

June 22, 1948.

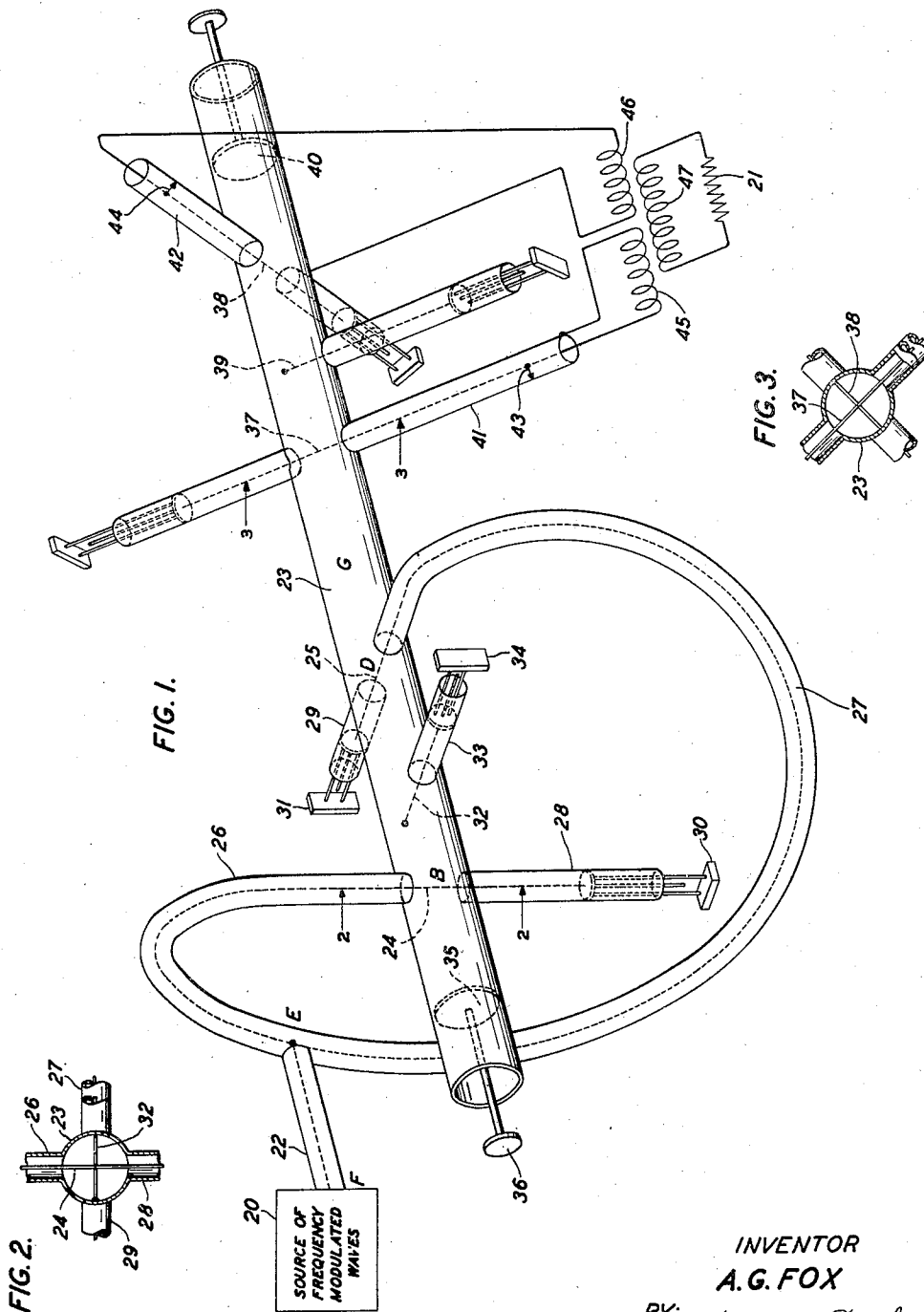
A. G. FOX

2,443,612

FREQUENCY SELECTIVE SYSTEM

Filed Aug. 17, 1943

3 Sheets-Sheet 1



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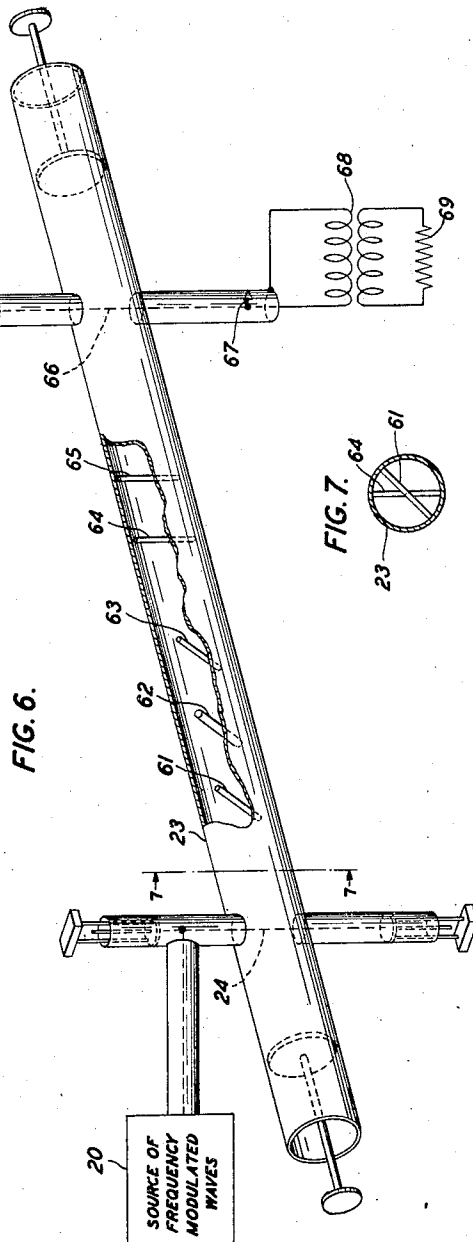
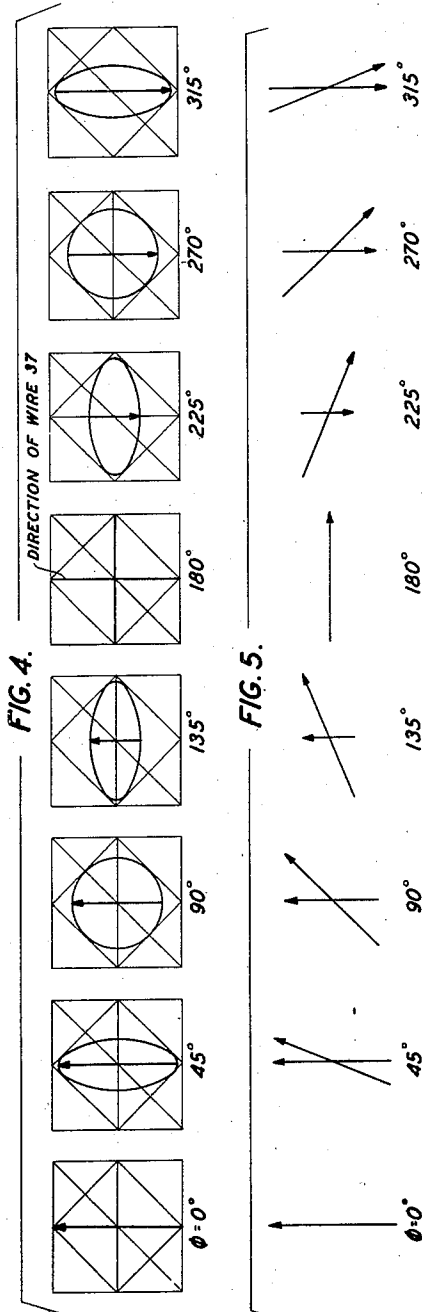
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FREQUENCY SELECTIVE SYSTEM

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FREQUENCY SELECTIVE SYSTEM

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FIG. 8.

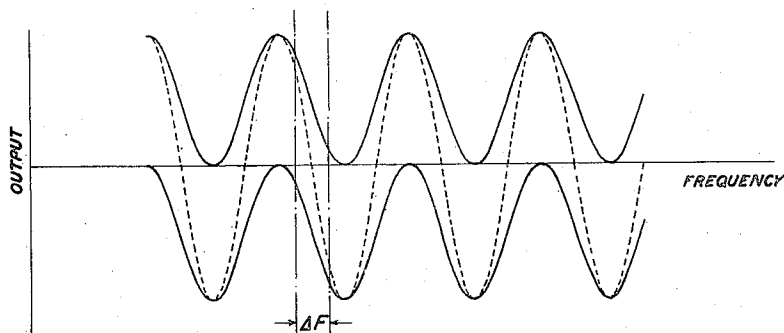


FIG. 9.

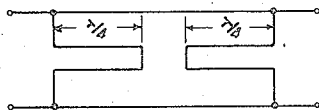


FIG. 10.

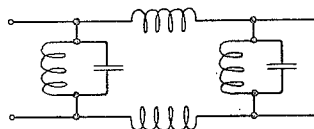


FIG. 11.

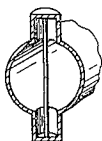


FIG. 12.

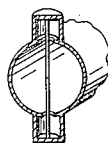


FIG. 13.

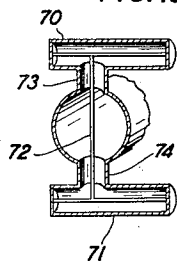


FIG. 14.



FIG. 15.



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FREQUENCY SELECTIVE SYSTEM

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Application August 17, 1943, Serial No. 499,023

11 Claims. (Cl. 250—27)

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This invention relates to arrangements for causing the energy of an impressed electromagnetic wave to divide between two mutually perpendicular directionally selective receivers in variable proportions depending upon the frequency of the impressed wave, or for variably energizing a single such receiver so that frequency variations in the impressed wave are converted into amplitude variations in the receiver. More particularly, the invention relates to receiving and detecting systems for use with frequency modulated waves and to frequency selective filtering or switching systems.

A feature of the invention is the use of certain properties of polarized waves in non-isotropic media.

In the drawings,

Fig. 1 is a perspective and partially schematic representation of a system embodying the invention;

Figs. 2 and 3 are sectional views of portions of the apparatus shown in Fig. 1;

Figs. 4 and 5 are diagrams illustrating various states of polarization which may occur in electromagnetic waves utilized in various embodiments of the invention;

Fig. 6 is a perspective view, partly broken away and partly schematic, showing another embodiment of the invention;

Fig. 7 is a cross-sectional view of a portion of the apparatus shown in Fig. 6;

Fig. 8 is a diagram useful in explaining the operation of the invention;

Figs. 9 and 10 are schematic circuit diagrams of electrical networks which may be employed in practicing the invention;

Figs. 11 to 15, inclusive, are sectional views in perspective illustrating various constructions of reactive elements which may be employed in practicing the invention.

Fig. 1 represents an illustrative embodiment of the invention in a receiving system for frequency modulated waves. A source of frequency modulated waves is represented at 20. As such sources are well known in the art it is not considered necessary to disclose herein any details of such a source. A load circuit is illustrated in the form of a resistor 21 into which it is desired to send amplitude modulated currents which will follow the frequency variations of the frequency modulated waves supplied by the source 20. A suitable transmission line, represented by a coaxial line section 22, is connected between the source 20 at a point F and the conversion apparatus to which connection is made at a point

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E. The points F and E may be any desired distance apart as, for example, at a transmitting station and a receiving station, respectively. At the receiving station there may be provided a hollow pipe wave guide 23 of suitable dimensions to freely transmit waves of all frequencies generated by the source 20. At a pair of points B and D suitably disposed within the wave guide 23 are provided a pair of mutually perpendicular radiating wires 24 and 25, respectively, which are preferably perpendicular to the longitudinal axis of the wave guide. These wires may be continuations of the respective inner conductor of a pair of coaxial transmission lines 26 and 27 connected with the line 22. The coaxial line 26 may thus provide the connection between the point E and the point B while the coaxial line 27 connects the point E with the point D. Extensions of the lines 26 and 27 are preferably made as shown to provide stubs 28 and 29, respectively, which may be tuned or adjusted for impedance matching by means of handles 30 and 31. The mutual perpendicularity of the wires 24 and 25 is shown most clearly in the sectional view of Fig. 2.

Between the radiating wires 24 and 25 and parallel to the wire 25 there is preferably provided a reflecting wire 32 which may have a stub 33 adjustable by means of a handle 34. As a reflector for the radiating wire 24 there may be provided a piston 35 which may be adjusted by means of a handle 36.

At a suitable distance to the right of the point D in Fig. 1 there are provided receiving wires 37 and 38, a reflecting wire 39 and a reflecting piston 40. The wires 37 and 39 should be parallel to each other and should be perpendicular to the wire 38. Both the wires 37 and 38 are to be disposed at angles of 45 degrees to the wires 24 and 25 as indicated by the sectional view in Fig. 3. Tuning and adjusting means are provided as shown in Fig. 1 for the wires 37, 38 and 39 and also for the piston 40. The arrangements in this respect are similar to those shown at the left-hand end of the guide 23. The wires 37 and 38 are connected to short, substantially equal lengths 41 and 42, respectively, of coaxial transmission lines each of which sections is shunted by one of a pair of similar rectifying elements 43 and 44 which are preferably symmetrically placed. The rectifiers feed into balanced transformer windings 45 and 46 which are coupled to the load resistor 21 through a common secondary winding 47.

In the operation of the system of Fig. 1 the fre-

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quency modulated wave from the source 20 supplies energy to the point E over the line 22, at which point the two line branches 26 and 27 respectively, carry substantially equal power components to the wave guide 23 over the separate routes EB and ED, respectively. At the points B and D, transverse electric waves are launched by the wires 24 and 25, respectively. By means of the adjustable elements shown, a substantial impedance match may be obtained in well-known manner for each of the wave components delivered to the wave guide 23. Provided that the range of frequencies covered by the frequency modulation is not too wide, the impedance adjustments will hold good to a sufficient degree over the entire frequency band. The piston 35 forms an end plate backing up the wire 24 to provide reflection of the waves travelling to the left from the wire 24. The wire 32 is a tuned or otherwise totally reflecting rod for the waves propagated by the wire 25 but constitutes no material obstruction to the waves from the wire 24 on account of the mutual perpendicularity of the wire 32 and the direction of polarization of the waves propagated by the wire 24.

With proper adjustment of the reflectors and tuning stubs it will be evident that the wires 24 and 25 will launch two waves of substantially equal power which are polarized at right angles to each other. The resultant polarization of waves at a point G somewhat removed from the points B and D will depend upon the time phase relationship between the two component waves at the point D. It will also be evident that the polarization of the resultant waves at the point G is a function of the separation between the points B and D and of the effective lengths of the coaxial line branches EB and ED. Assuming that the branches EB and ED are not of equal length, any change in the frequency of the impressed wave will be in general cause a change in the relative time phase of the waves launched at B and D. Accordingly, there will be a change in the polarization of the resultant wave at points of which G is representative. Thus, if the lines 26 and 27 are assumed to be identical in their transmission characteristics and if the length of the branch EB is designated by b and the length of the branch ED by d , then

$$\varphi_1 = \frac{2\pi}{\lambda_c} (b - d)$$

is the phase difference between the waves arriving at the points B and D, where λ_c is the wavelength of the operating frequency as measured inside the coaxial line. To this must be added the phase difference due to the spacing between the wires 24 and 25. If the spacing is designated l_{BD} and λ_g represents the wavelength of the operating frequency in the guide 23, then the phase displacement between the points B and D is

$$\varphi_2 = \frac{2\pi}{\lambda_g} l_{BD}$$

and the total phase difference between the wave components at the points D and G may be represented by

$$\varphi = \varphi_1 + \varphi_2$$

It is to be noted that this total phase difference depends upon λ and hence is a function of the frequency. In general, increase in frequency will increase φ .

Assuming that φ changes from 0 to 180 degrees,

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the polarization of the resultant wave will change from linear polarization at an angle of 45 degrees with the wires 24 and 25, through elliptical to circular polarization and through elliptical polarization back to linear polarization at an angle of 45 degrees with the wires 24 and 25 in the other direction. Thus the power in the resultant wave may be smoothly commuted according to a sinusoidal function of φ from linear polarization in one direction to linear polarization in a direction perpendicular to the first.

Accordingly, if a pair of directionally selective receiving devices are oriented so that each receives power selectively in one or the other of these two principal directions, the power received by each will depend upon the operating frequency of the transmitted wave. The wires 37 and 39 in the arrangement of Fig. 1 are so oriented as to receive selectively the waves polarized in the two principal directions, making angles of 45 degrees with the wires 24 and 25. The detectors 43 and 44 will each receive a variable input depending upon the frequency of the impressed waves and when a frequency modulated wave is received each detector will deliver an output the amplitude of which will vary in accordance with the frequency variations of the impressed waves. Either output alone may be employed and utilized in the load 21 or the two outputs may be combined advantageously in the transformer comprising the windings 45, 46 and 47 as shown in Fig. 1. Similar methods of combining the outputs of detectors in a frequency modulation receiver are well known in the art and any such suitable arrangement may be employed in connection with the present invention.

Fig. 4 represents graphically the succession of states of polarization in the wave striking the wire 37 as the phase difference φ is varied in steps of 45 degrees each from 0 to 315 degrees. The direction of the wire 37 is used as the direction of the vertical axis for all the curves shown in Fig. 4. The corresponding value of φ is given under each curve. The arrow in each case shows the magnitude of the component received by the wire 37 and is found by taking the vertical diameter of the ellipse in the case of elliptical polarization and the diameter of the circle in the case of circular polarization.

In some cases it may be desirable to convert the elliptical and circular polarized waves into linearly polarized waves before impressing them upon the receiver. It is feasible for this purpose to employ further phase shifting elements with the result that the output wave finally developed is always linearly polarized and the direction of polarization varies as a function of the operating frequency. The effect at the receiver is the same as in the case of the elliptically and circularly polarized waves.

Fig. 5 is a graphical representation of a succession of linearly polarized waves of varying direction as a function of φ , the vertical component in each case being represented as in Fig. 4 by a vertical arrow. It is found that the magnitude of the vertical component is the same in every case as the corresponding value in Fig. 4.

Fig. 6 shows a frequency modulation receiving system in which at an intermediate stage a linearly polarized wave variable in direction is supplied to a single directionally selective receiving element. In this embodiment, elliptically and circularly polarized waves are first developed, by means different from those illustrated in Fig. 1, and are subsequently converted into linearly po-

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larized waves. The source 20 of frequency modulated waves is shown energizing the single radiating wire 24 to generate a wave in the guide 23 which is linearly polarized in the vertical direction as shown in Fig. 6. In the path of this wave I place a band-pass filter structure such as is disclosed in Fig. 3 of my copending application serial No. 464,333, filed November 3, 1942, now U. S. Patent 2,438,119 and assigned to the assignee of the present application. The filter structure as shown in Fig. 6 comprises three spaced diametral rods 61, 62 and 63 the spacings and diameters of which may be designed in accordance with the teachings of my copending application to constitute a band-pass filter designed to pass the frequencies instantaneously assumed by the frequency modulated waves from the source 20, and having a phase shift characteristic in which the phase shift is a suitable function of the frequency within the transmission band. The rods 61, 62 and 63 are parallel to each other and are set at an angle of 45 degrees with the wire 24.

The effect of the filter structure 61, 62, 63 upon the waves propagated by the wire 24 will be evident when it is considered that with regard to the rods the impressed waves may be considered to have two mutually perpendicular components, namely, one parallel to the rods and the other perpendicular thereto. The perpendicular component will pass the rods and be substantially unaffected thereby while the component parallel to the rods will receive a phase shift the amount of which is a function of the frequency of the impressed wave. The resultant wave after passing the filter structure will, accordingly, be linearly, elliptically or circularly polarized depending upon the frequency. The structure may be regarded as a directionally selective reactive transmission medium.

To convert the complexly polarized wave to a linearly polarized wave the direction of which depends upon the frequency, I place beyond the filter structure a 90-degree phase shift structure comprising two spaced parallel rods 64 and 65 set parallel to the wire 24. This phase shifting device may be similar to one shown in Fig. 1 of my above-cited copending application and should be designed to introduce a 90-degree phase shift for all frequencies within the transmission band. A single receiving wire 66 with associated detector 67 is placed beyond the rods 64 and 65 to selectively receive the component parallel to the wire 24 (the vertical component as arranged in Fig. 6). The output of the detector 67 is delivered through a transformer 68 to a load 69, here represented by a resistor. Tuning and impedance matching devices are provided in conjunction with the wire 66 and may be of similar form to those shown in Fig. 1.

Fig. 7 is a sectional view of the device of Fig. 6 showing the 45-degree angular displacement between the rods 61 and 64.

To recapitulate the operation of the arrangement shown in Figs. 6 and 7, the frequency modulated wave is propagated into the wave guide 23 by the wire 24, converted into a complex polarized wave, the state of polarization of which depends upon the frequency, this transformation being accomplished by the filter structure comprising the rods 61, 62 and 63. The wave is then converted into a linearly polarized wave the direction of polarization of which is a function of the frequency, this being accomplished by the rods 64 and 65. The component of the resultant

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wave in the direction of the wire 24 is then selectively received by the wire 66, detected by the element 67 and the detected current is delivered to the load 69 through the transformer 68.

Fig. 8 represents the variation of the output current to the load 21 in the arrangement of Fig. 1 as a function of the instantaneous frequency. The solid curves represent the separate responses of the detectors 43 and 44. The resultant output is represented by the dotted line. The individual outputs vary in a sinusoidal manner with respect to frequency, the maximum response to one detector coinciding in frequency with the minimum response of the other detector. As shown, the pattern of the response may be repeated several times along the frequency scale, although only a small portion as shown by ΔF in Fig. 8 would ordinarily be used. It is assumed that the detectors respond approximately according to the square of the impressed voltage.

Filter structures such as shown in Fig. 6 may be made up of two or more elementary sections with the adjacent shunt elements merged into a single element. For example, the filter structure comprising the spaced rods 61, 62 and 63 in Fig. 6, is a two-section filter structure, the rod 62 in this case having approximately twice the diameter of the end rods 61 and 63. This method is recommended where large changes in phase are desired together with a minimum loss in transmission efficiency over the band.

The use of lumped shunt reactive elements as shown in Fig. 6 will result in filter sections having fairly slow changes in phase with respect to frequency. In this case the length of the filter section plays the primary role in determining the selectivity. Where a more rapid change of phase with respect to frequency is required, the selectivity may be greatly increased by employing shunt reactive elements which are themselves resonant or exhibit a high rate of change of reactance vs. frequency. Simple sections of this type are represented schematically in Figs. 9 and 10.

Fig. 9 represents a line shunted by two spaced quarter wavelength elements. Fig. 10 represents the equivalent of Fig. 9 assuming that the line elements may be replaced by lumped constants. The shunt arms are antiresonant circuits while the series arms are inductances.

Figs. 11 to 15, inclusive, represent alternative structures for antiresonant shunt elements which may be employed if desired in place of any of the rods 61 to 65, inclusive, of Fig. 6.

Fig. 11 is a form of shunt element comprising a wire which continues as the central conductor in coaxial tuning stubs at either end. The stubs may be adjusted in length to secure a maximum impedance at the desired antiresonant frequency and the wire diameter and the characteristic impedance of the coaxial stubs may be adjusted to obtain a desired shunt impedance effect at a second frequency. For simplicity, adjusting means are not shown in Figs. 11 to 15, inclusive as they may be readily supplied, or the structures may be predesigned to give the desired impedances.

Fig. 12 shows the use of a shunt capacitance in the coaxial tuning stub to increase the sharpness of resonance. The shunt capacitance is attained by passing the central conductor through a small hole in the wall of the wave guide as shown in the figure. Clearance is to be provided between the central conductor and the edge of

the hole, the amount of clearance largely determining the value of shunt capacity.

Fig. 13 shows the use of more complex tuning coaxials in the form of half wave resonators 70 and 71 coupled to a wave guide having a diametral wire 72 through predetermined lengths of coaxial coupling line 73 and 74. The half wave sections 70 and 71 are tuned to the frequency at which it is desired to have the wire 72 antiresonant. The length of the coupling lines 73 and 74 is adjusted to increase the antiresonant impedance at the wire 72. The characteristic impedance of the sections 70 and 71 and the diameter of the wire 72 are adjusted to obtain any desired shunt reactance at a second frequency.

Figs. 14 and 15 illustrate additional forms of shunt antiresonant structures.

What is claimed is:

1. A frequency selective system comprising a source of electromagnetic waves of varying frequency, a wave guide for transmitting waves of the frequencies supplied by said source, a pair of mutually perpendicular linear conductors extending transversely inside said wave guide to excite waves therein in space quadrature relation, a directionally selective detector inside said wave guide, and means to impress waves from said source upon said linear conductors in suitable time phase to produce at the position of said detector a time phase difference dependent upon the frequency, whereby the frequency variations of said waves cause amplitude variations in the output of said detector.
2. A frequency selective system comprising a source of electromagnetic waves of varying frequency, a wave guide for transmitting waves of the frequencies supplied by said source, a pair of mutually perpendicular linear conductors extending transversely inside said wave guide to excite waves therein in space quadrature relation, and a directionally selective detector inside said wave guide, said detector being oriented to selectively detect a wave component polarized at an angle of substantially 45 degrees from the direction of either of said mutually perpendicular linear conductors.
3. A frequency selective system comprising a source of electromagnetic waves of varying frequency, means to combine waves from said source in space quadrature and at the same time in varying time phase, the latter dependent upon the frequency, a directionally selective detector oriented to selectively detect a wave component at an angle of substantially 45 degrees to the direction of either of said space quadrature components, and means to impress the said combined waves upon said detector, whereby the frequency variations of the waves effect amplitude variations in the response of the said detector.
4. A frequency selective system comprising a source of electromagnetic waves of varying frequency, means to combine waves from said source in space quadrature and at the same time in varying time phase, the latter dependent upon the frequency, a pair of directionally selective detectors respectively oriented to detect mutually perpendicular wave components each at an angle of substantially 45 degrees to the direction of either of said space quadrature components, means to impress the said combined waves upon said detectors, and means to combine in additive phase relation amplitude variations in the respective output currents of said detectors.
5. Apparatus comprising a source of electro-

magnetic waves of varying frequency, a wave guide for transmitting waves of the frequencies supplied by said source, a pair of mutually perpendicular linear radiators extending transversely inside said wave guide, individual transmission lines connecting said source to said radiators, and a directionally selective linear detector extending transversely inside said wave guide in a direction at an angle of 45 degrees with respect to said radiators.

6. A frequency selective system comprising a source of electromagnetic waves of varying frequency, a wave transmission system connected to said source, means at a point in said transmission system to convert waves from said source into linearly polarized space waves within said system, means in said transmission system to convert said linearly polarized space waves into elliptically polarized space waves, the ellipticity of which waves is dependent upon the frequency, and the elliptical axes of which waves have an unchanging angular relationship to the direction of polarization of said linearly polarized waves, and a directionally selective detector for said space waves at a point in said transmission system beyond said second-mentioned wave converting means, the directional orientation of said detector having an unchanging angular relationship to the elliptical axes of said elliptically polarized waves.

7. A frequency selective system comprising a source of electromagnetic waves of varying frequency, a wave transmission system connected to said source, means at a point in said transmission system to convert waves from said source into linearly polarized space waves within said system, means in said transmission system to convert said linearly polarized space waves into elliptically polarized space waves, said last-mentioned means including means to divide waves from said source into two components and means to produce a difference in time phase between said components, the amount of said time phase difference depending upon the frequency, the elliptical axes of said elliptically polarized waves having an unchanging angular relationship to the direction of polarization of said linearly polarized waves, and a directionally selective detector for said space waves at a point in said transmission system beyond said second-mentioned wave converting means, the directional orientation of said detector having an unchanging angular relationship to the elliptical axes of said elliptically polarized waves.

8. Apparatus comprising a source of electromagnetic waves of varying frequency, a linear radiator connected to said source, for launching linearly polarized waves, a directionally selective detector mounted in the path of waves from said radiator, said detector being oriented to detect a wave component perpendicular to the direction of propagation of waves from said radiator and parallel to the direction of polarization of said waves, and a plurality of spaced parallel linear conductors mounted in the direct path of waves propagated from said radiator to said detector, said last-mentioned linear conductors being oriented perpendicular to the direction of propagation of said waves and inclined at an angle of substantially 45 degrees with respect to the direction of polarization of said waves, the orientation of said detector being that determinable in the absence of said last-mentioned plurality of spaced, parallel linear conductors.

9. Apparatus comprising a source of electro-

magnetic waves of varying frequency, a linear radiator connected to said source for launching linearly polarized waves, a directionally selective detector mounted in the path of waves from said radiator, said detector being oriented to detect the wave component perpendicular to the direction of propagation of waves from said radiator and parallel to the direction of polarization of said waves, a first plurality of spaced, parallel, linear conductors mounted in the direct path of waves propagated from said radiator to said detector, said first plurality of parallel conductors being oriented perpendicular to the direction of propagation of said waves and parallel to the direction of polarization of said waves, and a second plurality of spaced parallel linear conductors mounted in the direct path of waves propagated from said radiator to said detector between said radiator and said first plurality of spaced, parallel linear conductors, said second plurality of spaced, parallel linear conductors being oriented perpendicular to the direction of propagation of said waves and inclined at an angle of substantially 45 degrees with respect to the direction of polarization of said waves, the orientation of said detector being that determinable in the absence of said first and second pluralities of spaced parallel linear conductors, and the orientation of said first plurality of spaced parallel linear conductors being that determinable in the absence of said second plurality of spaced, parallel linear conductors.

10. A frequency selective system comprising a source of electromagnetic waves of varying frequency, a wave guide for transmitting waves of the frequencies supplied by said source, a linear conductor extending transversely inside said wave guide, means to impress waves from said source upon said linear conductor, a linear detecting conductor extending transversely inside said wave guide and oriented parallel to said first-mentioned linear conductor and a plurality of additional linear conductors extending transversely inside said wave guide intermediate said first-mentioned linear conductor and said linear de-

tecting conductor, said additional linear conductors being parallel to each other and inclined at an angle of substantially 45 degrees with respect to said first-mentioned linear conductor.

11. A frequency selective system comprising a source of electromagnetic waves of varying frequency, a wave guide for transmitting waves of the frequencies supplied by said source, a linear conductor extending transversely inside the wave guide, means to impress waves of said source upon said linear conductor, a linear detecting conductor extending transversely inside said wave guide and oriented parallel to said first-mentioned linear conductor, a plurality of additional linear conductors, extending transversely inside said wave guide intermediate said first-mentioned linear conductor and said linear detecting conductor, said additional linear conductors being parallel to each other and inclined at an angle of substantially 45 degrees with respect to said first-mentioned linear conductor, and a pair of linear conductors extending transversely inside said wave guide intermediate between said plurality of inclined linear conductors and said linear detecting conductor, said last-mentioned pair of linear conductors being parallel to each other and to said linear detecting conductor.

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