Jan. 19, 1965 M. J. BOCK ET AL 3,166,723

VARIABLE DIRECTIONAL COUPLER HAVING A MOVABLE ARTICULATED CONDUCTOR

Filed March 6, 1961 2 Sheets-Sheet 1

Fig. 1

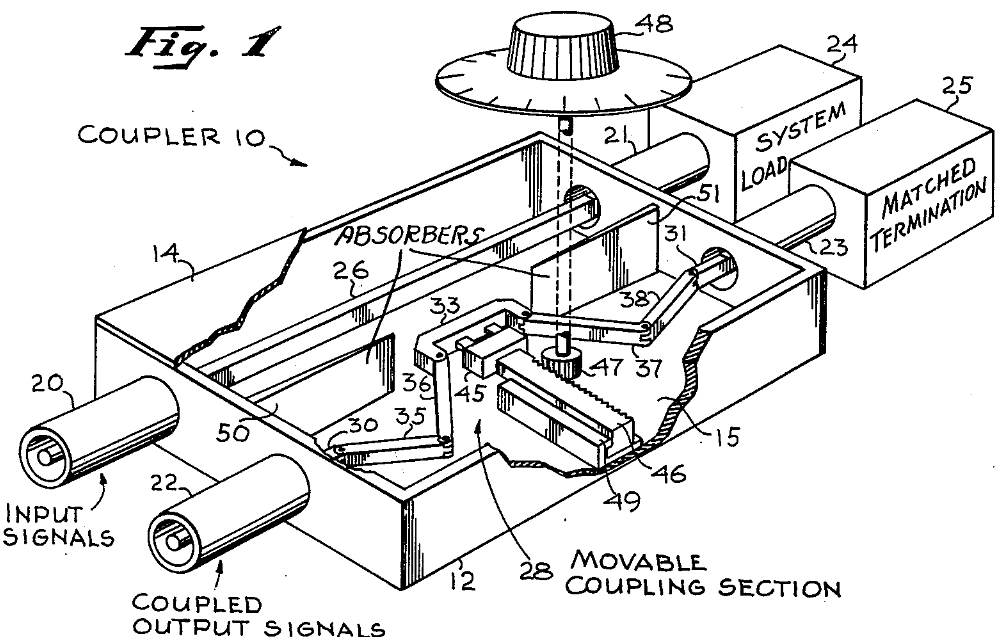

Fig. 2

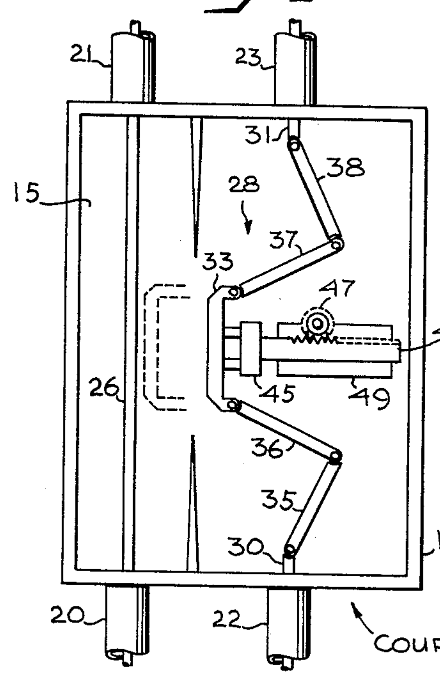

Fig. 3

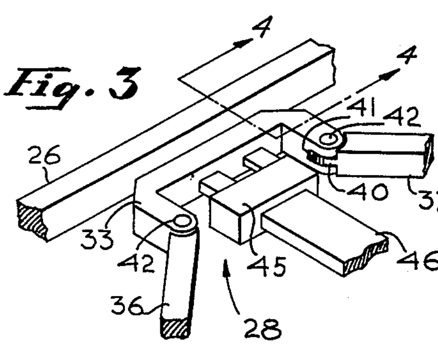

Fig. 4

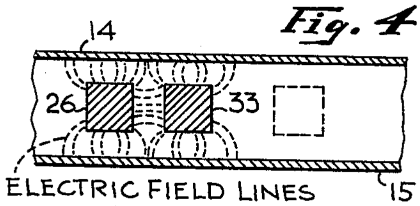

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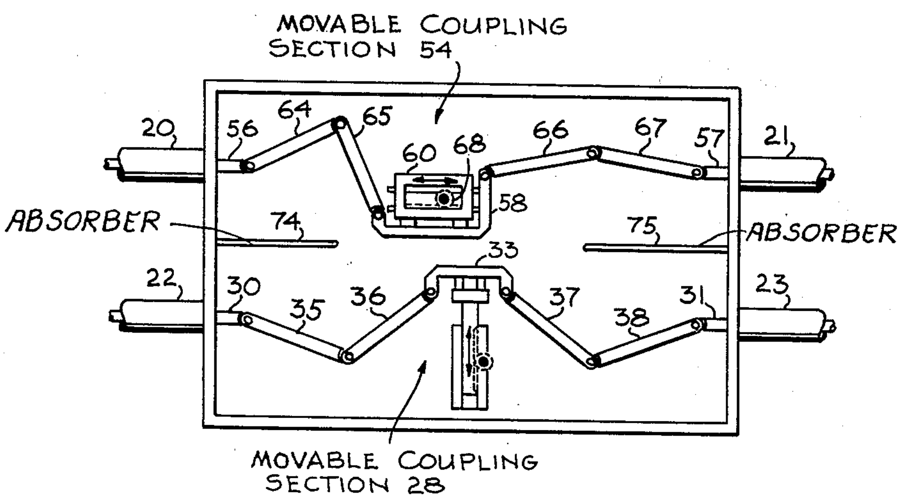
Fig. 5



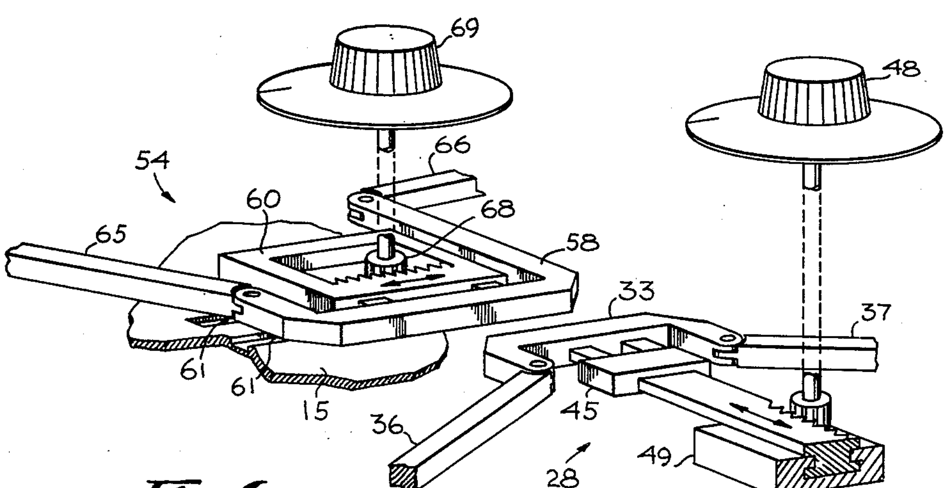


Fig. 6

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United States Patent Office 3,166,723 Patented Jan. 19, 1965

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VARIABLE DIRECTIONAL COUPLER HAVING A MOVABLE ARTICULATED CONDUCTOR

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Filed Mar. 6, 1961, Ser. No. 93,590
3 Claims. (Cl. 333—10)

This invention relates to devices for controlling the transmission of waves at microwave frequencies, and more particularly to devices for providing a mechanically variable coupling, attenuation, and amplitude control for microwave systems.

Couplers, attenuators, modulators and the like are basic components in microwave systems. Often a number of different functions may be performed by a single device, so that a coupler, for example, might be able to serve additionally as an attenuator or modulator. This may be better understood by reference to the senses in which the terms "coupling," "attenuation" and "modulation" are usually employed. The term "coupling" is used to indicate the transfer of a predetermined or selected amount of microwave energy from one conductor to another. The term "attenuation" is used to indicate the controlled dissipation of a selected amount of microwave energy which is propagated along a conductor. Where the attenuation is varied with time in some predetermined fashion, this may of course constitute an amplitude modulation. It is therefore evident that certain kinds of couplers may also operate as attenuators, and if they operate variably with time in addition serve the function of modulators.

A mechanically operable coupler which can perform all these functions is widely sought for microwave systems. Such devices have not heretofore been provided because of a number of difficulties which have been encountered in getting satisfactory electrical and mechanical performance. Many fixed couplers are known, but those which have wide band performance are usually not susceptible of conversion to a variable operation. Variable couplers have usually had limited band width, and particularly have been subject to troublesome non-linearities in operation. The non-linearities have required complicated mechanical motions in order to achieve accurate coupling settings, which in turn have greatly increased costs, limited accuracy and made reproducibility extremely difficult.

A microwave variable coupler of suitably small size and low cost which can be coupled into standard guide wave systems therefore may serve a wide variety of purposes. The versatility of such a device would be greatly increased if the device could operate bi-directionally, which is to say that different terminals might be utilized for input or output signals depending upon the requirements of the associated system. If the device could operate with accuracy over a wide frequency range, it would fulfill a basic function found in many different places in communications and ranging systems, instrumentation systems and testing equipment widely used at microwave frequencies.

It is therefore an object of the present invention to provide an improved microwave variable coupler.

A further object of the present invention is to provide an improved variable coupler which is precisely adjustable but which is simple and economical to construct.

Yet another object of the present invention is to provide an improved wave coupling device for microwave applications, which device may serve as a variable coupler, attenuator or modulator.

Another object of the present invention is to provide an improved mechanically variable microwave coupler which operates bidirectionally.

In accordance with the invention, variable wave coupling between two conductors is provided by transverse movement of one conductor section relative to another and the employment of an articulated conductive connection between the movable section and terminal points.

In a specific example of a mechanically variable coupler section in accordance with the invention, the coupler is arranged as a four-port slab transmission line device. A principal center conductor section is fixedly coupled between two of the ports, while the remaining two ports are coupled by an articulated center conductor section including a centrally located coupling element. The coupling element is transversely movable relative to the principal center conductor by a linear motion mechanism, and may occupy different positions in a wave coupling region. The relative transverse spacing between the center conductors in the coupling region exercises an extremely precise control over the amount of coupling. Further, incident waves may be propagated on either the principal center conductor or the articulated center conductor, so that the device is fully bidirectional. The entire coupler is extremely compact, simply constructed although linearly variable with changes of the control element, and fully compatible with coaxial and other guided wave systems. With the addition of an attenuator device at a selected terminal, waves variably coupled to the selected terminal may be dissipated so that the device functions as a variable attenuator. Further, the mechanical positioning of the coupler section may be varied with time so as to provide amplitude modulation.

Another aspect of the present invention is the provision of means by which the frequency response of the coupler may be varied as desired. In such arrangements, the coupling lengths of the center conductors are made not only transversely movable relative to each other, but are also longitudinally variable. Through the longitudinal variation, the length along the center conductors by which coupling is effected may be changed to be optimum for any given frequency. Accordingly, the already inherently wide band characteristics which the device provides may be extended to any useful range which is desired.

The novel features of the invention may be better understood by reference to the following description, taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a perspective view, partly broken away, of one form of guided wave coupler in accordance with the present invention;

FIG. 2 is a plan view of the arrangement of FIG. 1;

FIG. 3 is an enlarged perspective view of a fragment of the arrangement of FIG. 1;

FIG. 4 is a sectional view of the fragment of FIG. 3, taken along the line 4—4 in FIG. 3 and looking in the direction of the appended arrows;

FIG. 5 is a plan view, partly broken away, of a wide band variable coupler in accordance with the present invention, and

FIG. 6 is a perspective view of a fragment of the wide band variable coupler of FIG. 5.

A bidirectional variable coupler **10** (FIGS. 1–3) according to the invention employs slab transmission line construction for transmitting waves at microwave frequencies. Slab transmission line is a widely used guided wave device. Because it is essentially an open-sided coaxial line, it is often used in conjunction with coaxial line systems and related systems, such as strip transmission line units. A specific example is provided, by way of illustration, of a coupler covering a two to one frequency range and operating at a nominal frequency of

6 kilomegacycles (hereinafter kmc.) in the range 4 to 8 kmc. The main body of the coupler 10 is provided by a frame 12 of generally rectangular construction, the principal electrical elements which are used being a top plate 14 and a bottom plate 15, these plates serving as the ground plane conductors for the slab transmission lines. The remainder of the frame 12 may be completed by appropriate side and end elements which may or may not be conductors as desired, although conductive elements tend to reduce external radiation to a low magnitude and are preferred.

First to fourth terminal conductors 20–23 are coupled to the frame 12 for providing input signals to, and deriving output signals from, the various arms in the coupler 10. Any conventional form of connector may be employed for the terminal conductors 20–23, but type N connectors are particularly suitable. These are coaxial transmission line sections which are at least partially filled with dielectric material between their center conductors and their outer conductors. For smooth coupling of waves from the slab lines to the coaxial lines, and vice versa it is preferred to utilize an air transition section in those parts of the terminal conductors 20–23 which are directly joined to the associated center conductor of the slab lines. The various input and output terminals in FIG. 1 have been labeled for convenience with different input and output designations, but these are merely illustrative of different ways in which couplings may be effected. In this example, the first terminal conductor 20 is directly coupled to a system load 24 through the second terminal conductor 21. The coupled output signals are derived at the third terminal conductor 22, and may be applied to an associated system or matched termination (not shown) depending upon the use intended for the coupler 10. The fourth terminal conductor 23 is here unused, and is properly terminated in a matched termination 25.

The coupler 10 includes a fixed or principal length of slab line center conductor 26 coupled between the center conductors of the oppositely disposed first and second terminal conductors 20 and 21. A movable coupling section 28 forms a slab line center conductor which connects the center conductors of the third and fourth terminal conductors 22 and 23. At each end of the movable section 28, a fixed length of slab line center conductor 30, 31 is attached to the adjacent terminal conductor 22, 23, respectively. In the approximate center of the movable coupling section 28, the slab center conductor is in the form of a generally U-shaped coupling element 33 whose principal length is parallel to the fixed center conductor 26. The volume between the ground plane conductors 14, 15 which encompasses the associated lengths of the fixed and movable center conductors 26, 33 may be termed a wave coupling region. The free ends and the corners of the U-shaped coupling element 33 are designed in accordance with well known slab line construction techniques to minimize sharp transitions and impedance changes. Each end of the central coupling element is connected both electrically and mechanically to the closest fixed end 30 or 31 of the movable coupling section by a different pair of articulated arms 35, 36 or 37, 38, respectively, having the cross-sectional configuration chosen for the slab line center conductor.

The articulated construction of the paired arms 35, 36 and 37, 38 is achieved by a tongue and groove arrangement, as shown in best detail in the enlarged fragment of FIG. 3. A tongue 40 extending from one of the arms 37, for example, mates slidably in a matching groove 41 in the facing end of the coupling element 33. A pivot pin 42 extending through the coupling element 33 registers with an appropriate aperture in the tongue 40 and permits a pivotal movement of the arm 37 relative to the coupling element 33. The end surfaces of the various abutting sections are appropriately curved in mating fashion so that there is no binding between the arm sections. The relative pivotal motion which is permitted between various arms is restricted to a plane which is parallel to the plane of the ground plane conductors 14, 15. The two pairs of articulated arms 35, 36 and 37, 38 are generally similar, so that the base leg of the U-shaped central coupling element 33 may be maintained parallel to the fixed center conductor 26 despite transverse movement.

With this arrangement, the central coupling element 33 is moved transversely with respect to the length of the fixed center conductor 26, by a suitable mechanism which may be controlled externally to the frame 12. In the form shown by way of example, the central coupling element 33 is fixed to a dielectric insulator 45 which provides mechanical support but which insulates the center conductor sections from the remainder of the assembly. A rack member 46 is also coupled to the dielectric insulator 45, and extends between the ground plane conductors 14, 15 in a direction normal to the length of the fixed center conductor 26. Teeth in the rack member 46 are engaged by the teeth of a pinion 47, which is rotatably mounted in the top ground plane conductor 14. A control knob 48 mounted outside the frame 12 may be used to adjust the position of the rack member 46 through rotation of the pinion 47.

Several mechanical alternatives which may be employed have been omitted in order to simplify and clarify the drawings, inasmuch as these may assume a wide number of forms and are not essential to the operation of couplers in accordance with the invention. They may, however, be briefly discussed. In order to position the central coupling element 33 where desired, appropriate indicia (not shown) may be included on the top ground plane conductor 14 adjacent the control knob 48. For vernier control, a step-down gearing or coupling may be used for precise minute adjustment of the transverse position of the central coupling element 33. A setscrew or other lock arrangement may also be employed for retaining the movable elements in position, once a position has been selected. For firm support of the fixed center conductor 26 or the movable coupling section 28, dielectric elements having a low dielectric constant may be employed between the various center conductors and the ground planes. The central coupling element 33 and the articulated arms 35–38 of the movable coupling section 28 are slidably mounted on a support element 49 shaped to conform to the rack member 46 and affixed to either or both of the ground plane conductors 14, 15.

Resistive elements 50, 51 or other microwave energy absorbing elements are mounted between the top and bottom ground plane conductors 14, 15 in the areas between the fixed center conductor and the different articulated arm pairs 35, 36 and 37, 38, respectively.

In the operation of the arrangement of FIGS. 1–3 as a variable coupler, the transverse displacement of the central coupling element 33 from the fixed center conductor 26 in the wave coupling region determines the amount of coupling from a selected input terminal to a selected output terminal. Taking the first terminal conductor 20 as the source of input signals, a very close spacing between the central coupling element 33 and the fixed center conductor 26 would at the most cause a substantially equal split of the waves (3 db of coupling) between the second terminal conductor 21 and the third terminal conductor 22. The distribution of the electric fields in the coupling region with the center conductors 26 and 33 very closely juxtaposed would result in substantially like electric fields being associated with each of the center conductors 26 and 33. In this case, half the microwave energy would be transmitted directly to the system load 24 at the second terminal conductor 21, and half would be coupled onto the movable coupling section 28. The waves coupled onto the central coupling element 33 are reversed from the original direction, but again would constitute half of the total input energy. Thus, assuming maximum coupling, the coupled output signals would appear at the third terminal conductor 22 and the device would be a 3 db coupler.

In the majority of instances in which a variable coupler is used, 3 db of coupling is not sought. The above illustration is merely given to demonstrate the manner in which coupling is achieved.

A significant feature of devices provided in accordance with the present invention is that the transverse displacement of the central coupling element 33 from the fixed center conductor 26 determines the amount of coupling with a high degree of linearity. Thus, if the central coupling element 33 is moved further away from a selected spatial relationship to the fixed center conductor 26, the percentage of coupling is proportionately reduced. This direct relation between displacement and percentage of coupling which is a logarithmic factor is extremely useful, because percentage of coupling is the parameter which is controlled in system use.

FIG. 4 shows alternative transverse displacement positions of the central coupling element 33 of the movable coupling section 28 relative to the fixed center conductor 26. Dotted lines between the center conductors 26, 33 and the top and bottom plates 14, 15 represent electric field distributions in the slab transmission lines. With the present arrangement, there is a linear relationship between the percentage of coupling and the displacement of the center conductors 26, 33. As the movable coupling element 33 is moved transversely away from the fixed center conductor 26, the extent of coupling onto the movable coupling element 33 diminishes. This diminution is at a rate of approximately 1 db of coupling for 0.010 inch of displacement, in a typical practical device. For this same practical example, an accuracy of ±1 db is maintained between 5 and 70 db over a two to one frequency range. Thus the percentage of coupling, though a logarithmic variable, is achieved very simply by a linearly varying drive and indicated with commensurate ease by equally spaced indicia about the control knob 48 or other control element.

Another important feature of these devices is their bidirectional operation. If input signals are applied at the second terminal conductor 21, for example, there is direct transmission to the first terminal conductor 20, and coupled transmission to the fourth terminal conductor 23. The operation is therefore precisely as previously described except for the changes in the terminals at which the output signals appear. Through use of this capability the versatility of coupler systems is greatly enhanced. It will also be noted that any or all of the terminal conductors 20–23 may be shifted in the plane of the ground plane conductors by appropriate bends in the center conductors. Thus, two terminal conductors may extend normal to the others to accommodate particular system requirements.

In accordance with conventional fixed and variable coupler operations, in which the bidirectional properties are employed, waves may be propagated from any adjacent pair of terminal conductors 20, 22 or 21, 23 in a selected phase relation so as to be combined at a selected terminal conductor and cancelled at the other terminal conductor.

A surprising result which is achieved by arrangements in accordance with the invention is derived from the fact that the coupling, propagation and reflection are substantially unaffected by the use of articulated arms in the manner indicated. In effect, waves propagated between the first and second terminal conductors 20, 21 without coupling off involve substantially the same performance figures as for transmission of waves between the third and fourth terminal conductors 22, 23. There is therefore substantially no dependence of VSWR on either the direction in which waves are coupled, or on the relative transverse displacement between the central coupling element 33 and the fixed center conductor 26.

The resistive elements 50, 51 or other energy absorbers in the spaces between the fixed center conductor 26 and the articulated arms 35–38 also contribute materially to the linearity of the device. These cards 50, 51 suppress, by dissipation, higher order modes which might be set up along the slab transmission lines.

Devices in accordance with the invention may be used as attenuators without internal modification. The difference between the variable coupler and the variable attenuator results only from the external connections to the device, because with both applications selected proportions of energy are provided to a utilization device. In the attenuator, energy which is not coupled off is dissipated in a matched termination, whereas in the coupler, as shown in FIG. 1, this energy is the output signal. With an attenuator device, therefore, input signals might be applied to the first terminal conductor 20 while coupled wave output signals are derived at the third terminal conductor 22 and the second terminal conductor 21 is connected to a matched termination (not shown). The output signal may be referenced to either the input signal or the percentage of attenuation. In the coupler, the corresponding coupled wave will usually be referenced to the input signal.

The variable coupler which also has a variable frequency band is shown in FIGS. 5 and 6. There is a general correspondence between the elements of FIG. 5 and those of FIGS. 1–3, in that an articulated slab line construction is used to couple between four terminal conductors 20–23. As in the view of FIG. 2, the plan view of FIG. 5 is shown with the top ground plane conductor removed. Various sources, utilization devices and matched loads have been indicated but not shown in detail. It is assumed that input signals are provided to a third terminal conductor 22 which is coupled by a slab transmission line section having fixed ends 30, 31, and an intermediate transversely movable coupling section 28 to a fourth terminal conductor 23. The fourth terminal conductor 23 is connected to a system load. This portion of the arrangement corresponds essentially to the like numbered elements in the arrangement of FIG. 1.

A control knob 48 (FIG. 6) turns a pinion 47 which controls the position of the transversely movable coupling section 28.

A second movable coupling section 54 couples fixed center conductors 56, 57 which are connected directly to the first and second terminal conductors 20, 21. The second movable coupling section 54 includes an L-shaped central coupling element 58 having one leg which is maintained parallel to the principal length of the transversely movable coupling element 33. A dielectric support member 60 including a toothed rack surface includes extending arms having tongues 61 (FIG. 6) configured to register in grooves in the bottom ground plane conductor 15, or in a support member. The grooves confine the L-shaped coupling element 58 to longitudinal movement. That is, the leg of the L-shaped coupling element 58 which directly opposes the principal length of the transversely movable coupling element 28, and which is parallel thereto, moves along only its longitudinal axis. The arm and support mechanism which is shown is merely one expedient which may be used.

Pairs of articulated arms 64, 65 and 66, 67 having the cross-sectional configuration of the slab line center conductor couple each of the fixed center conductor segments 56, 57, respectively, to a different end of the L-shaped coupling element 58. The longitudinal position of the L-shaped coupling element 58 is controlled by a pinion 68 which registers with the teeth provided in the dielectric support member 60. The pinion 68 is directly connected to an external control knob 69 by which frequency range is selected. Resistive elements 74, 75 or other microwave absorbing elements positioned between the top and bottom plates 14, 15 and each extending into the region between the opposed articulated arm sections dissipate higher order modes propagated within the coupler section.

The arrangement shown in FIGS. 5 and 6 is adjustable so as to provide variable coupling or attenuation over an extremely wide range of frequencies. When used as a variable coupler, with input signals coupled into third terminal conductor **22**, output signals appear at the directly connected fourth terminal conductor **23** and, in a selected proportion, at the wave coupled to the first terminal conductor **20**. A matched resistive load or other termination coupled to the remaining second terminal conductor **21**, together with the presence of resistive elements **74, 75** permits operation with high efficiency. As before, the percentage of coupling is controlled by the transverse displacement between the U-shaped coupling element **33** and the parallel leg of the L-shaped coupling element **58**. For different frequency ranges, however, the relative longitudinal position of these two coupling elements **33, 58** may be adjusted so that the parallel lengths of the coupling elements **33, 58** are coextensive over a quarter wavelength of the waves at the central operating frequency. If it is desired to shift the variable coupler from the 2000–4000 mc. band to the 4000–8000 mc. band, for example, the coextensive length of the two coupling elements **33, 58** need only be adjusted to be a quarter wavelength at 6000 mc. instead of at 3000 mc.

The percentage of coupling between the two coupling sections is affected by the relative longitudinal positions of the coupling elements **33, 58**, only where frequency sensitivity becomes an important factor because of improper setting of the frequency control knob **69**. With the frequency control knob **69** initially set to a selected frequency, the length of exposed coupling loop is a quarter wavelength at the operating frequency. Given this proper prior adjustment, a given transverse displacement, as determined by the control knob **48**, provides a substantially constant percentage of coupling for all frequencies of interest. Both fabrication and adjustment are materially simplified thereby.

While a number of alternative elements and relationships have been pointed out in the foregoing discussion, it will be appreciated by those skilled in the art that other modifications and variations may be made. Accordingly, the invention should be considered to include all modifications and alternative forms falling within the scope of the appended claims.

We claim:

1. A variable microwave coupler including first and second spaced apart ground plane conductors, first, second, third and fourth coaxial terminal conductors positioned about the spaced apart ground plane conductors, a first fixed center conductor positioned between the ground plane conductors and connected to each of the first and second terminal conductors to provide a first slab transmission line electrically coupling the first and second terminal conductors, a second center conductor positioned between the ground plane conductors and providing a selected coupling length which is substantially one-quarter wavelength at the operating wavelength of waves propagated along the first slab transmission line, first and second articulated center conductor means, the first articulated center conductor means being coupled from the third terminal conductor to the adjacent end of the second center conductor and the second articulated center conductor means being coupled from the fourth terminal conductor to the adjacent end of the second center conductor, the first articulated center conductor means, the second center conductor and the second articulated center conductor means providing a second slab transmission line between the third and fourth terminal conductors, means coupled to the second center conductor for moving the second center conductor transversely relative to the first while maintaining the coupling length parallel to the length of the first center conductor, thus to provide variable coupling of waves between the first and second wave transmission lines, microwave energy absorbing means disposed between the first and second slab transmission lines between the first and second ground plane conductors for the suppression of higher order modes excited by waves propagated along the slab transmission lines.

2. The invention as set forth in claim 1 above, wherein the means for moving the second center conductor includes dielectric support means coupled to the second center conductor, a rack and pinion drive coupled to the dielectric support means, and a control member containing indicia which denote the relative percentage of coupling between the first and second slab transmission lines as determined by the relative transverse displacement of the first and second center conductors.

3. A variable, adjustable frequency, coupler for microwave applications including a pair of spaced apart ground plane conductors, a first center conductor coupling element positioned between the ground plane conductors and forming a portion of a first wave transmission line therewith, the first coupling element extending along a selected axis, means coupled to the first coupling element for selectively moving the first coupling element parallel to the selected axis, a second center conductor coupling element positioned between the ground plane conductors parallel to said first coupling element and providing a portion of a second wave transmission line therewith, said second coupling element being juxtaposed with respect to said first coupling element for a predetermined distance the magnitude of which is determined by the longitudinal position of the movable said first coupling element, means coupled to the second coupling element for moving the second coupling element relative to the first coupling element in a direction normal to the selected axis, means coupled to the first coupling element and completing a wave transmission line between first and second terminals of said coupler, and means coupled to the second coupling element and forming a wave transmission line between third and fourth terminals of said coupler.

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