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SIMULTANEOUS LOBE MATCHING DEVICE

Filed June 18, 1946

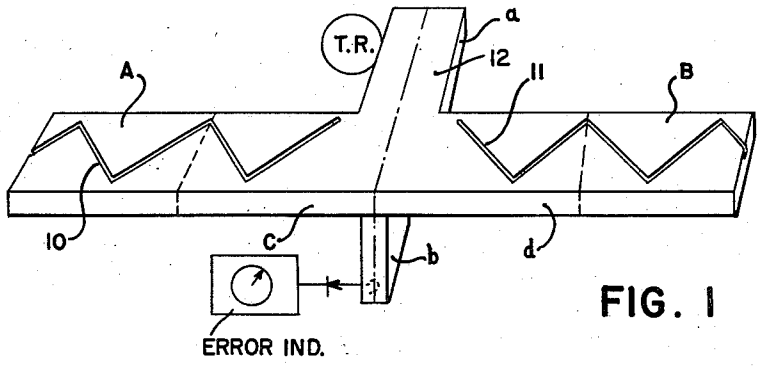


FIG. 1

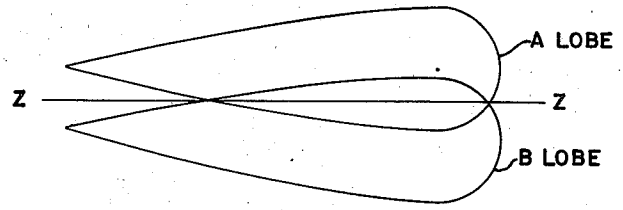


FIG. 2-A

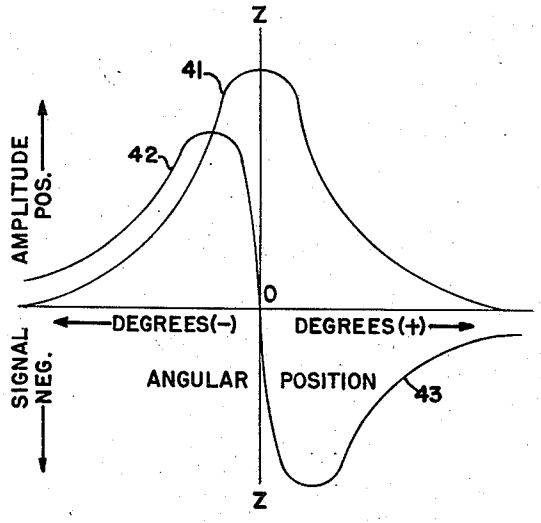


FIG. 2-B

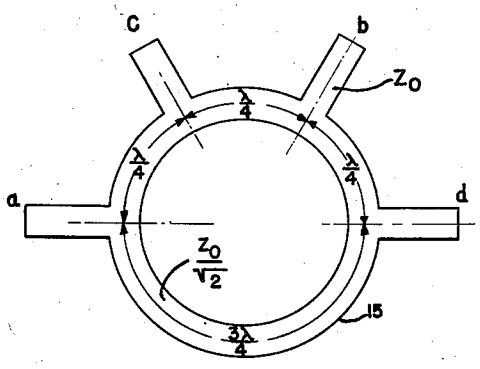


FIG. 3

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SIMULTANEOUS LOBE MATCHING DEVICE

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Application June 18, 1946, Serial No. 677,446

6 Claims. (Cl. 343—16)

The present invention relates in general to directional radio systems. More particularly this invention relates to directional radio systems incorporating antenna arrays and which yield information aiding in the maintenance of a true direction of the antenna, as for example, keeping an antenna pointed at a desired transmitter or target.

In radio communication between two directive radio stations, or in radar systems, and particularly in fire-control radar systems, it is often desirable to have an antenna system which is directional and which further has means for indicating when the antenna is pointed directly at the other station or at the desired target. Such systems as have been used in the past have involved mechanical lobe switching or systematic antenna scanning. In general, these past systems are characterized by a necessity for moving mechanical parts, such as rotating antenna configurations or rotating capacitor devices and associated motors, or for maintaining equal gains in two or more amplification channels. In my co-pending application, Serial No. 631,742, entitled "Lobe Comparison Systems," filed November 29, 1945, the aforementioned difficulties were alleviated. The present invention discloses means surpassing in accuracy those of the aforementioned co-pending application.

It is a specific object of the present invention to provide a directional radio system which will perform the function of a lobe switched or conically scanned antenna or other type of directional antenna of the character discussed without the use of moving parts. Accordingly, the present invention contemplates a radio system which may be either a receiver system or a radar system, as desired, having an antenna system comprising a pair of antenna elements which may be so fed that together these elements produce effectively a single directive beam for transmitting. During reception of the signals returning to the aforementioned individual antenna elements novel means are employed for determination of a directional error signal in at least one plane.

It is a further object of my invention to provide a directive simultaneous lobe comparison antenna system which will provide a directional error signal without the use of moving parts.

It is a still further object of my invention to provide a directive simultaneous lobe comparison antenna system for a radar system which may be used for both transmitting and receiving and will provide at least an azimuth or an elevation error signal without the use of moving parts.

It is also an object of my invention to provide a directive lobe comparison antenna system which will provide a directional error signal without the use of moving parts.

It is another object of my invention to provide a directive lobe comparison antenna system which will provide a directional error signal which may be employed according to the previous disclosure without the need for maintaining equality in the gains of two or more amplification channels.

These and other and further objects of the present invention will become more readily apparent upon examination of the following description and the accompanying drawings of which:

Fig. 1 is an oblique view of an embodiment of the present invention employing a slotted linear array;

Fig. 2A illustrates the beam pattern of the embodiment of Fig. 1;

Fig. 2B is a graph representing relative outputs from the arms of the embodiment of Fig. 1; and

Fig. 3 is a plan view of apparatus for use in connection with the present invention; namely, different coupling means to the linear array.

The present invention generally comprises two individual antenna arrays which are each coupled to a shunt arm of a magic tee to form a single array. The structure of Fig. 1 is a component of a complete radar system, the details of which have been omitted as they form no part of the present invention. A third shunt arm provides a connection to a transmit-receive (T–R) unit, an item well-known to those versed in the radar art, and a fourth arm connected in series provides a terminal for extraction of an error signal by a conventional crystal detector. The magic tee, otherwise known as a "duplex balancer," was disclosed in co-pending application of Warren A. Tyrrell for "Coupling Arrangement for Use in Wave Transmission System," Serial No. 470,810, filed December 31, 1942, now U. S. Patent No. 2,445,895, and assigned to Bell Telephone Laboratories, Inc. The "duplex balancer" is a system comprising a common junction of a plurality of transmission lines, as for example, four transmission lines *a*, *b*, *c* and *d* with each other or with a fifth line. If the system is matched to eliminate resonance in the various lines for the energy being carried therein, the electrical structure and symmetry of the system may be so arranged that the following characteristics are had among others:

(1) Power fed into line *a* passes into lines *c* and *d* in equal quantities, emerging from *c* and *d* in the same phase, no power passing into line *b*.

(2) Power fed simultaneously and in phase into lines *c* and *d* enters line *a* in additive fashion and line *b* in subtractive fashion. The electrical structure should be such that the lines *a*, *c* and *d* are joined in parallel and the line *b* in series to the others to provide these characteristics. Such a matched arrangement is more specifically termed a magic tee, and is described in greater detail in copending application of Robert H. Dicke for "Transmission System," Serial No. 581,695, filed March 8, 1945, and assigned to the United States Government, wherein certain matching means for a magic tee constructed of wave guides are disclosed. The above enumerated characteristics are employed in the present invention as will hereinafter be more fully explained.

An orthogonal magic tee construction is disclosed in its position in the present embodiment in Fig. 1. Orthogonal magic tee **12**, shown separated by dotted lines from the rest of the structure for the sake of visualization, has three shunt arms *a*, *c*, and *d* and one series arm *b* corresponding to the letters used in the preceding general description of the properties of the magic tee. Two linear radiating arrays of suitable form, herein shown as slotted linear arrays A and B, are attached to magic tee arms *c* and *d* respectively. The radiating slots **10** and **11** in this embodiment are shown extending into arms *c* and *d* of the magic tee. Slots **10** and **11** need not extend to or be continuous through the center of the magic tee.

In order to use other types of tees, the array may be interrupted at the expense of a slight increase in frequency sensitivity of the array. A good example of such a magnic tee is the circular magic tee, the series type of

which is portrayed in Fig. 3. The arms lettered *a*, *b*, *c*, and *d* correspond in electrical performance to those presented in Fig. 1, since it is known that for the dimensioning shown (approximately

$$\frac{\lambda}{4}, \frac{\lambda}{4}, \frac{\lambda}{4}, \frac{3\lambda}{4},$$

and whose summation equal the centerline circumference of the circular section) power sent into arm *a* will excite arms *c* and *d* equally and in phase, with no power emerging at *b*. It is also known that power sent into arm *b* will excite arms *c* and *d* equally and out of phase with no power emerging at *a*. Accordingly, radiating arms A and B, as in Fig. 1, are attached to arms *c* and *d* of circular magic tee **15**. It has been found that matching may be accomplished by making the impedance of the circular wave guide section **15** approximately $Z_0/\sqrt{2}$ where Z_0 is the characteristic impedance of the branch wave guide arms *a*, *c*, *b* and *d*. The advantage of the circular magic tee is its ability to carry higher power and its greater bandwidth.

In Fig. 1, energy entering the first line *a* of the magic tee **12** will, in accordance with the above discussion, divide and pass into third and fourth lines *c* and *d* of this magic tee in equal quantities and like phase. No energy will enter the second line *b*. Each of the antenna feeds A and B provides a lobe pattern, the A lobe and the B lobe respectively as shown in Fig. 2A, and the elements are so arranged coadjacently that the two lobes are similarly directed and partially overlap in space, so that the antenna system may be thought of as a single directive antenna having an axis Z—Z located substantially equidistantly between the lobes. However, it is convenient to consider the A lobe and the B lobe separately for the purposes of this explanation and the hereinafter following analysis of operation.

During transmission an effectively single lobe is transmitted inasmuch as the A and B lobes will add in phase to provide in effect a single lobe. Upon reception, however, each lobe will return energy to its own antenna feeds, A or B. This energy in turn returns to magic tee **12** through the third and fourth arms *c* and *d* thereof. In accordance with the second characteristic of a magic tee as hereinabove set forth, the energy in feeds A and B enters the first line *a* of the magic tee **12** in additive fashion $(A+B)$, and the second line *b* of the magic tee is in subtractive fashion $(A-B)$. Reference to the graph of Fig. 2B will aid in explaining in greater detail how magic tee **12** provides the two signals $(A+B)$ and $(A-B)$, proportional in amplitude respectively to the magnitude of the vector sum of and difference between the amplitudes of the signals in feeds A and B. This is modeled upon an experimental graph and illustrates that the amplitude of the signal $(A+B)$ out of the first line *a* of the magic tee **12** is proportional in amplitude to the sum of the amplitudes of the signals in each of antenna feeds A and B. The first curve **41** illustrates the amplitude of the signal $(A+B)$ that will be present in the first line *a* of magic tee **12** when that signal is received in various directions ahead of antenna feeds A and B. According to curve **41** for the output from the first line *a*, the amplitude of the signal in this first line *a* is at a maximum when received from a direction dead ahead, and falls uniformly to a minimum at the extremes as the number of degrees from the axis is increased. The $(A-B)$ condition, which is the output from the second line *b* of magic tee **12**, is illustrated by the second, two-humped, curve **42**, **43**. This curve shows that the amplitude of the signal $(A-B)$ from the second line *b* falls sharply to zero or a null in the direction dead ahead where antenna feeds A and B receive signals of equal amplitude, and therefore, where the amplitude of the signal $(A-B)$ should be expected to become zero. These curves **42** and **43** rise to humps or peaks at directions somewhat off the axis Z—Z and then further fall to zero again. The negative signal curve **43** illustrates the voltage condition of $(A-B)$ for a direction on one side of the axis. It is to be expected that $(A-B)$ should be positive on one side of the axis Z—Z and negative on the opposite side of the axis Z—Z. Since, on the axis Z—Z the amplitudes of the signals in the A lobe and in the B lobe are the same, $(A+B)$ is actually equal to 2A. The $(A-B)$ signal from series arm *b* is fed to suitable error indicating means.

This arrangement for "simultaneons lobing" is not identical to the case of a parabola fed by a double feed. In that case the signals from the magic tee represent the sum and difference of the two original signals, as previously disclosed in the description of the properties of a magic tee, and the two lobes being compared differ in angular direction so that the lobes are compared on the sides, at half power points or thereabouts. In this case the signals entering the two arms of the magic tee are not of identical phase except when the target lies on axis Z—Z, so that it is not a question of amplitude variations only. Moreover, since both lobes are sighted in the same direction, the amplitude variations near the axis will be small and in the same sense. The error signal, appearing in series arm *b*, in this case represents a phase difference and is, in effect, the sum of the sin ϕ components of the two signals from the two halves of the total array. The normal output signal, appearing in shunt arm *a*, is on the other hand the sum of the cos ϕ components. ϕ is defined by the following equation:

$$\phi = \frac{\pi D}{2\lambda} \sin \theta$$

where D is the total length of the array, θ is the azimuth angle with respect to axis Z—Z, and where uniform illumination is assumed. The two signals are employed in many ways to provide indication of the information they contain. One method is more explicitly disclosed in the copending application of the present inventor Serial No. 631,742, entitled "Lobe Comparison Systems," filed November 29, 1945, and assigned to the United States Government. The above-described use of a linear array makes possible its use for automatic tracking in one coordinate without scanning. For high resolution systems wherein a linear array is used because of its convenient design, the present invention affords a more accurate indication of the beam center than is obtainable by methods dependent upon maximizing the main lobe signal. This feature is highly advantageous in gun laying where high angular accuracy is desired. In such cases the array could serve as a line source for a parabolic reflector or for a cylindrical lens.

While the foregoing description has presented an explanation of this invention in the particular application of a simultaneous lobe matching device for linear arrays, the principles of this invention are of broader application in ways which will be apparent to those versed in the art. Accordingly, it will be understood that the above-disclosed embodiment is primarily illustrative and the invention includes such other embodiments as fairly fall within the spirit and scope of the appended claims.

What is claimed is:

1. In an electrical system including a transmit-receive unit, a combined directional radiating system and direction indicator comprising, a magic tee having four arms, the construction of said magic tee being such that a signal applied to a first arm appears at second and third arms in equal amplitudes and in phase, and such that a signal equal to the vector difference of signals applied simultaneously to said second and third arms appears at said fourth arm and a signal equal to the vector sum of said two simultaneously applied signals appears at said first arm, said transmit-receive unit being coupled to said first arm, first and second antenna arrays coupled to said second and third arms, respectively, and signal detecting means coupled to said fourth arm, said signal detecting

means providing an output indicative of the amplitude of the signal in said fourth arm.

2. In an electrical system including a transmit-receive unit, electrical apparatus comprising an orthogonal magic tee having two opposite shunt arms, an additional shunt arm and a series arm, said additional shunt arm being connected to said transmit-receive unit, a first antenna array coupled to one opposite shunt arm of said magic tee, a second antenna array coupled to the other opposite shunt arm of the magic tee and signal detecting means coupled to said series arm of said magic tee.

3. In a radar system including a transmit-receive unit, electrical apparatus comprising an orthogonal magic tee having two opposite shunt arms, an additional shunt arm and a series arm, said additional shunt arm being connected to said transmit-receive unit, a first linear antenna array coupled to one opposite shunt arm of said magic tee, a second linear antenna array coupled to the other opposite shunt arm of the magic tee and signal detecting means coupled to said series arm of the magic tee, said signal detecting means providing an output indicative of the amplitude of the signal in said series arm.

4. In a radar system including a transmit-receive unit, a combined directional antenna and direction indicator comprising an orthogonal, rectangular wave guide magic tee having two opposite shunt arms, an additional shunt arm and a series arm, said additional shunt arm being connected to said transmit-receive unit, each of said two opposite shunt arms of said magic tee being formed with radiating slots in a broad wall thereof, and signal detecting means coupled to said series arm of the magic tee, said signal detecting means providing an output indicative of the amplitude of the signal in said series arm.

5. In a radar system for directing energy at a target in space and for receiving echoes reflected from said target, a combined directional antenna and indicator comprising

an orthogonal, rectangular wave guide magic tee having two opposite shunt arms, an additional shunt arm and a series arm, each of said two opposite shunt arms being formed with radiating slots in a broad wall thereof, the two broad walls in which said slots are formed lying in the same plane, and signal detecting means coupled to said series arm, said signal detecting means providing an output indicative of the amplitude of the signal in said series arm, the amplitude of said signal in said series arm being indicative of the direction of a target from said antenna.

6. In combination, a magnic tee wave guide assembly consisting of a first rectangular wave guide section terminating in a pair of oppositely extending H-plane sidearms which are in a parallel electrical relationship thereto and an E-plane arm extending perpendicular to the plane of said H-plane sidearms at the intersection formed by said sidearms and said first wave guide section, said E-plane arm being in a series electrical relationship with respect to said sidearms, and antenna means coupled to each sidearm, each antenna means comprising a rectangular wave guide length having a cross-sectional area corresponding to that of said sidearms with longitudinal apertures formed in one of its broad walls.

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