrangements, which can be used together or in vairous combinations. The main line conductor **10** and one of the metallized meeting paths **11**a can be fitted with confronting short contact tabs **43, 44**, and a diode **45** can be mounted on one of these tabs **44**. A conductor **46** can then be connected from the diode to the other confronting tab **43**, thereby connecting the diode in shunt from the main line conductor **10** to ground. A slot **48** may be provided through the upper surface **14***b* of the wall **15***b* of the ground plane conductor **14**, to accommodate a bias feed-through conductor **49** across the path **11***b*, the metallizing of which is interrupted for this purpose. The feed-through conductor connects to a long thin conductor **51** which connects at its remote end to the main line conductor **10**, and has a length parallel to that conductor sufficient to provide a choke at the operating microwave frequency. This is a bias choke, and a by-pass capacitor **52**, which may for example be an RF by-pass semiconductor chip capacitor, is connected between the feed-through conductor **49** and ground via the ground-contact path **11**b metallizing, to complete a bias network.

FIG. 9 illustrates an arrangement, which is easily possible in the present invention, that provides the ability to do final tuning of a microwave circuit with a screwdriver, using a non-radiating screw **61** accessible from outside the finished transmission line structure. Again, parts in common with FIG. 2 bear the same reference characters, FIG. **9***a* being a longitudinal section through an embodiment like FIG. **2**. A gap **62** is provided in the main conductor **10**, and the screw **61** is threaded through the bottom **15** of the ground plane member **14**, where it is located precisely with reference to the gap. This is a capacitive screw, which is grounded, and with it the coupling of a series gap **62** can be varied, as shown. Similarly the effective length of an open stub (see FIG. **13**) can be varied. In either case, the radiation trapping properties described above will be found to be effective.

The series gap **62** and its equivalent circuit are illustrated in FIGS. **9**b and **9**c, respectively. The equivalent circuit consists of a series capacitive susceptance B_b and two shunt susceptances B_a, in a π network. Two sets of reference planes P_1 P_2 and T_1 are shown for this circuit. For narrow gaps it is convenient to use a single reference plane through the center line T_1 of the gap, and for this reference the shunt capacitors are negative to account for missing line capacitance. For wide gaps **62** it is more accurate to consider a pair of reference planes P_1 and P_2 at the ends of the gap. Here, while the same equivalent π network applies, the shunt capacitors are positive to account for fringing at the open ends. In the limit, of course, the gap may be treated as infinitely wide, and then it is conventianal to treat the open circuit capacitance as an equivalent length of line and to define a corresponding line length correction.

A series of gaps **62**, each with its tuning screw **61**, appropriately spaced along the main line conductor **10**, will provide a gap filter.

Transition from a coaxial line to a trapped-radiation line of the invention may follow the technique used with microstrip, and is illustrated in FIG. **10**. A coaxial line **61** is represented by its inner and outer conductors **62, 63**, respectively, the inner conductor being connected to the main line conductor **10** of the trapped-radiation line, and the outer conductor being connected to the ground plane member **14**. Test models made according to FIG. **11**, in which the trapped radiation line of the invention was designed to have $Z_o = 50$ ohms, and in which the coaxial line was used to launch microwave energy into the new line, indicated VSWR per transition to be about 1.2 at X-Band, and 1.4 at 18.0 GHz, prior to any development work aimed at reducing the VSWR.

The branch line hybrid coupler is often used for 3dB couplers since it affords the desired tight coupling. FIG. **11** illustrates a circuit configuration that uses a pair of off-center main line conductors **70, 71** mounted on a dielectric substrate **74** and suspended in a common channel **72**, the channel being formed in a ground-plane member (not shown) which corresponds to the ground-plane member **14** in FIGS. **1** and **2**, and has side walls **73, 73**. In FIG. **11**, the main line conductors **70** and **71** are connected by branch line conductors **75**, 76, which are formed with the main line conductors on the substrate **74**. At higher frequencies, when the diameter of the hybrid ring can become so small that the coupled circuits may be effectively merge together, the coupler is reduced to a suspended substrate circuit and undesired coupling across the ring will degrade performance. The provision of an island-like conductive element **78**, projecting from the bottom of the ground-plane member (not shown) into the center of the hybrid ring will reduce such undesired coupling at all higher frequencies. Additional islands **77** and **79** may be provided between the main lines **70, 71**, as shown, to further enhance the reduction of undesired coupling.

A simple arrangement of a pair of coupled strips (or main line conductors) **80, 81** is illustrated in FIGS. **12***a* and **12***b*. This arrangement is useful for directional couplers, as illustrated, and for half wave resonator filter circuits, to cite a few examples. The coupled strips are located closely spaced in the same channel **13** of FIGS. **1** and **2**, for example. Because the lateral confinement of the electric and magnetic fields by the channel provides excellent isolation among various circuits that may be formed on the same substrate **11**, the feed lines **82, 83, 84** and **85** to the pair of coupled strips **80, 81** can be easily, simply and cleanly separated from each other. Each feed line is located in its own channel **82′**, **83′**, **84′** or **85′**, respectively, thereby helping to reduce parasitic reactances and undesired coupling between the two lines. By properly proportioning the thickness of the dielectric **11** and the depth of the channel **13** at the coupled-line pair **80, 81**, it is also possible to equalize the phase velocities of the even-and odd-mode waves. This has the advantage of making broader-band higher directivity couplers easier to achieve in lines according to the invention than in microstrip.

FIGS. **13***a* and **13***b* show how to make an open stub in a transmission line according to the invention. A section of FIG. **13***a* taken along line **2—2** will look identical to FIG. **2.** The channel **13** is terminated or blocked at one end 13.5 and the main line conductor **10** terminates short of that end. A non-radiating turning screw **61**, like the same component in FIG. **10**a, serves to capacitively terminate the stub. Trapping lines **101, 102** show how the dielectric member **11** and the screw **61** (which is grounded) reduce radiation from the free end of the stub.

FIGS. **14***a* and **14***b* show how to make a closed stub. The technique is similar to that in FIGS. **13***a* and **13***b*, except that the top surface **91** of the end wall **13***b* obstruction is fitted with a groove **90**, and the main line conductor extends into that groove to make electrical contact with the ground-plane member **14.**

The embodiments of the invention which have been illustrated and described herein are but a few illustrations of the invention. Other alternative circuit arrangements 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 only to illustrate its principles and the best manner presently known to practice it. Therefore, while certain specific 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.

I claim:

1. An electric wave transmission line comprising a dielectric body and an electrically-conductive body spaced apart a distance (h) in fixed relation with respective first surfaces of each confronting each other and forming in part the enclosing walls of an enclosed elongated channel of width (S), said conductive body having two side walls bounding said channel extending toward said dielectric body into contact therewith along two paths each having a width (y), an electrical conductor strip of width (W) supported on said first surface of the dielectric body within and extending along the channel, the dielectric body having a second surface outside the channel and opposite to said first surface, which second surface directly confronts the surrounding region free of any intervening electric conductor, said width (y) being approximately W/2, said width (S) being less than half a wavelength at the operating frequency, and being substantially two to three times greater than said width (W), said distance (h) being less than the quantity (S—W)/2.

2. A transmission line according to claim **1** including electrically conductive closure means across said channel in electrical connection with said conductive body, said conductor strip terminating short of said closure means and thereby having an open end confronting said closure means, an electrically conductive adjustable means supported on said conductive body movably relative to said open end for confining the microwave radiation from said open end substantially to said channel and said dielectric body.

3. A transmission line according to claim **1** composed of a trough-shaped conductive body having up-standing side parts and a substantially planar dielectric body, said dielectric body being in contact along two spaced-apart paths on said first surface thereof with the ends of said side parts, said conductor strip being between said paths.

4. In a transmission line according to claim **3**, a gap in one of said paths, an electrical conductor passing through said gap out of electrical contact with said conductive body and extending to a point on said conductor strip, for bringing a bias voltage to said condutor strip from outside said transmission line.

5. In a transmission line according to claiam **1**, at least one gap in said conductor strip, and an electrically-conductive adjustable means supported on said conductive body movable adjacent to and movable relative to each such gap for tuning the gap.

6. In a transmission line according to claim **3**, a second conductor strip on said first surface of said dielectric body in one of said paths, for making electrical contact with said conductive body, and supported on at least one of said conductor strips an electric wave modifying member.

7. A transmission line according to claim **1** including electrically-conductive closure means across said channel in electrical connection with said conductive body, said conductor strip extending into electrical contact with said closure means.

8. A transmission line according to claim **1** having two electrical conductor strips supported on said first surface of said dielectric body within and extending in spaced-apart relation along said channel, in a wave-coupling to each other.

9. A transmission line according to claim **8** in which at least two bridging conductors connecting said conductor strips are also supported on said first surface, said bridging conductors being spaced apart along said channel.

10. A transmission line according to claim **1** in which said conductive body is made of thin metal, and elongated flat sheets of metal each having a width Y at least approximately W/2 are fitted one to each of said ends of said side walls.

11. A transmission line according to claim **1** in which said conductive body is a rigid block of metal containing said channel, said side walls having said width Y that is at least approximately W/2.

12. A transmission line according to claim **1** in which the thickness d of said dielectric body is at least W/3.

13. In a transmission line according to claim **1**, diode means in the space between said dielectric body and said conductive body, and means connecting said diode means between said conductor strip and said conductive body in the vicinity of one of said paths.

14. In a transmission line according to claim **1**, a stub transmission line section connected between said conductor strip and said conductive body in one of said paths, said section having a conductor supported on said surface of said dielectric body and connected at one end to said conductor strip.

15. In a transmission line according to claim **1,** passage means through one of said paths, bias conductor

means in said passage means, a reactive connection from said bias conductor means to said conductor strip, and a capacitive connection from said bias conductor means to said conductive body in the vicinity of said one path.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,904,997 Dated September 9, 1975

Inventor(s) Harold Eugene Stinehelfer, Sr.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 65, change "enclou" to --enclo--

Column 2, line 6, change "aa" to --a--

Column 4, line 17, of "width of paths 11a-14a and 11b-14b", after "width" insert --y--

line 48, change "computer-generator" to --computer-generated--

Column 5, line 53, change "and" to --had--

Column 8, line 51, delete "be"

line 55, after "bottom" insert --wall--

Column 9, line 21, change "turning" to --tuning--

Signed and Sealed this

first **Day of** *June 1976*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks