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3,295,073

FREQUENCY DISCRIMINATING CIRCULATOR

Filed Dec. 24, 1964

2 Sheets-Sheet 1

FIG. 1

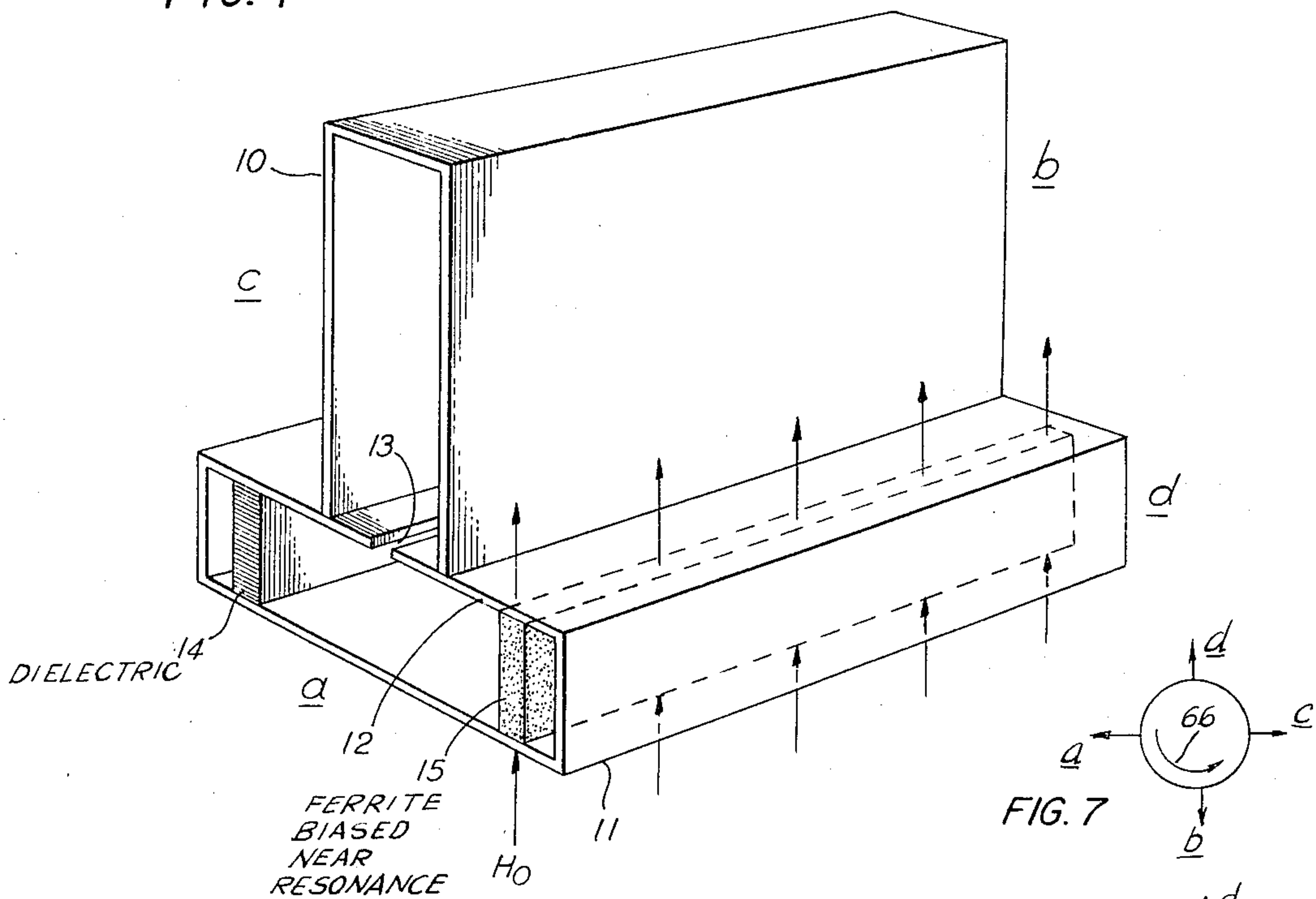


FIG. 2

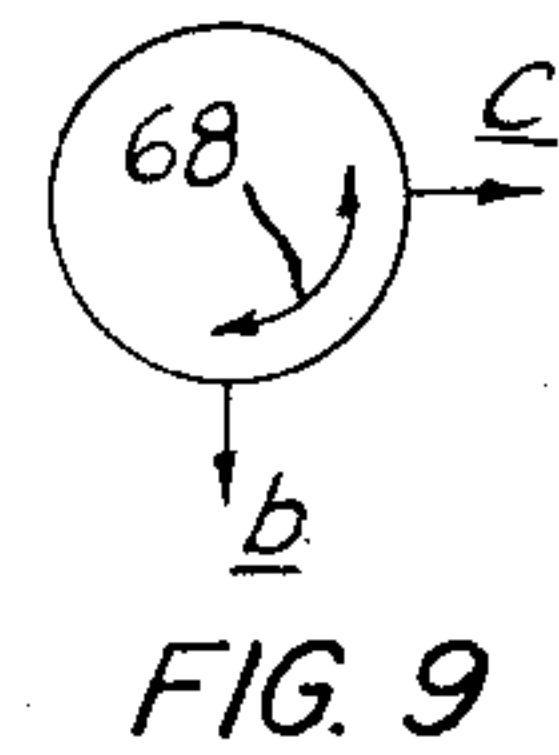
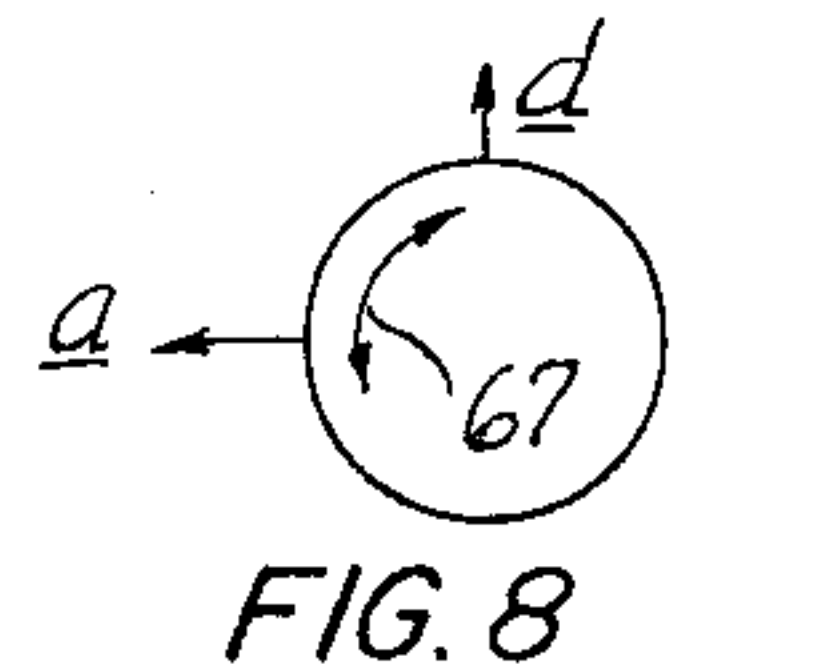
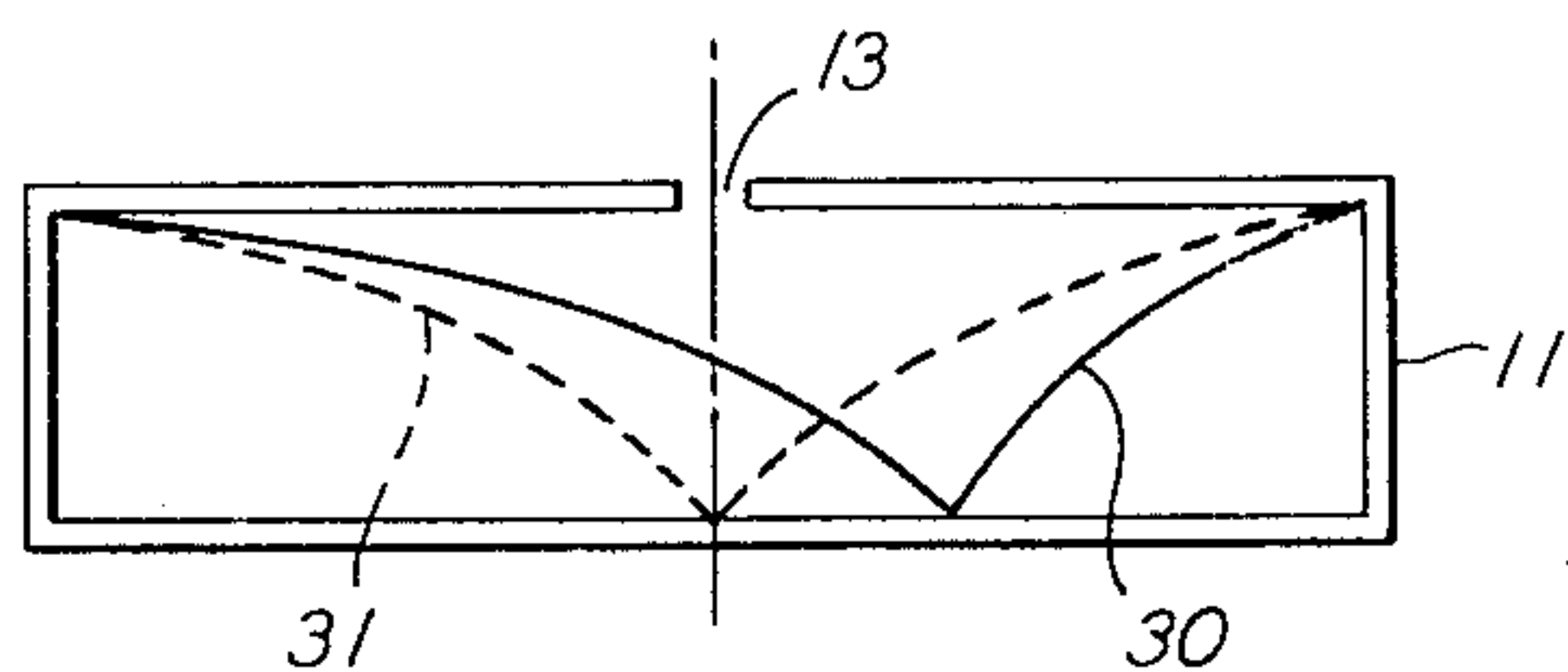
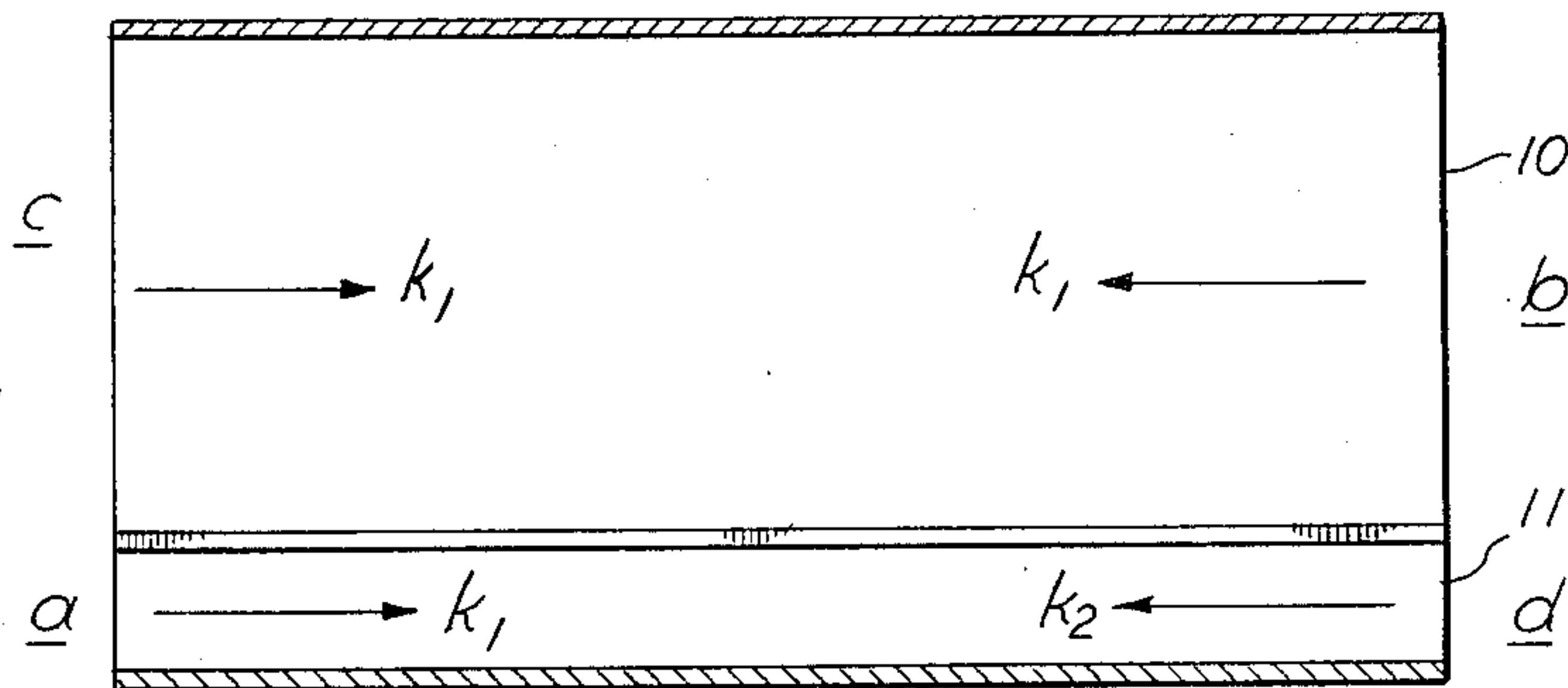


FIG. 3



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FIG. 4

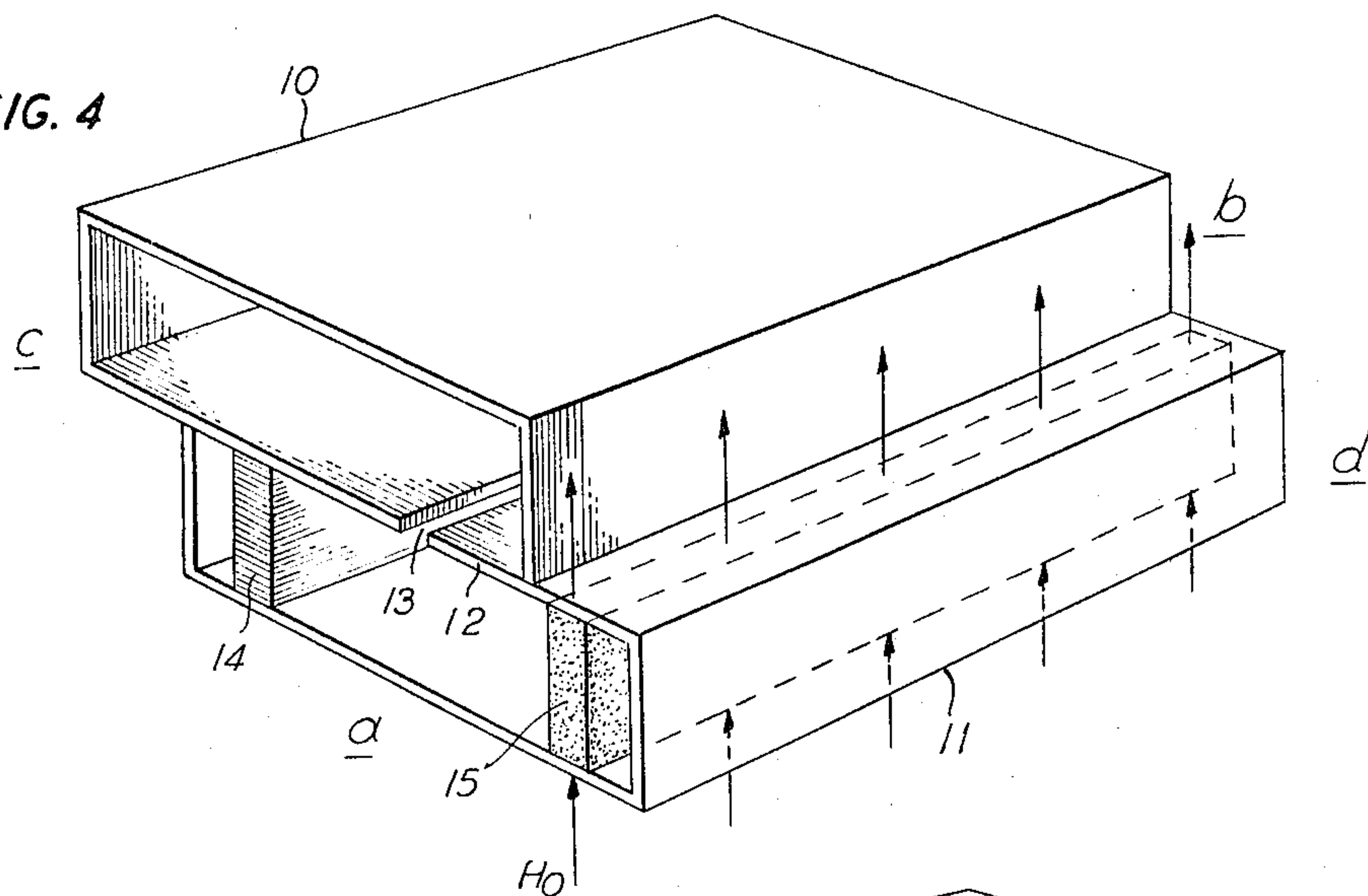


FIG. 6

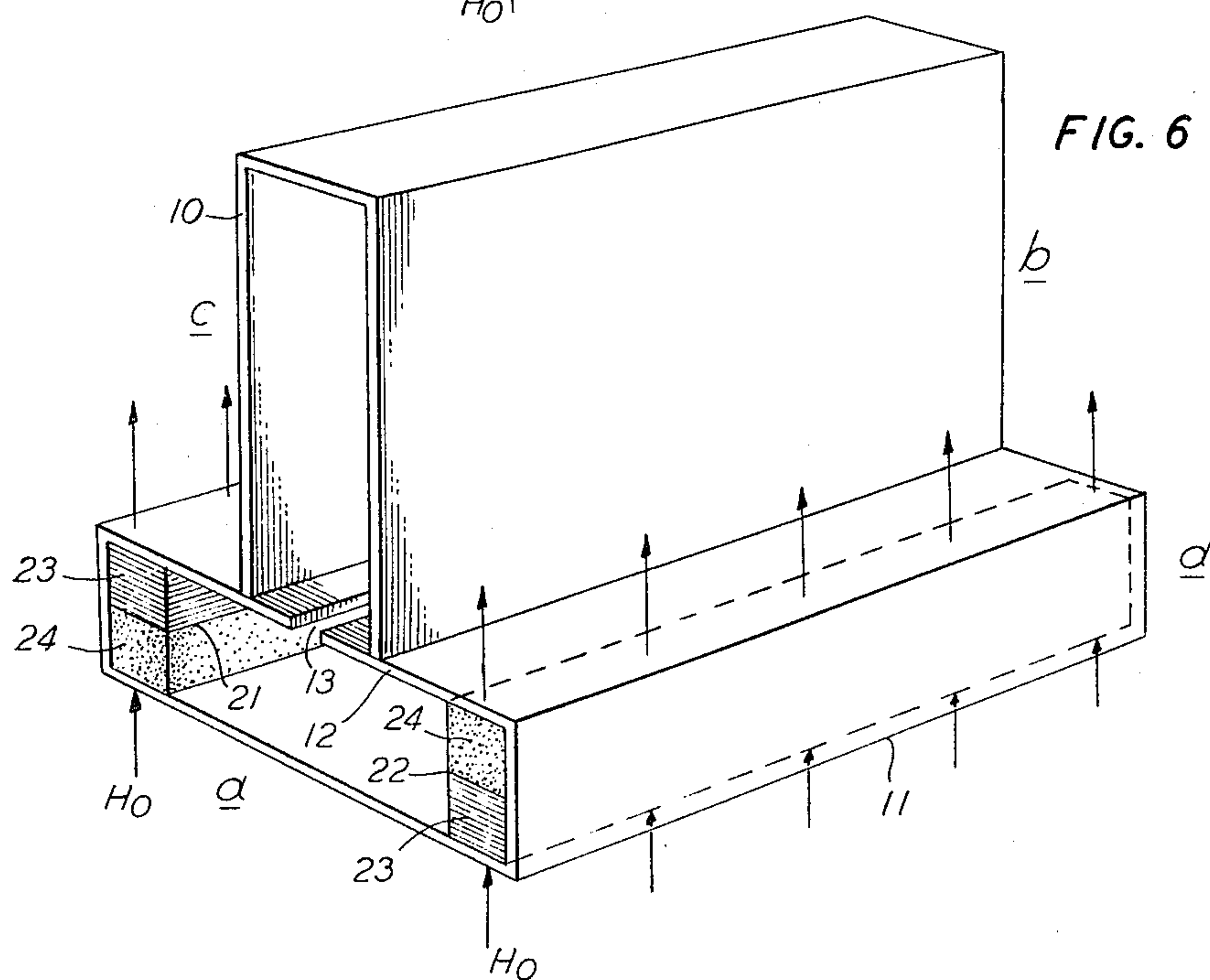
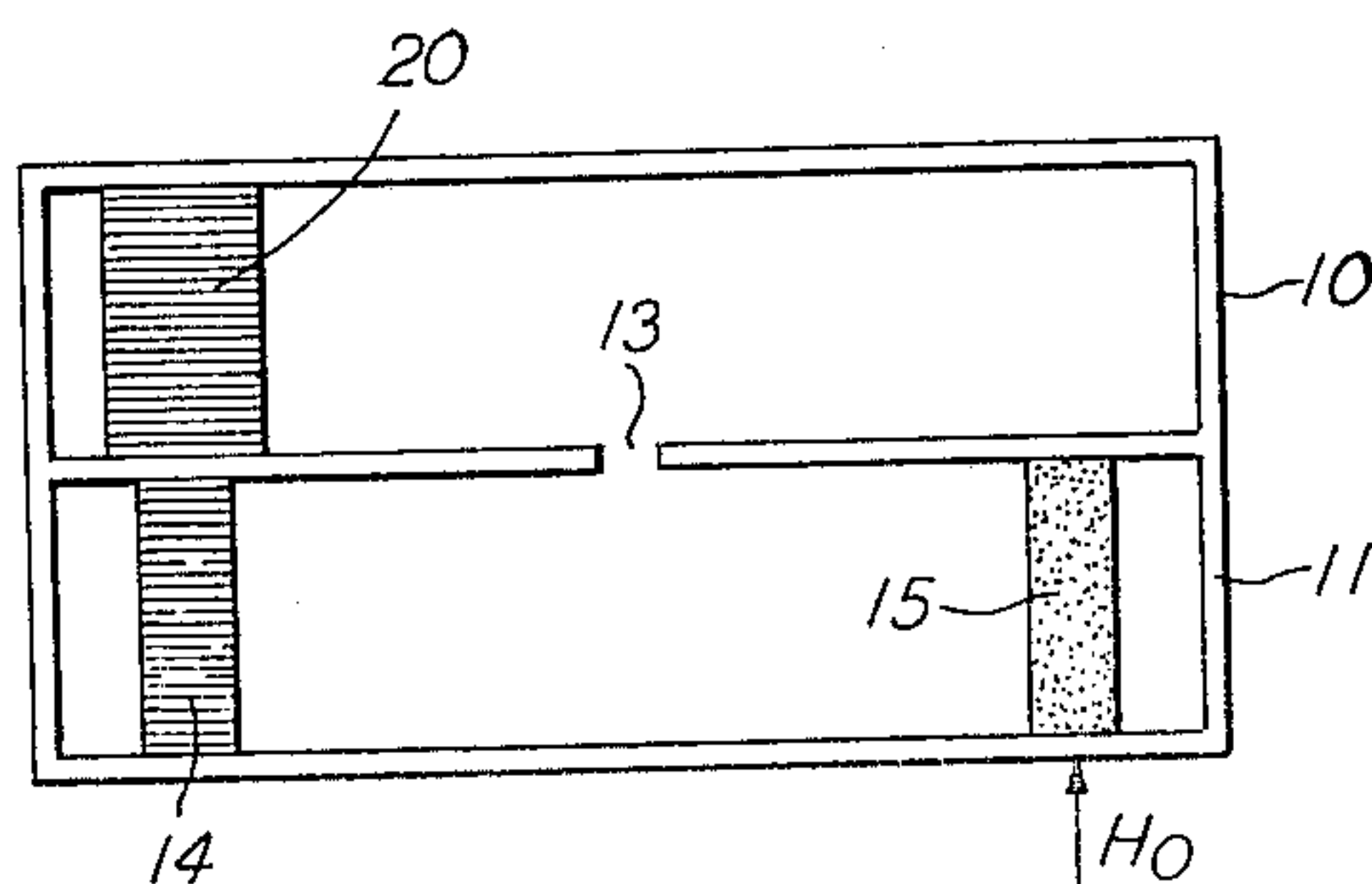


FIG. 5



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FREQUENCY DISCRIMINATING CIRCULATOR
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20 Claims. (Cl. 333-1.1)

This invention pertains to nonreciprocal transmission devices and more particularly to multibranch circuits such as circulators exhibiting frequency discrimination characteristics.

Circulators are nonreciprocal microwave devices which have a number of ports to which are connected separate information carrying transmission channels. Energy from a particular channel introduced into one port will emerge substantially unchanged at a second port for retransmission along a second information channel. Similarly, energy appearing at a second port will emerge only at a third port so that there is in effect a commutation of power from one transmission terminal to another.

Amongst the numerous applications found for circulators are those which require that the transmitted signal be substantially free of harmonic distortions. For example, in high performance waveguide repeaters it has been recognized that the presence of harmonics as well as other product frequencies well removed from the signal band have caused undesirable loading of modulators and oscillators. This undesirable loading by spurious signals results in inefficient operation and where the situation warrants, filters have of necessity been included to separate the unwanted signals from the information carrying signals.

Accordingly, it is an object of the present invention to improve and simplify a nonreciprocal electrical connection between a plurality of branches of a multibranch network.

It is another object of the present invention to provide a microwave circulator having frequency discrimination characteristics.

In accordance with the objects of this invention a bounded transmission structure such as a hollow waveguide is provided with longitudinally extending slabs of dielectric including at least one slab of gyromagnetic material biased near ferromagnetic resonance at frequencies corresponding to the signal band. The slabs are positioned to provide for a nonreciprocal alteration of the magnetic field symmetry at signal frequencies while preserving, for frequencies substantially different from the signal, the symmetry relative to the fixed point. Some means for coupling exclusively to the longitudinal component of propagating magnetic field, such as a narrow slot, is longitudinally placed at the fixed point and a second bounded transmission structure, having reciprocal transmission properties and propagation constants compatible with the first transmission structure, is located relative to the coupling means so that a region of non-zero longitudinal component of magnetic field exists within the second structure adjacent to the coupling means.

As a consequence of this arrangement, the mode of circulation exists only for the information band signals by virtue of their capability to pass through the coupling means to terminals situated in different waveguides while higher frequencies such as harmonics are transmitted in a normal reciprocal fashion between terminals of the waveguide in which they are introduced.

Accordingly, a principal feature of this invention is the provision of a means for nonreciprocally and asymmetrically distorting the signal frequency magnetic field while reciprocally preserving the symmetry of higher frequency

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magnetic fields about a coupling means within a bounded transmission structure.

These and other objects and features of this invention will be better understood upon a consideration of the following detailed description of the invention as presented hereinbelow in connection with the accompanying drawing in which:

FIG. 1 is a perspective view of the first principal embodiment of the invention showing two coupled waveguides one of which has included therein a field displacement medium of polarized gyromagnetic material;

FIG. 2 given by way of illustration shows the magnetic field configuration of a dominant mode wave in a rectangular waveguide;

FIG. 3 is a simplified longitudinal cross-sectional view of the embodiment of the invention shown in FIG. 1 and is used as an aid in the explanation thereof;

FIG. 4 is a perspective view of another embodiment of the invention;

FIG. 5 is a cross-sectional view of an embodiment of the invention which is a modification of the embodiment in FIG. 4;

FIG. 6 is a perspective view of still another principal embodiment of the present invention;

FIG. 7 is a schematic representation of the circulator coupling characteristics at the signal frequency for each of the embodiments shown; and

FIGS. 8 and 9 are schematic representations of the circulator coupling characteristic at harmonic frequencies for each of the embodiments shown.

Referring more specifically to FIG. 1, a nonreciprocal four-branch microwave network, or four-branch circulator circuit, is shown as an illustrative embodiment of the present invention. The network comprises a first section 10 of bounded electrical transmission line which may be a rectangular waveguide of the metallic shielded type having a wide internal cross-sectional dimension of at least one half the wavelength of wave energy to be conducted therethrough and a narrow dimension substantially one half the wide dimension. Located adjacent to line 10 and running contiguous and parallel thereto is a second section of transmission line 11 dimensioned in a manner similar to transmission line 10. A narrow wall of line 10 is placed with its center line coextensive with the center line of the broad wall of line 11 so that a portion of wall 12 is shared in common by both lines. A narrow longitudinal slot 13 is placed in the common portion of wall 12 and is dimensioned so that the width of the slot is small enough to prevent the coupling of transverse magnetic fields (e.g., fields existing in planes parallel to wall 12 having a direction perpendicular to the longitudinal dimension of the slot). A dielectric slab 14 and a slab of gyromagnetic material 15 are longitudinally placed in line 11 to be symmetrically disposed on either side of slot 13. The dimensions, the permeability and the dielectric constant of each of the slabs and the positioning of each slab with respect to the slot is chosen so that the magnetic field pattern within line 11 is distorted at a given frequency or band of frequencies but preserved at higher frequencies such as harmonics. In the illustrative embodiment of FIG. 1 these alterations of the magnetic fields are accomplished by symmetrically placing slabs 14 and 15 on either side of slot 13, by dimensioning each of the slabs to be substantially identical and by selecting the material of each slab to provide substantially identical dielectric constants. Furthermore, lines 10 and 11 are constructed to provide compatible phase constants as will be discussed hereinbelow.

At this point it is appropriate to note that in order for there to be a coupling of energy from one transmission medium into another, no one of the following three con-

ditions may be violated. In the first instance there must exist at the coupling means energy capable of being radiated; this condition is satisfied in the present invention when the transmitting medium supplies at slot 13 a non-zero longitudinal component of magnetic field. Secondly, there must exist at the coupling means a medium capable of receiving any energy radiated; this condition is met by locating the receiving transmission structure so that the slot is positioned in a region where the longitudinal component of a propagated wave within the receiving structure is nonzero. Finally, the phase constant of the receiving medium for the desired direction of propagation therein must be substantially identical with the phase constant of the transmitting medium. With these principles in mind the explanation of the operation of the invention may proceed.

The magnetic field distortions desired are obtained by means of the nonreciprocal properties of gyromagnetic slab 15. If, for example, slab 15 is composed of material comprising iron oxide with a small quantity of one or more bivalent materials such as nickel, magnesium, zinc, manganese or other similar material in which the other materials combine with the iron oxide in a spinel structure and these materials are then molded with a small percentage of plastic material such as Teflon or polystyrene, the resulting substance is a gyromagnetic material known as ferromagnetic spinel or ferrite. As a specific example, slab 15 may be made of nickel-zinc ferrite prepared in the manner described by C. L. Hogan in his Patent No. 2,748,353, issued May 29, 1956. The interaction of a polarized gyromagnetic material such as ferrite with a circularly polarized magnetic field is well known and much employed in nonreciprocal microwave devices and as described in an article written by A. G. Fox, S. E. Miller, and M. T. Weiss in Bell System Technical Journal, volume 34, pages 5-103. It has been shown that the permeability of ferrite for a given strength of polarizing magnetic field applied perpendicularly to the plane of polarization of a circularly polarized propagating magnetic field is a bivalued function which depends upon the sense of rotation of the circularly polarized wave. In addition, it must be noted that the permeability of the ferrite approaches unity as the frequency of the circularly polarized wave gets further away from the ferromagnetic resonant frequency. The magnetic and electrical properties described have been derived from the mathematical analysis of D. Polder and explained in Philosophic Magazine, January 1949, volume 40, pages 99 through 115.

The ports of the four branches of the circulator shown in FIG. 1 have been labeled so that the forward and backward ends of guide 11 are labeled terminals *a* and *d*, respectively. Schematically represented is an external magnetic field applied perpendicular to the broad wall 12 of line 11 and through the ferrite slab 15 as shown by the arrows labeled H_0 . This field may be produced by an electromagnet having pole faces contiguous to each of the broad walls of line 11 at the location of slab 15. It is, of course, known that the high frequency magnetic field of a dominant mode wave in a rectangular waveguide can be represented by a number of concentric loops which are in planes parallel to the broad walls of the guide. At any selected position along the length of slab 15 the propagating magnetic field pattern appears as a circularly polarized wave having a first direction of rotation for energy transmitted from terminal *a* towards terminal *d* and an opposite direction of rotation for energy traveling for terminal *d* towards terminal *a*. Consequently, if the ferrite slab 15 is biased near ferromagnetic resonance by means of field H_0 , the permeability of slab 15 for waves traveling from terminal *a* towards terminal *d* is substantially higher than the corresponding permeability for waves traveling in the opposite direction. The nonreciprocal effect due to the gyromagnetic properties of slab 15 and more particularly the effect of the bivalued per-

meability of slab 15 is best illustrated by reference to FIG. 2 which is a cross-sectional view of line 11 shown with the slabs 14 and 15 omitted. For a wave traveling in the forward direction in line 11, that is from terminal *a* to terminal *d* away from the viewer, a high permeability is presented to wave components on the right side of the guide by virtue of the fact that the slab is biased near ferromagnetic resonance. On the other hand for energy propagated in the backward direction from terminal *d* to terminal *a*, or towards the viewer, the permeability of slab 15 is smaller and close to unity. As a result of these effects the magnetic field pattern for energy traveling in the forward direction is distorted so that the lines of magnetic field are concentrated in the region of high permeability or the right side of line 11. The solid curve 30 in FIG. 2 represents a plot of the absolute value of the longitudinal component of magnetic field intensity of energy propagated in guide 11 from terminal *a* towards terminal *d*. The zero of longitudinal field intensity is shifted from the center of the guide to the right or towards the region of high permeability so that at the center line of the guide the longitudinal component of magnetic field is a nonzero value. On the other hand, magnetic wave energy traveling towards the viewer suffers relatively little field distortion since no such concentration of magnetic field is experienced by virtue of the fact that slab 15 has for this direction of travel a permeability which is closer to that of slab 14. Furthermore, while it is not necessary for the operation of this invention, it is possible to adjust the combined effect of slab dimensions, relative slab location and the respective magnetic parameters of the slabs to produce for waves traveling in the backward direction in line 11 a symmetrical field distribution about center line 13 through the cross-sectional area to obtain a distribution (as illustrated by dotted curve 31) having a zero of longitudinal field component at the center line. In any event, and despite any difference from unity of the permeability of slab 15 for energy propagating from terminal *d* towards terminal *a*, the phase constant *k* is different for each direction of travel since it is a function of the product of $\mu\epsilon$, the permeability and dielectric constant, respectively.

Thus, as shown in FIG. 3 the phase velocity in guide 11 for energy traveling from terminal *a* to terminal *d* is represented by k_1 while the corresponding phase velocity for energy traveling in the opposite direction is designated by k_2 . At frequencies substantially different from the information band of frequencies as, for example, the harmonic frequencies, the effects of the gyromagnetic properties of slab 15 are vitiated so that slab 15 appears as a nonmagnetic dielectric having permeability substantially identical with that of slab 14. Consequently, for harmonic frequencies the plot of the absolute value of longitudinal magnetic field intensity for the wave propagating in either direction in line 11 can be represented by dotted curve 31. This wave is symmetrical about the zero point at center line 13 and rises uniformly to a maximum at each of the side walls.

By utilizing the nonreciprocal properties of ferrite slab 15, the magnetic symmetry in line 11 is altered so that at signal frequencies the zero value of the longitudinal component of magnetic field is shifted away from the center line for the forward direction of travel while the magnetic symmetry is restored for harmonic frequency magnetic waves propagating in either direction. As a consequence of this the first recited criterion for energy transfer exists in the form of nonzero values of the longitudinal component of magnetic field at slot 13 for signal frequency energy propagated from terminal *a* towards terminal *d*. For this direction of energy transmission the slot 13 acts as a directional coupler and can be made, in accordance with principles well known in the art, to effect a complete energy transfer from line 11 to line 10 which, as shown in FIG. 3, is designed to provide phase constants which are substantially equal to k_1 . The second criterion

for energy transfer is present by virtue of the fact that slot 13 is positioned longitudinally along the side wall of line 10, as shown in FIG. 1, where the value of the longitudinal component of any magnetic field propagating therein is a nonzero value. (In fact it is a maximum at this point.) Finally, the third criterion required for circulator action is satisfied by virtue of the fact that the phase constant in line 10 is (reciprocally) chosen to be equal to k_1 , the phase constant in line 11 for transmission in the forward direction. Therefore, and in accordance with the principles of directional couplers, the energy which began its travel from terminal *a* towards terminal *d* in line 11 is transferred into line 10 and continues its travel towards terminal *b*.

Should energy be applied to terminal *b* of guide 10, it will remain in guide 10 and emerge at terminal *c*. No energy will be transferred from line 10 to line 11 because of the failure of either or both of two of the three criteria discussed. In the first instance with reference to FIG. 3 the phase constant for transmission in guide 10 from terminal *b* towards terminal *c* is k_1 —different from the phase constant k_2 for travel in the same direction in the lower guide 11. Secondly, transmission from line 10 through slot 13 into line 11 is further hindered by the fact that the magnetic field pattern just below slot 13 in line 11 may be fashioned to have a zero longitudinal component as previously discussed and as illustrated by dotted curve 31 in FIG. 2.

Should energy now be applied to terminal *c* of guide 11, substantially all of it will be coupled through slot 13 to terminal *d* because of the satisfaction of the required three criteria and the directional coupler action of the slot. That is, there is a capacity to radiate by virtue of the fact that there exists a maximum of the longitudinal component of transmitted magnetic field in line 10 opposite slot 13; there exists a capacity in line 11 to accept radiated energy as shown by curve 30 of FIG. 2; and finally, the phase constants for this (forward) direction of travel in lines 10 and 11 are identical and equal to k_1 .

Finally, energy entering terminal *d* remains in line 11 and emerges at terminal *a* because of two factors already discussed—namely, the fact that phase constant k_2 in line 11 for travel in the backward direction is different from the phase constant k_1 for the same direction of travel in line 10 and the fact that, as illustrated by dotted curve 31 in FIG. 2, the longitudinal component of magnetic field is approximately zero in guide 11 at the location of slot 13.

Thus, the device shown in FIG. 1 functions to commutate signal frequency power from one terminal to the next in an orderly sequence. That is, energy entering terminal *a* emerges at terminal *b*, energy entering terminal *b* emerges at terminal *c*, energy entering terminal *c* emerges at terminal *d* and energy entering terminal *d* will emerge at terminal *a*. The same is not true, however, for frequencies very much different from the signal frequency. Since the ferrite slab 15 was biased to be near gyromagnetic resonance for signal frequencies, substantially higher frequencies such as harmonics for all practical purposes do not experience the nonreciprocal effects of change in permeability discussed above. That is, the higher frequency dielectric slab 15 loses its magnetic properties and acts as a nonmagnetic dielectric similar to dielectric slab 14 with a permeability which approximates unity. Because of the manner in which the dielectric constants of slabs 14 and 15 have been chosen, the dimensions of each of the slabs and their relative positions with respect to slot 13, line 11 appears as a reciprocal and symmetrical transmission medium with a zero of the longitudinal component of magnetic field existing at the center as shown in curve 31 of FIG. 2. The first of the three criteria necessary for energy transfer fails because of the zero of the longitudinal component of magnetic field in line 11 at slot 13 thereby rendering impossible the coupling of energy between lines 10 and 11 in either direction through the

slot. Consequently, at higher frequencies each line acts as an isolated transmission medium transmitting energy reciprocally between its respective terminals. Thus, energy at harmonic frequencies entering terminal *a* in line 11 emerges at terminal *d* and energy entering terminal *d* emerges at terminal *a*. Similarly, harmonic frequency energy entering terminal *c* of line 10 emerges at terminal *b* and energy entering terminal *b* emerges from terminal *c*.

Another principal embodiment of the invention is illustrated in FIG. 4. This arrangement is a modification of the embodiment which is shown in FIG. 1 obtained by altering the orientation of line 10 with respect to line 11. The structural arrangement and mode of operation of line 11 remains the same as described with FIG. 1, but now line 10 is positioned so that instead of a narrow wall being parallel to and contiguous to the broad wall 12 of line 11, a broad wall of line 10 is placed adjacent to the broad wall 12 of line 11. In addition, line 10 is placed so that the longitudinal center line of its broad wall is offset from slot 13 which lines along the longitudinal center line of the broad wall of line 11 so that the slot is located in a region of nonzero longitudinal component of magnetic field in line 10. As discussed above, the longitudinal component of magnetic field in a rectangular waveguide increases from a zero at the center of the guide to a maximum at each of the side walls.

By positioning line 10 with respect to line 11 in the manner described and assuming all other magnetic field distortions and phase constants to be the same as that described in connection with FIG. 1, the device illustrated in FIG. 4 exhibits a circulatory mode for signal frequencies by constraining the energy transfer to be from the respective terminals *a* to *b*, *b* to *c*, *c* to *d*, and *d* to *a*. Magnetic field energy entering terminal *a* suffers the distortion described above in connection with the device of FIG. 1 because of the polarization of ferromagnetic slab 15. Consequently, the magnitude of the longitudinal component of magnetic field is as shown in curve 30, FIG. 2 with a nonzero value at slot 13. Since the value of the longitudinal component of a magnetic field propagating in line 10 is also a nonzero quantity because of the asymmetrical placement of slot 13 with respect to line 10, the energy from terminal *a* is completely coupled into line 10 to emerge at terminal *b*.

Energy entering terminal *b*, however, emerges at terminal *c* for the same reasons that it would do so in the device of FIG. 1—phase constant k_1 for travel in the backward direction in line 10 being different from phase constant k_2 for the same direction of travel in line 11 and/or a zero of longitudinal component of magnetic field at slot 13 in guide 11 for magnetic fields propagating in the backward direction. Similarly, energy entering terminal *c* emerges at terminal *d* and energy entering terminal *d* emerges at terminal *a* for the same reasons discussed above in connection with the device of FIG. 1.

Another embodiment of the invention is illustrated in FIG. 5 wherein the device of FIG. 4 is modified by positioning line 10 directly over line 11 with the common slot 13 being placed along the center line of the broad wall of each line. The structural composition of line 11 remains the same but now dielectric slab 20 is asymmetrically placed in line 10 to provide reciprocal asymmetrical magnetic field patterns due to the alteration of the permeability of the transmission medium therein. It will be recognized by those versed in the art that the inclusion of dielectric slab 20 in line 10 acts to concentrate the magnetic field pattern so that the natural zero of longitudinal component of magnetic fields within the waveguide is shifted from a plane perpendicularly bisecting the broad walls to a parallel plane closer to slab 20. The placement of slab 20 as shown acts to produce a nonzero value of longitudinal component of magnetic field at slot 13 to produce magnetically the exact equivalent of the structure shown in FIG. 4. As a result, the structure

of FIG. 5 operates exactly as described for the structure shown in FIG. 4.

In another embodiment of the invention as shown in FIG. 6 the orientation of lines 10 and 11 is similar to that of FIG. 1, but now longitudinally placed slabs 21 and 22 are included in line 11. Slabs 21 and 22 are constructed so that one portion of their height consists of dielectric material 23 and the remaining portion of their height consists of ferrite material 24. The slabs are placed in line 11 so that the ferrite bulk of each is positioned in diagonally opposite corners of line 11. Thus, the ferrite material of slab 21 is positioned in the lower left-hand corner while the ferrite bulk of slab 22 is placed in the upper right-hand corner of line 11. An external magnetic field H_0 is applied as shown through each of the slabs with the same direction of polarization. The combined effect of dimensioning the slabs alike and positioning them symmetrically about slot 13 located along the center line of the broad wall 12 of line 11, positioning line 10 so that its side wall is placed longitudinally over slot 13 and by properly dimensioning each of the lines 10 and 11, is the satisfaction of all of the required three criteria for the coupling of energy from one line to the other. It is important to note that in this embodiment of the invention circulator action is independent of any requirement of differing phase constants for each direction of propagation in line 11. That is, the devices shown in FIGS. 1, 4 and 5 had in line 11 unequal phase constants k_1 and k_2 for forward and backward direction of energy propagation respectively and partially depended on this difference for the existence of circulatory mode characteristics. This partial dependence existed in the sense that circulator action could be insured without considering this difference only if, with all other things remaining the same, the longitudinal component of backward propagating signal frequency magnetic field could be accurately represented by curve 31 of FIG. 2. No such requirement exists in the embodiment shown in FIG. 6. Indeed, the phase constants for forward and backward energy propagation in line 11 are identical to each other and substantially identical with the corresponding parameters for line 10. The device of FIG. 6 functions as a circulator, therefore, not by virtue of a judicious arrangement of phase constants but rather because of magnetic field alterations in line 11 somewhat similar in nature to those already discussed.

The effect of the gyromagnetic nonreciprocal properties of the polarized ferrite portion 24 of slabs 21 and 22 is to concentrate the magnetic field, as seen by a viewer looking in the forward direction of propagation, in the northeast quadrant of line 11 (i.e., where the ferrite element 24 in slab 22 is located) for transmission from terminal a towards terminal d and to concentrate the magnetic field in the southwest quadrant of line 11 (i.e., where the ferrite element 24 in slab 21 is located) for transmission in the direction from d to a . Consequently, for energy introduced at terminal a there exists nonzero values of the longitudinal component of magnetic field at slot 13 for coupling therethrough and transmission to terminal b . Energy entering terminal b , however, cannot be coupled through slot 13 since there exists substantially zero longitudinal magnetic field components for the backward direction of transmission in guide 11 by virtue of the concentration of magnetic field in the southwest quadrant thereof. In other words, the second criterion enumerated above, or the ability to accept radiated energy, fails for this situation and the energy continues along line 10 to emerge at terminal c . Energy entering terminal c emerges at terminal d because of the nonzero values of longitudinal magnetic field components for transmission in the forward direction in line 11 and by virtue of the directional coupler action of slot 13. In other words, the energy from terminal c is transferred to terminal d because of the existence of all of the required conditions for energy transfer through the coupling means. Finally,

energy entering terminal d emerges at terminal a because of the magnetic field concentration effected by ferrite 24 in slab 21 as discussed previously.

Since harmonic frequencies are substantially different in value from the ferromagnetic resonance value and the frequency of the signal, reciprocal symmetrical transmission is restored to line 11 by virtue of the fact that the ferrite material 24 in slabs 21 and 22 no longer behaves as magnetic material with the above-described property of bivalued permeability. Therefore, the ferrite portions 24 behave as an ordinary dielectric having parameters which are substantially identical with those of the dielectric portions 23 of slabs 21 and 22 and there is no concentration of magnetic field to shift the zero of longitudinal magnetic field component from the region of slot 13 for either direction of propagation. Consequently, harmonic energy entering either terminal of line 11 emerges at the other terminal. The same confinement is of course true with respect to the energy introduced into either terminal of line 10.

The properties of the devices described may be utilized in one significant manner to construct a device which functions as a circulator for signal frequencies and as an isolator for harmonic frequencies. If two of the four ports are terminated in matched loads, energy which is substantially free of harmonics can be arranged to be transmitted from a particular one of the two remaining terminals to the other. Illustratively, it may be assumed that terminals c and d are terminated with characteristic impedance value terminations and the device (as it is disclosed in any of the embodiments shown) is biased by the external magnetic field H_0 so that the circulatory mode is a, b, c, d, a . Energy entering terminal a consisting of signal and harmonic frequencies will be acted upon so that only signal frequencies emerge from terminal b , while harmonic frequencies are absorbed in the matched load at terminal d . On the other hand, energy of all frequencies which is introduced at terminal b travels to terminal c at which point it is absorbed so that nothing emerges at terminal a .

FIG. 7 is a schematic representation of the circulator coupling characteristic of each of the embodiments at signal frequency. Arrow 66 indicates the direction of coupling of electrical energy from one port of the device to another as explained above. FIGS. 8 and 9 are schematic representations of the coupling characteristic of the embodiments shown at harmonic frequencies. Illustratively, arrow 67 in FIG. 8 indicates that harmonic frequency energy in waveguide 11 is reciprocally coupled between ports a and d . Similarly, arrow 68 in FIG. 9 indicates that harmonic frequency energy in waveguide 10 is reciprocally coupled between ports b and c .

It is to be recognized that the slabs employed in the devices illustrated in the drawings may be tapered in accordance with standard techniques to diminish unwanted reflections and that coupling means other than the slot which is shown herein may be employed in a fashion similar to that described. It must be recognized that any coupling means which selects the longitudinal component of transmitted magnetic field to the exclusion of the transverse component will be sufficient.

It is to be understood that the above-described arrangements are illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A electromagnetic wave transmission path exhibiting primary and secondary frequency discrimination characteristics including a first transmission path adapted for reciprocally propagating in respectively opposite longitudinal directions secondary frequency magnetic wave energies, means included in said path for nonreciprocally concentrating in a transverse direction the longitudinal lines of primary frequency magnetic wave energies and

means for coupling exclusively to said longitudinal lines of magnetic field disposed longitudinally in a region of vanishing longitudinal lines of secondary frequency magnetic wave energy.

2. A circulator exhibiting primary and secondary frequency discrimination characteristics comprising a first longitudinally extending bounded transmission structure, a second longitudinally extending bounded transmission structure disposed contiguous to said first structure and supporting magnetic fields having a region of nonzero longitudinal component, magnetic means included in said first structure for nonreciprocally distorting primary frequency magnetic fields while reciprocally preserving the secondary frequency magnetic fields and means common to said first and second structures for coupling exclusively to the longitudinal component of propagating magnetic field, said means disposed adjacent to said nonzero region in said second structure and simultaneously disposed in a region in said first structure of zero longitudinal component of secondary frequency magnetic field and substantially nonzero longitudinal component of primary frequency magnetic field.

3. A circulator in accordance with claim 2 wherein said first and second transmission structures comprise respectively first and second rectangular waveguides having a common wall and wherein said coupling means is included in said common wall.

4. A circulator in accordance with claim 2 wherein said magnetic means comprises a pair of slabs disposed longitudinally about said coupling means including a first ferromagnetic slab biased near resonance for said primary frequencies and a second dielectric slab.

5. A circulator in accordance with claim 2 wherein said coupling means comprises a longitudinal slot in said common wall.

6. A circulator exhibiting fundamental and harmonic frequency discrimination characteristics comprising a first longitudinally extending rectangular waveguide, field controlling means included in said first waveguide for reciprocally preserving harmonic frequency magnetic fields and nonreciprocally distorting fundamental frequency magnetic fields to produce a region of zero longitudinal component of harmonic frequency magnetic field and substantially nonzero longitudinal component of fundamental frequency magnetic field, a second longitudinally extending rectangular waveguide supporting a magnetic field having a region of nonzero longitudinal component, said second waveguide disposed contiguous to said first waveguide with a common wall shared by each and means included in said common wall for coupling exclusively to the longitudinal component of propagating magnetic field simultaneously disposed adjacent to said region of nonzero longitudinal component of magnetic field in said second waveguide and said region in said first waveguide.

7. A circulator in accordance with claim 6 wherein a broad wall of said first waveguide and a narrow wall of said second waveguide correspond respectively to said common wall and a portion of said common wall.

8. A circulator in accordance with claim 7 including in said field controlling means a pair of longitudinally extending slabs having respective cross sections divided into a region of ferrite material biased near ferromagnetic resonance and a region of dielectric material, said slabs being disposed on either side of said coupling means with said ferrite region of each disposed respectively at opposite diagonal corners of said first waveguide cross section.

9. A circulator in accordance with claim 8 wherein the cross section of each of said slabs is an identically dimensioned rectangle and wherein each of said slab cross sections is partitioned into two homogeneous rectangular regions corresponding to said ferrite and dielectric regions.

10. A circulator in accordance with claim 9 wherein each of said slabs is positioned against a narrow wall of said first waveguide and wherein a biasing magnetic field is directed in the same direction through each of said slabs perpendicular to said broad wall of said first waveguide.

11. A circulator in accordance with claim 10 wherein said coupling means comprises a longitudinally disposed slot positioned at the center line of said broad wall of said first waveguide.

12. A circulator exhibiting signal and harmonic frequency discrimination characteristics comprising a first longitudinally extending rectangular waveguide having a narrow longitudinally disposed slot cut through a broad wall for coupling exclusively to the longitudinal component of a propagating magnetic field, means including both a ferrite slab biased near ferromagnetic resonance and a dielectric slab longitudinally placed in said waveguide for producing relative to said slot nonreciprocal asymmetrical magnetic field distortions at said signal frequency and reciprocally preserving relative to said slot said magnetic field symmetry at harmonic frequencies and a second longitudinally extending rectangular waveguide for supporting a magnetic field having a region of nonzero longitudinal component, said second waveguide arranged to share in common with said first waveguide said slotted wall and disposed with said slot adjacent to said nonzero region of field component.

13. A circulator in accordance with claim 12 wherein said slot is disposed along the longitudinal center line of said broad wall of said first waveguide.

14. A circulator in accordance with claim 13 wherein a narrow wall of said second waveguide is shared in common with a portion of said broad wall of said first waveguide.

15. A circulator in accordance with claim 14 wherein the longitudinally extending center line of said narrow wall of said second waveguide is coextensive with said center line in said broad wall of said first waveguide.

16. A circulator in accordance with claim 15 wherein said dielectric slab and said ferrite slab have substantially identical cross sectional dimensions and dielectric constants and wherein said slabs are positioned equidistantly about said slot within said first waveguide.

17. A circulator in accordance with claim 13 wherein a broad wall of said second waveguide is shared in common with a portion of said broad wall of said first waveguide.

18. A circulator in accordance with claim 17 wherein the longitudinal center line of said broad wall in said second waveguide is parallel to and offset from said center line of said broad wall in said first waveguide.

19. A circulator in accordance with claim 17 wherein the longitudinal center line of said broad wall in said second waveguide is coextensive with said center line of said broad wall in said first waveguide and wherein there is included in said second waveguide means for reciprocally and asymmetrically concentrating the magnetic field transmitted therein.

20. A circulator in accordance with claim 19 wherein said reciprocal concentrating means includes a longitudinally disposed slab of dielectric material having a dielectric constant substantially different from the surrounding volume.

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