United States Patent

[11] 3,581,243

[72] Inventor **Andrew Alford**
71 Bacon St., Winchester, Mass. 01890

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[54] **DIRECTIONAL COUPLER WHEREIN DIELECTRIC MEDIA SURROUNDING MAIN LINE IS DIFFERENT FROM DIELECTRIC MEDIA SURROUNDING COUPLED LINE**
7 Claims, 11 Drawing Figs.

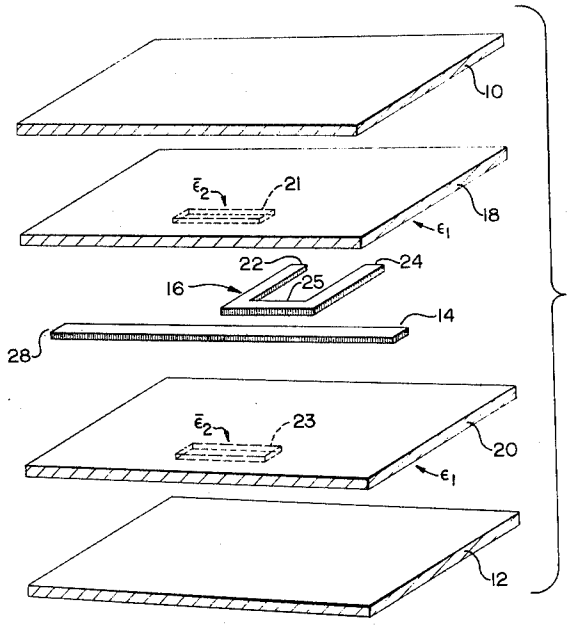
[52] **U.S. Cl.** **333/10,** 333/84
[51] **Int. Cl.** **H01p 5/14,** H01p 3/08
[50] **Field of Search** ..... 333/10, 84 M

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Primary Examiner—Herman Karl Saalbach
Assistant Examiner—Paul L. Gensler
Attorney—Morse, Altman and Oates

ABSTRACT: In a transmission line device for coupling a wave traveling in a particular direction along a main line to a coupled line, higher directivity is obtained by utilizing dielectric media of dissimilar dielectric constants in the main line and the coupled line, or by changing the relative propagation velocity along the main line with respect to the propagation velocity along the coupled line.



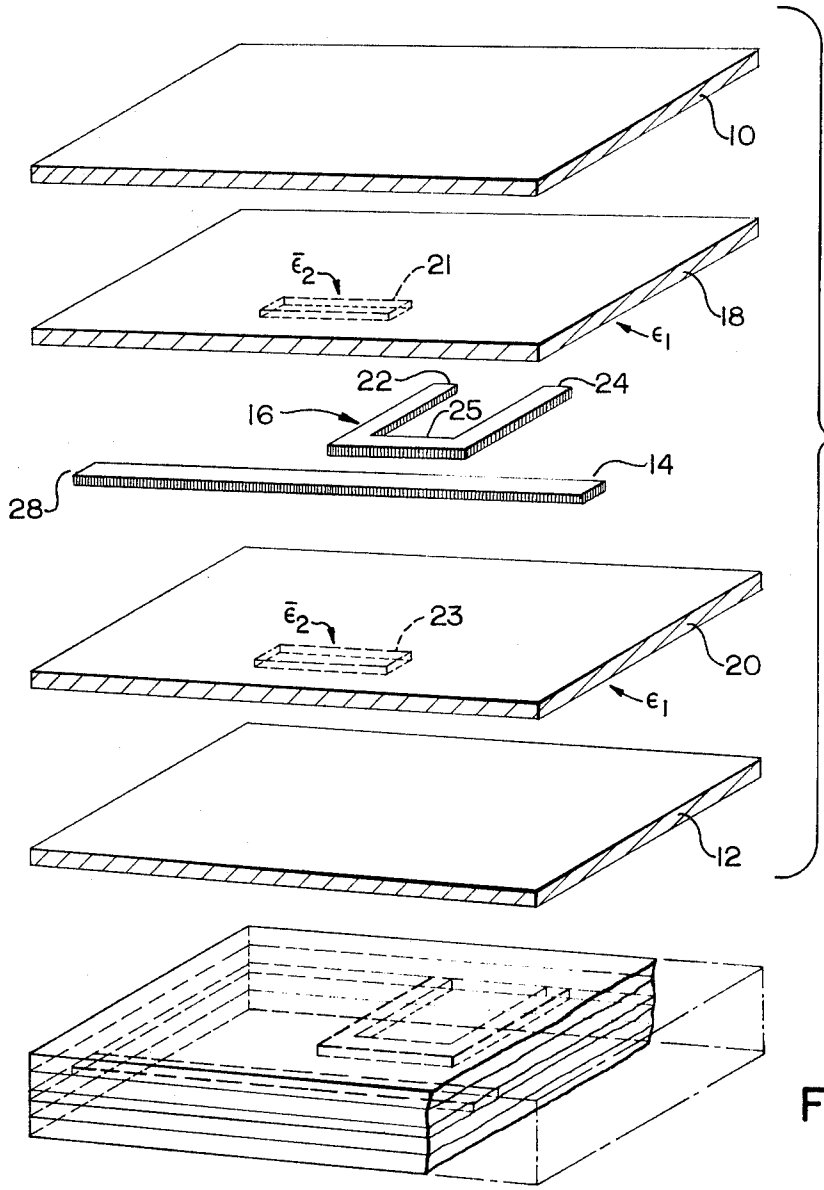


FIG. I

FIG. IA

INVENTOR.
Andrew Alford
BY
Morse, Altman & Oates
ATTORNEYS

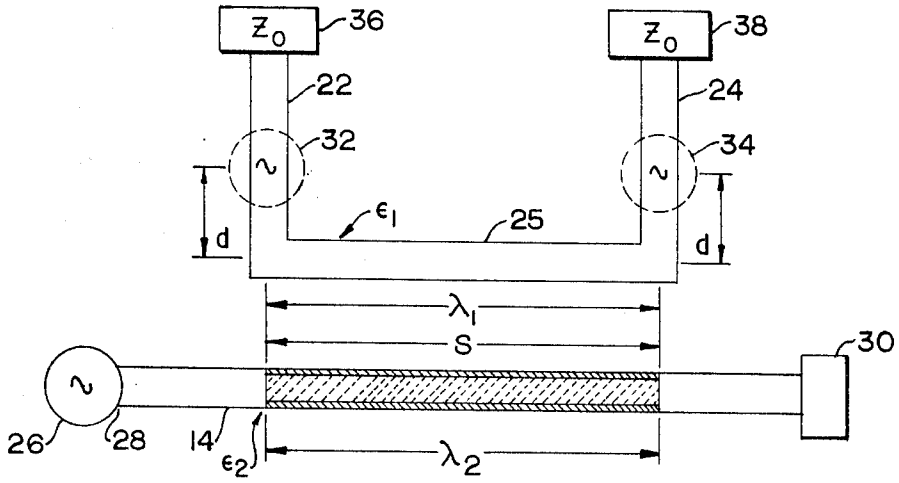


FIG. 2

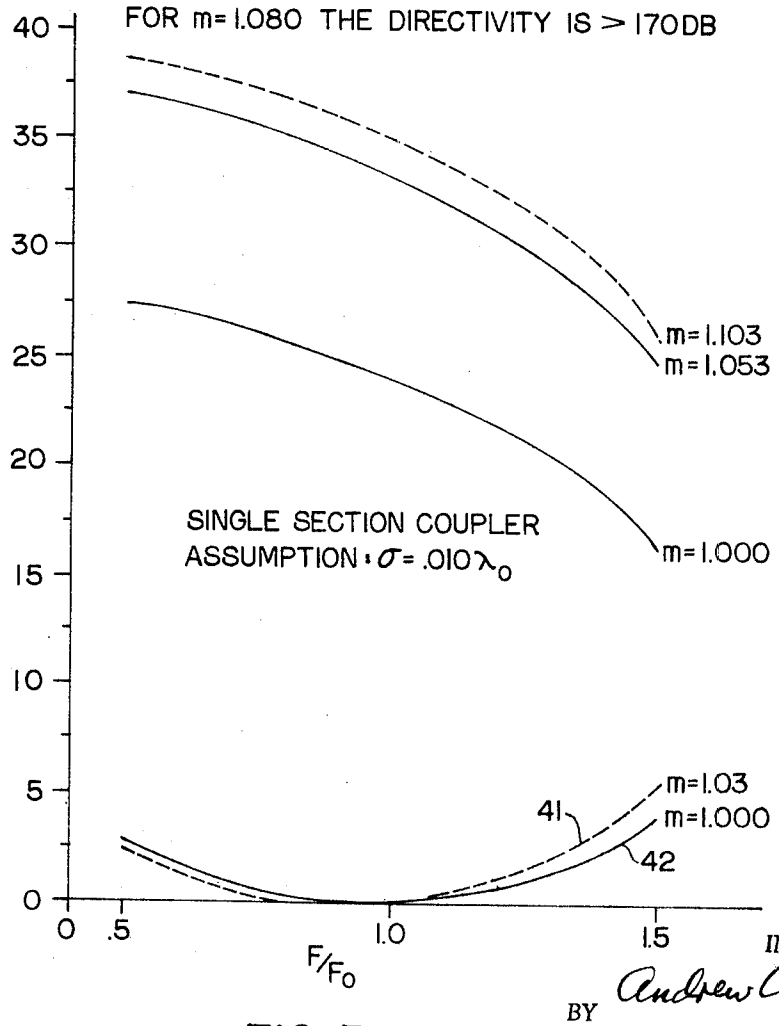


FIG. 3

INVENTOR.
Andrew Alford
BY
Morse, Altman & Oates
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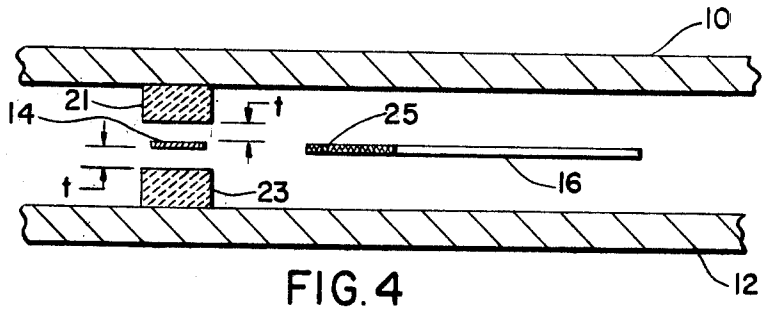


FIG. 4

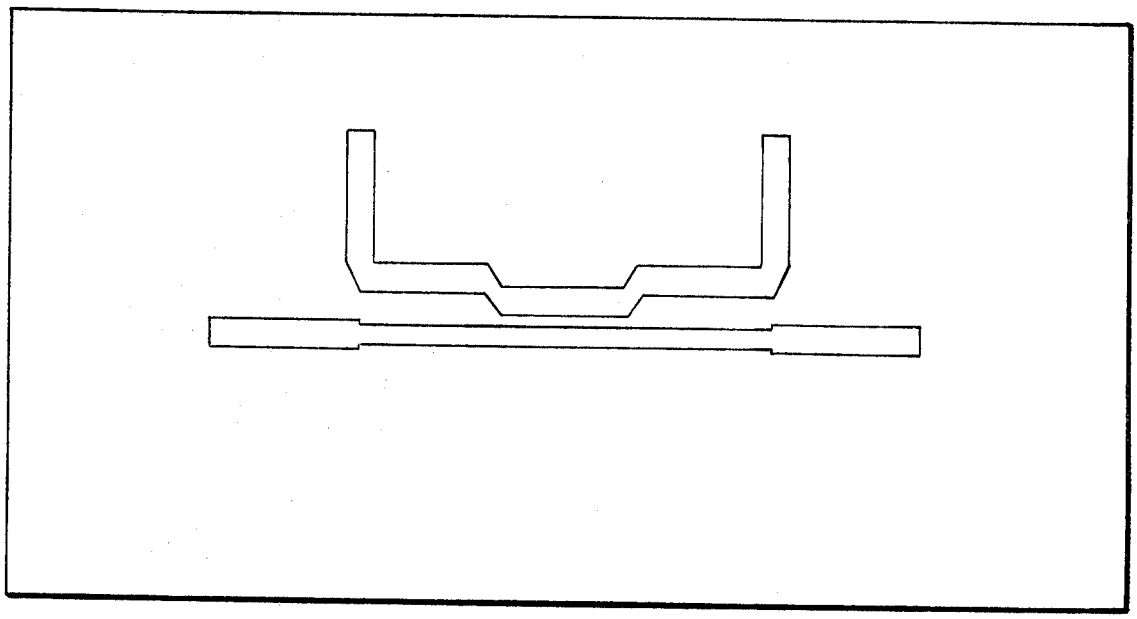


FIG. 5

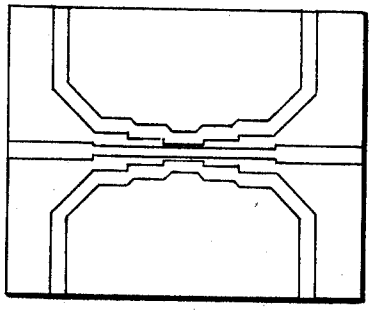
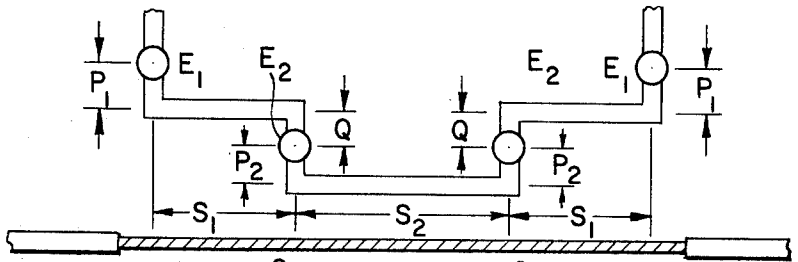


FIG. 6

INVENTOR.
Andrew Alford
BY
Morse, Altman & Oates
ATTORNEYS



$$\theta_1 = \frac{2\pi}{\lambda} S_1 \quad ; \quad \theta_2 = \frac{2\pi}{\lambda} S_2$$

$$\bar{\theta}_1 = \frac{2\pi}{\lambda} S_1 \quad ; \quad \bar{\theta}_2 = \frac{2\pi}{\lambda} S_2$$

$$\delta = \frac{2\pi}{\lambda} Q \quad ; \quad \varphi_1 = \frac{2\pi}{\lambda} P_1 \quad ; \quad \varphi_2 = \frac{2\pi}{\lambda} P_2$$

FIG. 7

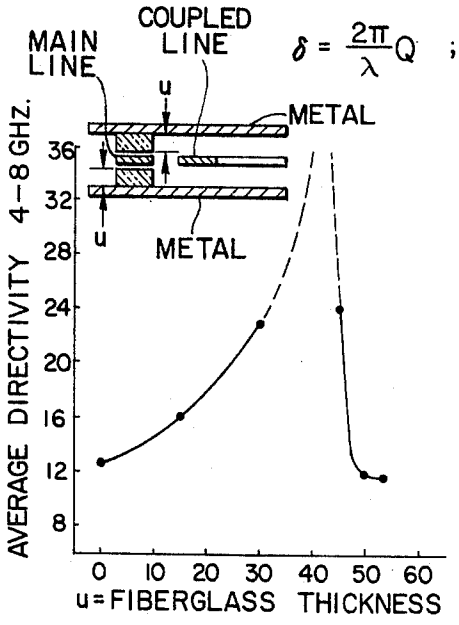


FIG. 7A

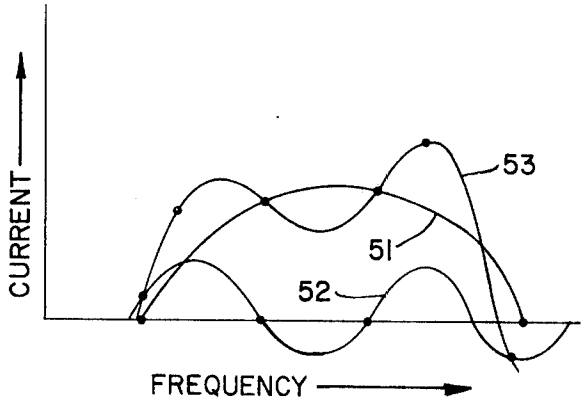


FIG. 8

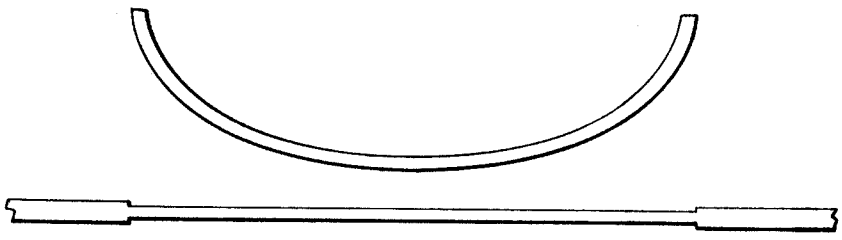


FIG. 9

INVENTOR.
Andrew Alford
BY
Morse, Altman & Oates
ATTORNEYS

DIRECTIONAL COUPLER WHEREIN DIELECTRIC MEDIA SURROUNDING MAIN LINE IS DIFFERENT FROM DIELECTRIC MEDIA SURROUNDING COUPLED LINE

BACKGROUND AND SUMMARY

The present invention relates to transmission line circuits, and more particularly to transmission line coupled circuits. In the transmission line couples circuit, a wave is guided along the main line, for example along a flat conductor in a dielectric medium, which is sandwiched between ground planes. A second "coupled line" usually of the same type is placed in the field of the main conductor. In an ideal directional coupler, the coupled line responds only to a wave traveling in a favored direction on the main line. In actual directional couplers, the coupled line responds to a wave traveling in the backward direction. The ratio of the responses to waves traveling in the two directions on the main line is called directivity of the coupler. For example, a directivity of 20 db. means that the undesired induced wave is 20 db. means that the undesired induced wave is 20 db. weaker than the desired induced wave when equal waves travel in opposite directions on the main line. When a directional coupler is used in wave guide measurements, for example, power monitoring of the wave traveling on the main line in the favored direction, sizable errors are introduced if the coupler also responds to a wave traveling in the backward direction. It is well known in the art that wideband strip-type transmission line directional couplers have low directivity at the higher frequency ends of their frequency ranges.

A primary object of the present invention is to provide, in transmission line coupled circuits, a novel technique of coupling utilizing dielectric media of different dielectric constants, for example, polyolefin, and "microy,"or fiber glass about the main line and the coupled line, whereby higher directivity is obtained.

The invention accordingly comprises the apparatus possessing the construction, combination of elements, and arrangements of parts that are exemplified in the following detailed disclosure, the scope of which will be indicated in the appended claims.

BRIEF DESCRIPTION OF DRAWINGS

For a fuller understanding of the nature and objects of the present invention, reference should be had to the the following detailed description taken in connection with the accompanying drawings wherein:

FIG. 1 is an exploded view of a strip-type transmission line directional coupler embodying the present invention;

FIG. 1A is a schematic diagram of the assembled strip-type transmission line directional coupler of FIG. 1; and

FIGS. 2 to 9 illustrate details and principles of the present invention.

DETAILED DESCRIPTION

Generally, the strip-type transmission line directional coupler of FIG. 1 comprises ground planes **10** and **12** for providing an outer conductor surface, a main line **14** along which a wave is traveling in a particular direction, a coupled line **16** through which a portion of the signal in the main line is coupled, primary dielectric media **18** and **20** having dielectric constant ϵ_1, for controlling the velocity of propogation of the wave in the coupled line **16**, and secondary dielectric media **21** and **23** of dielectric constant $\bar{\epsilon}_2$, for controlling the velocity of propogation of the wave in the main line **14**. In the illustrated directional coupler of FIG. 1, dielectric media **21** and **23** are oriented in juxtaposition with the main line **14** and adjacent to a segment **25** of coupler **16**. It will be understood that in alternative embodiments, the location of dielectric media **21** and **23** is other than in juxtaposition with the main line, for example, in juxtaposition with the segment **25**.

In the device of FIG. 1, a wave is applied at an input **28** of the main line **14** from an external source **26**. The wave is guided along the main line through dielectric mediums **18**, **20**, **21**, and **23**, which are sandwiched between ground planes **10** and **12**. The velocity of propagation of the wave is controlled by the dielectric media in juxtaposition with the main line. For example, the velocity of propagation for the wave in the main line is decreased as the wave is guided past dielectric media **21**, and **23**. As the signal is propagated along the main line, a signal is induced into segments **22** and **24** of coupler **16**. Directivity of the coupler **16** is defined as the ratio of a response to a wave traveling in a favored direction to a response to a wave traveling in a backward direction. By controlling the velocity of propagation of the wave travelling on the main line with respect to the velocity of propagation of the wave traveling on the coupled line, the response to the wave traveling in the favored direction is not greatly changed but the response to the wave traveling in the backward direction is minimized, whereby higher directivity is obtained. In the strip-type transmission coupled circuit of FIG. 1, main line **14** and coupler **16** are flat rectangular conductors. It will be understood in alternative embodiments the main line and coupler are other than flat, for example, circular in cross section.

For a clearer understanding of the present invention, reference is made to FIG. 2. According to FIG. 2, a wave is generated from a source **26** and is applied to the main line **14** at input **28**. As this wave is propagated along the main line to a load **30**, a voltage E is induced in segment **22** and segment **24** of coupler **16**. The induced voltage is represented by virtual generators **32** and **34** in segments **22** and **24**, respectively. The virtual generators **32** and **34** in segments **22** and **24**, respectively. The virtual generators **32** and **34** are located at a distance, denoted by the character **d**, from the segment **25**. The segments **22** and **24** are terminated into load impedances (Z_o) **36** and **38**, respectively. The velocity of propagation of the wave in the main line **14** is controlled by the dielectric media **21** and **23**. The effective dielectric constant of media **21**, **23** is hereinafter denoted by the character ϵ_2. The velocity of propagation of the wave in the coupled line **16** is controlled by the dielectric mediums **18** and **20**, and their dielectric constant is hereinafter denoted by the character ϵ_1.

The equivalent electrical length θ in degrees for the distance S in the coupler **16** is given by the expression

$$\theta=(2\pi/\lambda)S$$

where wave length λ, is given by the expression $\lambda=\lambda o/\sqrt{\epsilon_1}$ where λo =wavelength in vacuum.

The equivalent electric length $\bar{\theta}$ in degrees for the distance S along the main line **14** is given by the expression

$$\bar{\theta}=(2\pi/\bar{\lambda})S$$

where wave length $\bar{\lambda}$, is given by the expression

$$\bar{\lambda}=\frac{\lambda_0}{\sqrt{\epsilon_1}}$$

The equivalent electrical length σ is given by $\sigma=(2\pi/\lambda)d$ for the distance d between the centerline of segments **25** and the equivalent generators in branches **22**,**24** A current i_{32} from virtual generators **32**, which is flowing in segment **24** to the matched load **38**, is given by the expression

$$i_{32}=\frac{E}{Z_0}e^{-j(2\sigma+\theta)}$$

A current i_{34} from virtual generator **34**, which is flowing in segment **24** to the matched load **38**, is given by expression

$$i_{34}=-\frac{E}{Z_0}e^{-\bar{\theta}}$$

The total current i, which is flowing in segments 22 and 24 to load 38, is given by the expression

$$i=i_{32}+i_{34}$$

or

$$i=\frac{E}{Z_0}e^{-(2\sigma+\theta)}-\frac{E}{Z_0}e^{-j\bar{\theta}}$$

The equation for i may be expressed as

$$i=\frac{E}{Z_0}e^{-j(2\sigma+\theta)}[1-e^{-j(\bar{\theta}-\theta-2\sigma)}]$$

This equation may be rewritten as

$$i=2j\frac{E}{Z_0}e^{-\left(\frac{\theta+\bar{\theta}}{2}+\sigma\right)}\cdot\sin\left(\frac{\bar{\theta}-\theta}{2}-\sigma\right)$$

From the above equation it follows that the magnitude of current i, is given by the following equation

$$|i|=2\frac{E}{Z_0}\sin\left(\frac{\bar{\theta}-\theta}{2}-\sigma\right)$$

By a similar analysis one can derive an expression for the magnitude of current i_2 which flows into matched load 36 in Fig. 2. The value of i_2 is given by

$$|i_2|=2\frac{E}{Z_0}\sin\left(\frac{\bar{\theta}+\theta}{2}+\sigma\right)$$

Directivity D of the directional coupler of Fig. 2, is given by the expression

$$D=20\log_{10}\frac{|i_2|}{|i_1|}\text{ decibels}$$

where $|i_1|$ is the current which is flowing in segment **24** to load **36** and $|i_2|$ is the total current which is flowing in segment **22** to load **36**. By minimizing the current i_1, higher directivity is obtained. The current i_1 is minimized as the function

$$\left(\frac{\bar{\theta}-\theta}{2}-\sigma\right)$$

is decreased and $|i_1|$ approaches zero.

Let

$$m=\frac{\sqrt{\epsilon_2}}{\sqrt{\epsilon_1}}$$

then

$$\frac{\bar{\theta}-\theta}{2}=\frac{m-1}{2}\cdot\theta$$

and

$$\frac{\bar{\theta}+\theta}{2}=\frac{m+1}{2}\theta$$

and

$$D=20\log_{10}\frac{\sin\left[\frac{2\pi}{\lambda}\left(\frac{m+1}{2}S+d\right)\right]}{\sin\left[\frac{2\pi}{\lambda}\left(\frac{m+1}{2}S-d\right)\right]}dB$$

From this equation it follows that if the value of m can be chosen so that

$$\left(\frac{m-1}{2}S-d\right)=0$$

the value of D would be infinity. Experimental results have confirmed that by selecting the value of m by selecting dielectric media ϵ_1 and ϵ_2, the current $_1$ can be minimized and thus increased directivity can be obtained. The effect of varying the value of

$$m=\sqrt{\frac{\epsilon_2}{\epsilon_1}}$$

is illustrated in FIG. 3 which shows how the directivity and the coupling are affected by changes in the value of m. In this figure the lower two curves **41** and **42** show the deviation in the value of coupling with frequency from a nominal value such as, for example, 20 db. The coupling deviation curves corresponding to values of m between those shown next to the curves **41**, **42** fall between these curves.

The upper three curves in FIG. 3 show how the directivity over the useful frequency range is affected by the value of m. The fourth curve corresponding to m=1.080 could not be shown on the same paper because the lowest point on the curve is above 170 db.

In practice, as the value of m approaches the critical value such as m=1.080 in FIG. 3, other effects and principally reflections from discontinuities in the circuit of the coupler and the mismatches at the loads begin to control the highest value of the directivity which can be achieved. The effects of discontinuities and load mismatches on the value of directivity may be masked by the phase error which is present in the conventional couplers for which m=1.

When relatively high values of directivity are achieved, in spite of the phase error they are obtained by the introduction of mismatches to cancel out the effect of the phase error. Since such cancellation is usually frequency sensitive, it is increasingly difficult to obtain high values of directivity over a wide band of frequencies.

The critical value of m depends on the value of the coupling and one the geometry of the coupler, because both of these factors control the value of distance d in FIG. 2. The value of d is relatively small when the separation between the main line **14**, **28** and the coupled line **16** is small. The value of d increases as the separation between the coupled line and the main line is increased for a constant value of coupling. The value of d also increases as the distance between the ground plates **10** and **12** in FIG. 1 is increased.

The value of m depends on the effective value ϵ_2 of the dielectric constant $\bar{\epsilon}_2$ of the insert. This useful distinction between the two values of the dielectric constant may be visualized with the aid of FIG. 4 which shows a cross section of the coupler of FIG. 1. This view is in the plane at right angles to plates **10** and **12**, but with the difference that the material of dielectric constant $\bar{\epsilon}_2$ is not inserted all the way up to the metal strip, but only part way so that there is left a thickness t of dielectric material of dielectric constant ϵ_1, between the metal strip conductor of the main line and the insert of dielectric constant $\bar{\epsilon}_2$. This arrangement is not only a simpler one to make but also one which provides a ready method of controlling the effective value ϵ_2 of the dielectric constant. When $\bar{\epsilon}_2>\bar{\epsilon}_1$ the effective dielectric constant ϵ_2 is increased as the thickness t is decreased. The width of line **14** is made narrower where dielectric material of higher dielectric constant is present to correct for a change in the characteristic impedance that would otherwise occur.

When it is desired that the coupling be nearly constant over a very wide frequency range, the secondary line may be made of a number of sections as shown in FIGS. **5** and **6**. The first of these two couplers may be referred to as a three section coupler and the second as a five section coupler. The second coupler is a dual coupler to which the principles described here apply equally well.

The action of a three section coupler may be visualized by using the method described in connection with a single section coupler of FIGS. **1** and **2**. In the case of the three section coupler there are four virtual generators as shown in FIG. **7**. The locations of these four generators are also in the figure. For convenience, all distances shown in this figure are in electrical radians and each of the values therefore varies over the operating frequency range in proportion to the frequency. As in the case of single stage coupler, the directivity of a multistage coupler is increased by slowing down the propagation of waves along the main line as already described in connection with the coupler of FIGS. **1** and **2**. The magnitudes of the currents i_1 and i_2 can be calculated by the method explained above, for a three stage coupler they are found to be given by the following equations:

$$|i_1|=\frac{2E2}{Z_0}\left[\sin\left(\frac{m-1}{2}\theta_2-\varphi_2\right)+\frac{E1}{E2}\sin\left[\frac{m-1}{2}(2\theta_1+\theta_2)-(\varphi_1+\sigma+\varphi_2)\right]\right.$$

$$|i_2|=\frac{2E2}{Z_0}\left[\sin\left(\frac{m+1}{2}\theta_2+\varphi_2\right)+\frac{E1}{E2}\sin\left[\frac{m+1}{2}(2\theta_1+\theta_2)+(\varphi_1+\sigma+\varphi_2)\right]\right.$$

The directivity is, as usual, given by $D=20\log_{10}\frac{|i_2|}{|i_1|}$

It is again found that the value of the directivity D can be made very high by choosing the value of m which makes i_1 as small as possible. It is also found that usually nearly the same value of m makes both terms of i_1 approach zero. Equations

for a five, seven, etc. section couplers can be denied in a similar way. FIG. 7A shows measured effect of adding material of a higher dielectric coustant to a five section coupler.

The value of i_2 can be plotted as a function of frequency as shown in FIG. 8. In this figure curves 51 and 52 correspond respectively to the first and the second terms in the equation for $|i_2|$ $|i_2|$. Curve 51 is a portion of a sine curve. Curve 52 is also a sine curve, but with a period approximately one third of curve 51 when the three sections of the coupler are of approximately the same length. Curve 53 in FIG. 8 is the sum of curves 51 and 52 and is a plot of current i_2 when all three sections of the coupler are of equal lengths, that is, when as indicated. When the value of D is plotted against frequency in decibels as is customary, the minimum in the higher frequency region is deeper than the minimum in the lower frequency region. I found this to be typical behavior of three and five section couplers when the section lengths are equal. This phenomenon is exaggerated when the values of stagger, for example P_1 and (P_2+Q) in FIG. 7 are increased and also when the coupling is loosened. This phenomenon is somewhat changed but not eliminated when the value of m is chosen to obtain maximum directivity. A more uniform coupling is obtained by making the outer sections in a multiple section coupler somewhat shorter than the central section or sections.

It is not necessary that the coupled line consists of a ladder-like structure, on the contrary, it is possible to make a coupler which comprises a straight main line and a gradually curved coupled line as shown in FIG. 9. In this kind of a coupler the two currents i_1 and i_2 and given by the following equations

$$i_2=\int_0^{X_0} e^{-j(s+mx)}\cdot E(y)dy/dx\cdot dx$$

$$i_1=\int_0^{X_0} e^{-js_0}\cdot e^{-j(s-mx)}\cdot E(y)dy/dx\cdot dx$$

As in the case of the step coupler current i_1 can be reduced by slowing down the propagation along the main line. This has the effect of making the electrical length along the main line more nearly equal to the length of the arc measured along the curve at least in those portions of the curve where dy/dx is not close to zero. When the value of S is nearly equal to the value of mx along the important portions of the coupled circuit where the coupling occurs, the second integral is approximately equal to

$$i\approx\int_0^{X_0} e^{-js_0}E(y)dy/dx\cdot dx=F(y)\Big|_{y_1}^{y_2}$$

which is equal to zero providing the coupled circuit is symmetrical about its center. ($y_1=y_2$) In this case, the shape of the curve affects the coupling curve, but not, at least in the first approximation, the value of current i_1 which acts as the denominator in the fraction which determines the directivity D.

In the case when the primary line is not straight, but is curved, the phenomena are more complicated, but it is still worthwhile to slow down the propagation along the main line with respect to the velocity of propagation along the coupled line when the effective radius of curvature of the main line is substantially greater than the effective radius of curvature of the coupled line.

While up to this point I have described the invention in connection with stripline couplers, the principles detailed in this specification may be equally applied to couplers in which the main line as well as the coupled line conductors have other than flat shapes. For example, they may be circular, elliptical or rectangular in cross section, or even of other shapes.

The coupled conductor may also be supported by pins or thin beads in such a way that an effective dielectric around this conductor is of dielectric constant close to unity. To apply the invention in this case we may choose a lower value of dielectric constant for the material used to slow down the propagation along the main line.

The velocity of propagation may also be slowed down by other means, for example, the main line may be made like a slow pass filter having the operating range of the coupler substantially below the cut off frequency of the filter. This can be done without changing the value of the dielectric constant of the supporting material, but instead by incorporating periodic changes in the cross section of the main line conductor.

While it is often convenient to make the space enclosing the primary and secondary lines of the coupler of rectangular cross section, as for example, as shown in FIG. 1, the enclosing rounded conductor may be of other cross sections, for example, a circular tube.

It should be added that the formulas which have been used in this specification are approximate and become more nearly accurate as the coupling is made looser. The measurements, however, have confirmed the validity of the main aspect of the theory, in the case of couplers with uniform degree of coupling. For example, couplers with 20 db. of coupling, or 15 db. of coupling behave substantially in accordance with the theory described above.

Since certain changes may be made in the foregoing disclosure without departing from the scope of the invention herein involved, it is intended that all matter contained in the above description and shown in the accompanying drawings be construed in an illustrative and not in a limiting sense.

What I claim is:

1. A strip-type transmission line coupled circuit device for coupling a wave generated by an external source, said device comprising:
   a. a pair of ground plane means operating as outer conductors;
   b. a pair of first dielectric media means sandwiched between said pair of ground plane means;
   c. main line means for receiving said wave generated by said external source, said wave traveling along said main line means;
   d. coupler line means coplanar with said main line means for coupling a portion of said wave traveling along said main line means, said main line means and coupler line means sandwiched between said pair of first dielectric media means; and
   e. second dielectric media means having a dielectric constant different from that of said first dielectric media means coplanar with each of said first dielectric media means, said second dielectric media means registerable with said main line means proximate to said coupled line means, said second dielectric media means controlling the velocity of propagation of said wave in said main line means, said first dielectric media means controlling the velocity of propagation in said coupled line means.

2. The device of claim, 1 wherein said main line means is a flat rectangular conductor.

3. The device of claim, 1 wherein said main line has a circular cross section.

4. A strip-type transmission line coupled circuit device for coupling a wave generated by an external source, said device comprising:
   a. a pair of ground plane means operating as outer conductors;
   b. a pair of first dielectric media means sandwiched between said pair of ground plane means;
   c. main line means for receiving said wave generated by said external source, said wave traveling along said main line means;
   d. coupler line means coplanar with said main line means for coupling a portion of said wave traveling along said main line means, said main line means and coupler line means sandwiched between said pair of first dielectric media means; and
   e. second dielectric media means having a dielectric constant different from that of said first dielectric media means coplanar with each of said first dielectric media means, said second dielectric media means registerable with said coupled line means proximate to said main line

means said second dielectric media means controlling the velocity of propagation of said wave in said coupled line means, said first dielectric media means controlling the velocity of propagation in said main line means.

5. The device of claim 4, wherein said main line means is a flat rectangular conductor.

6. The device of claim 4, wherein said main line means has a circular cross section.

7. A strip-type transmission line directional coupler device for coupling a wave, said device comprising:

a. input means for receiving said wave from an external source;

b. main line means for guiding said wave traveling in a particular direction on said main line means;

c. directional coupler means coplanar with said main line means, said coupler means having a plurality of sections, each said section coupling a portion of said wave traveling in said particular direction on said main line means;

d. primary dielectric media means registerable with said main line means for controlling the velocity of propagation of said wave traveling on said main line means; and

e. secondary dielectric media means having a dielectric constant different from that of said first dielectric media means registerable with said directional coupler means for controlling the velocity of propagation of said wave coupled in said sections;

f. ground plane means for providing an outer conductor surface for said transmission line.