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MICROWAVE PHASE COMPENSATION SYSTEM

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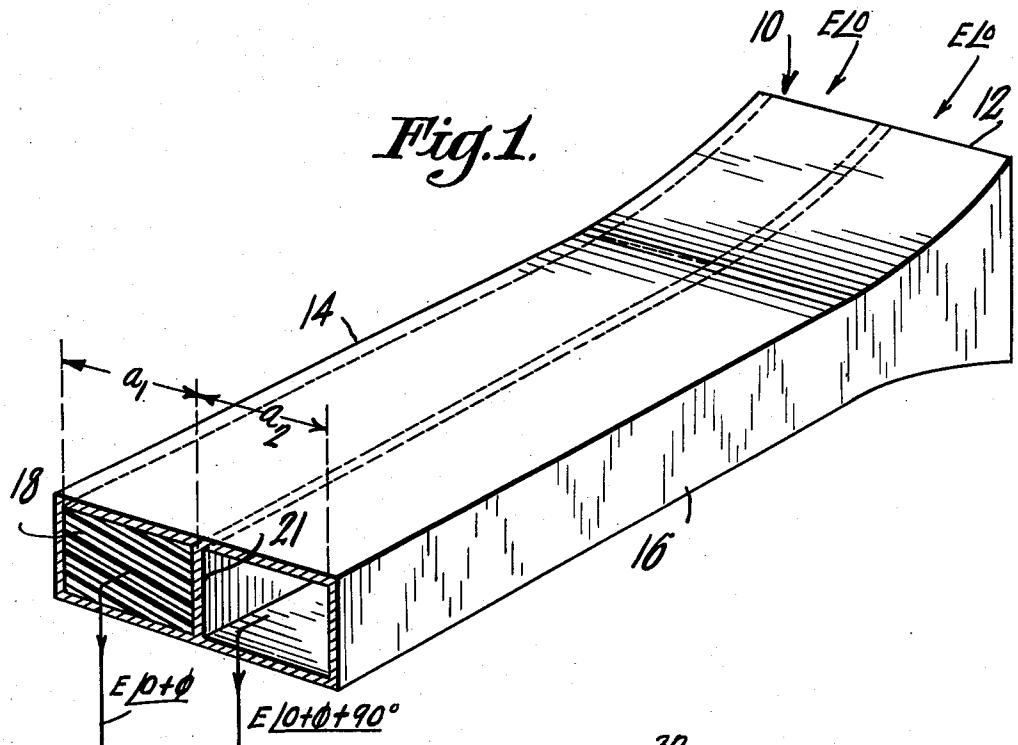
Fig. 1.



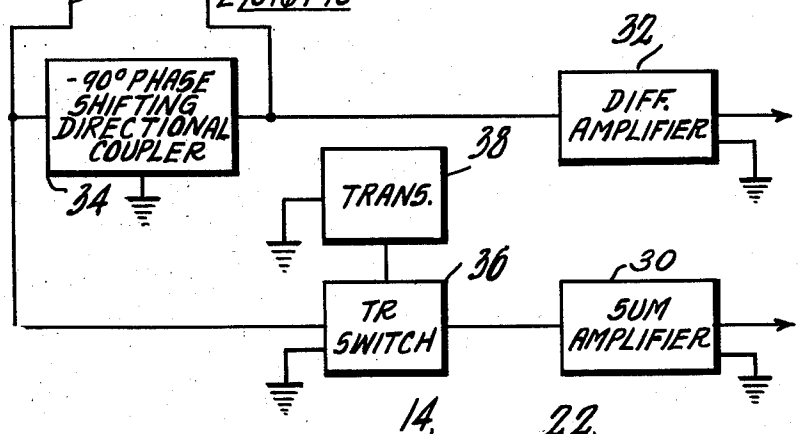
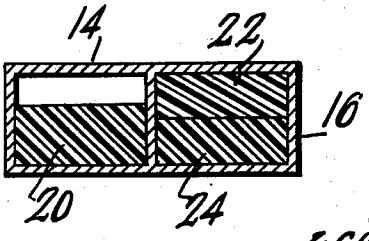


Fig. 2.



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MICROWAVE PHASE COMPENSATION SYSTEM

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8 Claims. (Cl. 343—786)

This invention relates to microwave guide transmission systems that involve in their operation the use of phase relationships in two wave guide components of the system, and particularly to a pair of waveguides having a relative phase shift maintained substantially constant over a wide frequency band about an operating frequency.

In one conventional simultaneous lobing tracking radar system, for example, energy from an oscillating source is fed to a simultaneous lobing horn fed antenna array through a single wave guide. Adjacent to and connected to a second horn of the antenna array is a second wave guide that is coupled by a directional slot coupler to the first guide. To compensate for the 90 degree shift in phase occurring at the slot coupling, a 90 degree phase shifter is inserted in the first guide between the slot and the antenna feed. As a result, energy is radiated simultaneously from the antenna array in a pencil beam pattern.

When the reflected pulses are received back by the antenna array, the received energies pass from the separate feed horns through their two transmission guides until they reach the slot coupler, where the energy in each guide divides and part of the energy in each guide passes into the other guide. By suitably combining these outputs, sum and difference outputs can be formed. The difference output amplitude is proportional to the absolute error between the bearings of the target and the antenna while the sum output amplitude is relatively insensitive to this error. By comparing the sum and difference outputs in a phase detector, a D.-C. voltage can be obtained that has directional sense and which is proportional to the error.

One method of maintaining the desired phase relationships of a pair of waveguides over a broad band, is by constructing one waveguide longer than the other and making the waveguides of different cross-sectional dimensions thereby to change the phase velocity of one with respect to the other. Further, by suitably selecting the dimensions so that the product of the waveguide length and the propagation wavelength in the waveguide for one waveguide is equal to the like product for the other waveguide, as taught in the copending application of Nathaniel I. Korman, Ser. No. 165,016 filed May 29, 1950, entitled Microwave Phase Compensation System, a broadband effect is secured. As a result of this broadband effect, a desired change in phase relationship between two waveguides (e. g. 90°) may be maintained over a broad band of frequencies. However, to get different relative phase shifts, the two waveguides must be of different lengths. As both the entry points of the waveguides are at one place and the exit points at another, at least one bent waveguide is required. But bent waveguides are often difficult to construct.

It is an object of the present invention to provide a novel and different arrangement in which there is a relative phase shift over a pair of waveguide lengths, the shift being insensitive to frequency changes, or broad banded, at the operating frequency.

It is a further object of the invention to provide a novel arrangement of a pair of waveguides in which the phase shift over one may differ from that over the other by a predetermined amount which is substantially independent of frequency at or near a known mean operating frequency.

It is another object of the invention to provide such an arrangement with a pair of waveguides of equal physical length, and which may therefore be straight and have the same energy entrance and exit points.

It is another object of the invention to improve simultaneous lobing radar systems, particularly by providing an improved pair of waveguides which may be of the same length, and yet afford a desired relative phase shift over an especially broad band of frequencies near the operating frequency.

In accordance with the invention, one of a pair of waveguides of the same length has a phase shift for energy at the operating frequency passing therethrough different from that for energy at the said frequency passing through the other. Notwithstanding the equality of physical lengths and the different electrical lengths, the rates of change of phase shift with frequency of the two waveguides are equalized at the operating frequency by proper selection of the waveguide dielectrics and the waveguide dimensions.

The result of such selection is that the relative phase shift of energy between the two waveguides is the same over a broad band of frequencies in the region of the operating frequency. The said selection of dielectrics and dimensions is made so that the product of the dielectric constant and propagation wavelength in the waveguide at the operating frequency for one waveguide is equal to the like product for the other waveguide. It may then be shown that the rates of change of phase shift for energy passing through the waveguides are equal at the operating frequency. The desired broad banded effect is thereby achieved.

The foregoing and other objects, advantages, and novel features of the invention will be more apparent from the following description when taken in connection with the accompanying drawing in which:

Fig. 1 is a longitudinal cross-sectional view of a preferred embodiment of the invention employing air dielectric in one of a pair of waveguides, and

Fig. 2 is a transverse cross-sectional view of another embodiment of the invention.

Referring to Fig. 1, a portion of a simultaneous lobing radar system is shown comprising a pair of horn antennas **10, 12**, supplying energy respectively from or to a pair of hollow pipe rectangular waveguides **14, 16**. The waveguide **14** may be filled with a dielectric **18**. The remainder of the system may be the same as that shown and described in the copending application of W. P. Bollinger et al., Serial No. 198,272, filed November 30, 1950. Briefly, in the system as explained in the said Bollinger et al. application, signals from the two-horn antenna are applied respectively to the two waveguides **14, 16**. In one waveguide **16** there is a phase advance of 90° relative to the other waveguide **14**. The two phase shifted outputs are coupled in a 90° phase shifting directional coupler **34**, and two outputs, one a vector sum voltage and the other a vector difference voltage are applied respectively to a sum amplifier **30** and a difference amplifier **32**. These amplifiers provide two outputs, that from sum amplifier **30** proportional to the amplitude of the echo from an echoing object; and that from difference amplifier **32** proportional in sign and amplitude to the angular displacement of the echoing object from the optical axis of the system as a whole. The echoes may arise from energy applied from a transmitter **38** to a suitable transmit-receive switch arrange-

ment **36** interposed between the coupler **34** and the sum amplifier **30**. If the switch is properly located in a manner which is known to those skilled in the art, pulsed energy on transmission will fire the switch and pass to the antennas. After transmission ceases and on reception, echo energy from objects reflecting the transmitted energy will pass uninterrupted to the sum and difference amplifiers as heretofore explained. These two outputs may be used in various known ways, for example as explained and described in the said Bollinger et al. application. It is not necessary to describe the system further to explain the invention. The portions of the system in the Bollinger et al. application which may be replaced by the portion of the system here shown will be obvious to those skilled in the art. The description of the invention will make apparent to those skilled in the art the use of the invention in this system or in others.

The waveguides **14, 16** are of different electrical lengths but the same physical length, and may therefore conveniently be placed side by side and have a common wall such as wall **21**, if desired. In the example shown here, the electrical lengths are to differ by 90 electrical degrees at the operating frequency. It is desirable to preserve this relative phase shift between energy passing through waveguides **14** and **16** over a wide frequency band about the operating frequency.

Let the dielectric constant of dielectric **18** be ϵ_1, and the dielectric constant of the dielectric in the other waveguide be ϵ_2. Let the wavelengths in the waveguides **14, 16** at the operating frequency be respectively λ_{g1}, and λ_{g2}, and the waveguide widths be a_1 and a_2 respectively. The phase shift in a length l of waveguide for waveguide **14** is:

$$\theta=\frac{2\pi l}{\lambda_{g1}}=\frac{2\pi l}{\lambda_0}\sqrt{\epsilon_1-(\lambda_0/2a_1)^2} \tag{1}$$

where l is the length of waveguide, λ_0 is the free space wavelength at the operating frequency, and a_1 is the width of the rectangular waveguide **14**. It is assumed that the waveguides are operated in the dominant and usual TE_0, **1** mode.

The wavelength in waveguide **14** is:

$$\lambda_{g1}=\frac{\lambda_0}{\sqrt{\epsilon_1-(\lambda_0/2a_1)^2}}=\frac{1}{\sqrt{\epsilon_1/\lambda_0^2-1/(2a_1)^2}} \tag{2}$$

From Equations 1 and 2 it can be shown that:

$$\frac{\vartheta\theta}{\vartheta\lambda_0}=\frac{-2\pi l\epsilon_1\lambda_{g1}}{\lambda_0^3} \tag{3}$$

Therefore, the phase shift of energy at an operating frequency in waveguide **14** remains relatively the same as that for energy of the same frequency in waveguide **16** when

$$\epsilon_1\lambda_{g1}=\epsilon_2\lambda_{g2} \tag{4}$$

The relation (4) is that the product of the dielectric constant and the waveguide wavelength at the operating frequency in one waveguide is equal to that product for the other waveguide. When this relation holds for waveguides of equal physical length, their electrical lengths will have the same difference over a broad band of frequencies about the operating frequency.

An especially desirable embodiment can be formed with both waveguides of the same internal dimensions, but different dielectric media, one being air filled. Suppose then that $a_1=a_2=a$, and that one wevaguide **16** has air dielectric.

Then we desire to have

$$\epsilon_1\lambda_{g1}=\lambda_{g2} \tag{5}$$

because $\epsilon_2=1$, substantially, waveguide **16** having air or vacuum as the dielectric medium.

It may be proved that it is sufficient in this case if

$$\epsilon_1=\left(\frac{\lambda_{g2}}{2a}\right)_1^2=\frac{\lambda_0^2}{(2a)^2-\lambda_0^2} \tag{6}$$

whereupon (5) is satisfied and one waveguide may have air dielectric and $a_1=a_2$.

To satisfy Equation 6 however, requires that a certain relationship exist between the dielectric constant ϵ_1 of waveguide **14** and the waveguide widths "*a*."

The differential phase shift between the points of energy input and output of the equal lengths of waveguide is

$$\phi=\frac{2\pi l}{\lambda_{g2}}(\epsilon_1-1)=\frac{2\pi l}{\lambda_{g2}}[\lambda_g^2/(2a)^2-1]=\pi l/\lambda_{0a}\frac{\lambda_0^2-2a^2}{\sqrt{4a^2-\lambda_0^2}} \tag{7}$$

when waveguide **16** is air filled. Since hollow-pipe waveguides are manufactured in standard widths, the value of "*a*" to be inserted in Equations 6 and 7 is preferably that usually selected for the operating frequency. However, the length l and the dielectric constant ϵ may still be selected to satisfy the desired criteria, because it turns out that in most practical cases the dielectric constant required is less than is available in several low loss materials. Hence the required value of ϵ is readily realized by filling only a portion of the waveguide with a single dielectric or using two dielectrics as more fully described in connection with Fig. 2. Hence Equations 6 and 7 can always be satisfied. There is, however, one additional criteria in a practical design that may make it necessary to use a non-standard width "*a*," in order to broadband at a given wavelength λ_0. In order to avoid reflections in the loaded guide, the loaded section should preferably be exactly an integral number of half guide wavelengths long at the center operating frequency. If this is done the reflection arising at the beginning of the section cancels out the reflection arising at the end of the section.

It may at times be desirable to use different solid dielectric media in waveguides **14** and **16**. Various values of ϵ_1 and ϵ_2 can be obtained, if not directly, by completely filling the waveguide, then by partially filling the waveguide, for example, as illustrated by the dielectric **20** partially filling waveguide **14** shown in Fig. 2; or by using two different solid dielectrics in one waveguide, as the dielectrics **22** and **24** in waveguide **16** of Fig. 2. Other arrangements by which different effective dielectric constants ϵ_1 and ϵ_2 can be derived are known to those skilled in the art.

Thus the invention disclosed comprises a system wherein a pair of hollow pipe waveguides are of the same physical length, and in which the dielectric constant and transverse waveguide dimensions may be selected to make the rate of change of phase shifts with respect to wavelength (or frequency) equal at the operating frequency. A broad-banded effect is thereby secured, whereby the relative phase shift in the two waveguides is maintained over a large band of frequencies about the operating frequency.

What is claimed is:

1. A microwave antenna system for maintaining substantially constant the relative phase shift of microwave energy transmitted or received over a broad range of frequencies about an operating frequency comprising, a first hollowpipe waveguide of physical length l, width a_1, height b, guide wavelength λ_{g1}, and an effective dielectric constant ϵ_1 at said operating frequency, a second hollowpipe waveguide of physical length l, width a_2 height b, guide wavelength λ_{g2} where λ_{g2} is different from λ_{g1}, and an effective dielectric constant ϵ_2 at said operating frequency where ϵ_2 is different from ϵ_1, ϵ_1, λ_{g1}, ϵ_2, and λ_{g2} being related by the equation $\epsilon_1\lambda_{g1}=\epsilon_2\lambda_{g2}$, said first and second waveguides being positioned side by side, means coupled to one end of said first and second waveguides for introducing microwave energy into said waveguides whereby the phase of the energy introduced into said first waveguide differs from the phase of the energy introduced into said second waveguide by an amount equal to the difference

in phase shift of the energies transmitted through said waveguides, and a microwave horn connected to the other end of said first and second waveguides for radiating a pair of overlapping beams of microwave energy.

2. Apparatus as claimed in claim 1 wherein $a_1=a_2$.

3. Apparatus as clamed in claim 1, said second waveguide having an effective dielectric constant of unity, and a wavelength λ_{g2} at the operating frequency, said first waveguide having an effective dielectric constant ϵ and a waveguide wavelength λ_{g1} at the operating frequency, ϵ_1, λ_{g1}, and λ_{g2} being related by the equation $\epsilon\lambda_{g1}=\lambda_{g2}$.

4. Apparatus as clamed in claim 1, said waveguide being rectangular, and being proportioned for the transmission energy at the operating frequency in the dominant mode and having metallic walls and equal internal transverse dimensions between said walls, one of said waveguides having an effective dielectric constant substantially equal to unity, the other said waveguide having a dielectric of dielectric constant ϵ, and

$$\epsilon\lambda_{g1}=\lambda_{g2}$$

where λ_{g1} is the waveguide wavelength at said operating frequency for the solid dielectric waveguide and λ_{g2} is the waveguide wavelength at the operating frequency of the other said waveguide.

5. Apparatus as claimed in claim 1, said first and second waveguides having a common wall.

6. Apparatus as claimed in claim 1, said first and second waveguides being straight along their lengths and disposed side-by-side with said ends to which energy is applied at substantially the same point, and the other ends of said waveguides at substantially another point.

7. Apparatus as claimed in claim 1, said first waveguide being filled with a single solid dielectric substance and said second waveguide being air-filled.

8. Apparatus as claimed in claim 1, said first waveguide being only partially and not entirely filled with a solid dielectric, and said second waveguide being filled with two different solid dielectrics.

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