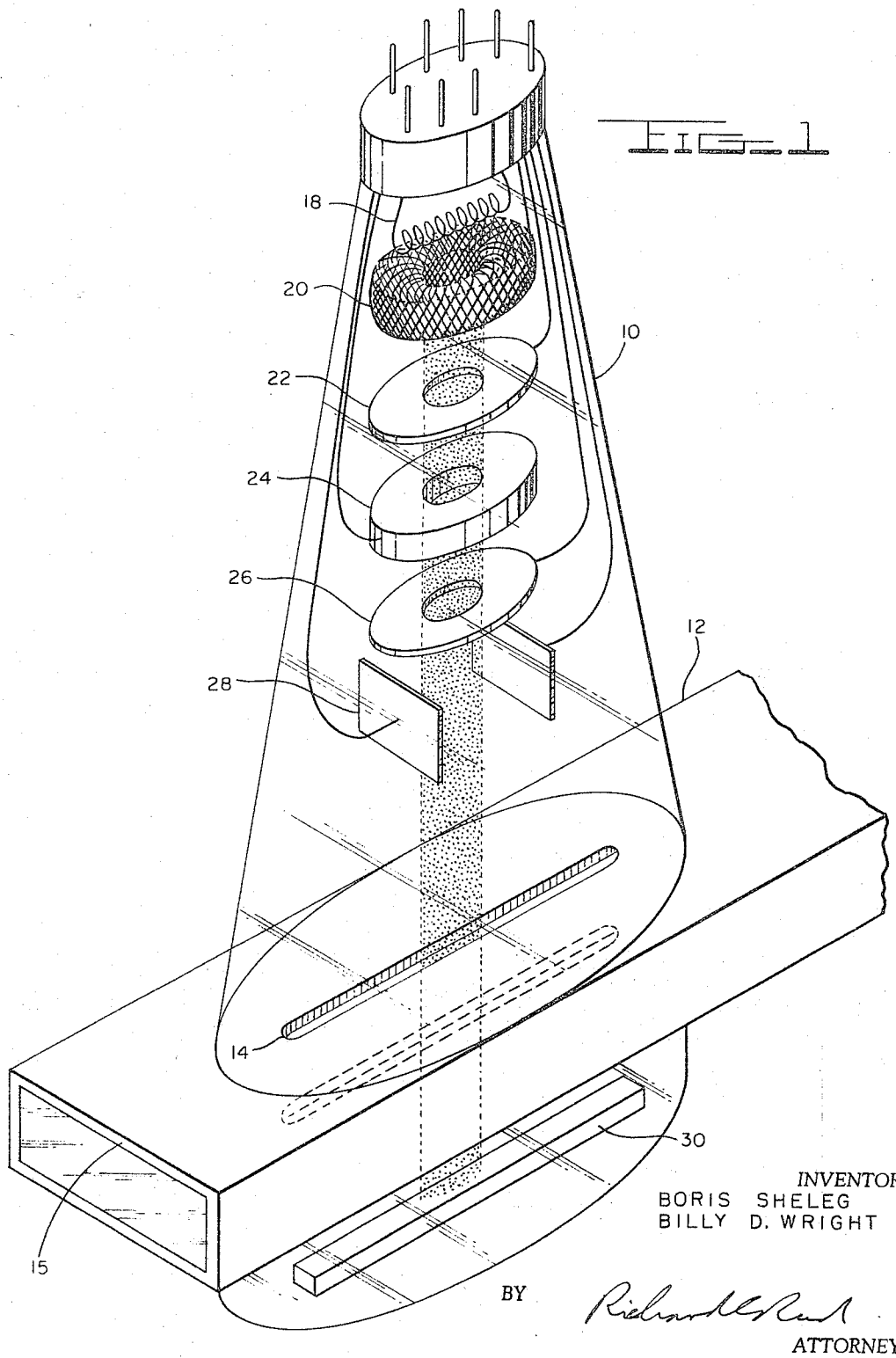
Feb. 28, 1967 B. SHELEG ET AL 3,307,194

HIGH SPEED MICROWAVE PHASE SHIFTER USING A POSITIONABLE ELECTRON BEAM TO CAUSE ELECTRO-MAGNETIC-WAVE REFLECTION

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FIG. 1




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FIG. 2

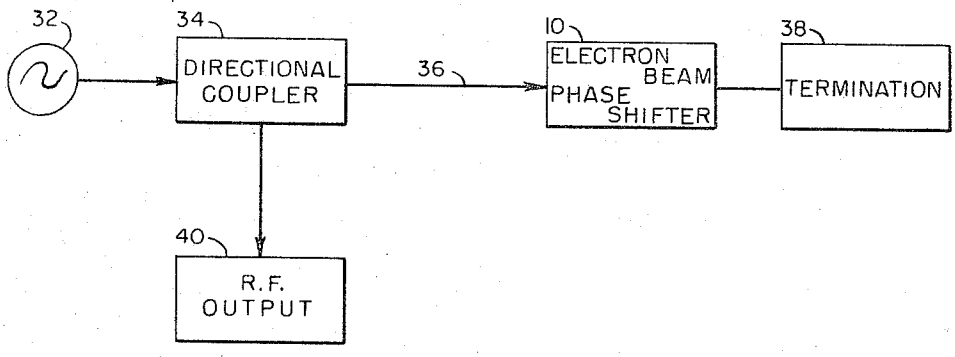
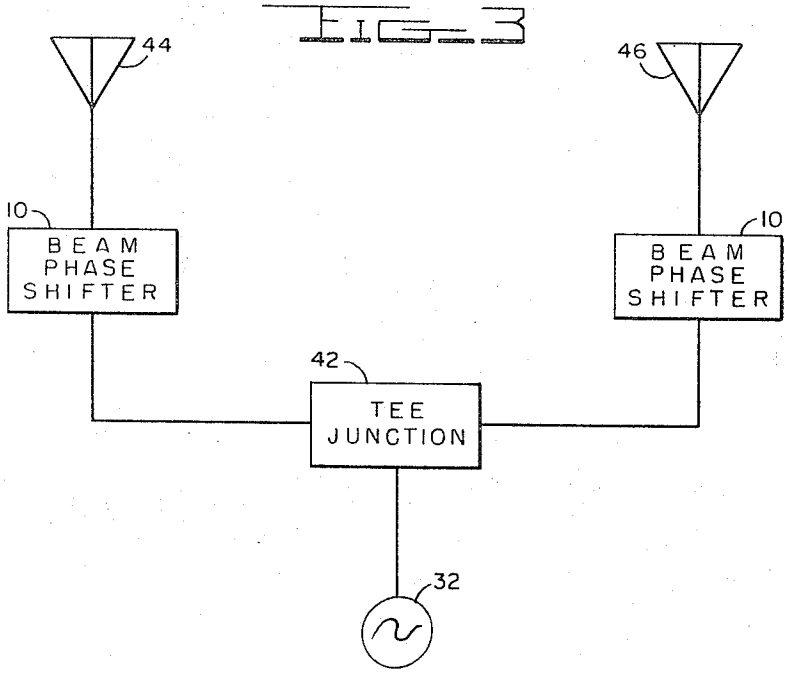



FIG. 3





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3,307,194

# HIGH SPEED MICROWAVE PHASE SHIFTER USING A POSITIONABLE ELECTRON BEAM TO CAUSE ELECTROMAGENTIC-WAVE REFLECTION

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5 Claims. (Cl. 343—701)

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

The present invention relates to a high speed phase shifter and more particularly to a microwave phase shifter employing an electron beam.

In general the means of rapidly phase shifting microwave energy in scanning arrays and microwave systems heretofore available have been in the nature of line stretchers, frequency changers, and ferrite phase shifters. The line stretchers and ferrite phase shifters have a relatively slow response time, while the frequency changer, which has a fast enough response time, has limitations when used in scanning arrays.

The present invention is an electronic phase shifter employing an electron gun emitting a stream of electrons across a waveguide requiring neither frequency change nor additional material to effect a phase shift.

An object of the present invention is the provision of a high-speed phase shifter.

Another object is to provide an electronic on-off switch.

A further object of the invention is the provision of a power monitor.

Still another object is to provide an amplitude modulator.

A final object of the present invention is the provision of a variable attenuator.

Other objects and advantages of the invention will hereinafter become more fully apparent from the following description of the annexed drawings, which illustrate a preferred embodiment, and wherein:

FIG. 1 shows an isometric view of the present invention.

FIG. 2 illustrates how the present invention is integrated into a complete system to provide a variable phase to an antenna.

FIG. 3 is a block diagram showing how two units of the instant invention may be incorporated and combined in a system to provide a scanning antenna.

Briefly, the invention embodies a waveguide which has a longitudinal slot therein, with an electron gun providing an electron beam into the longitudinal slot and across the waveguide. By deflecting the beam along the longitudinal slot, the phase angle of the energy projected into the waveguide can be effectively phased, modulated, attenuatedd, or completely blocked.

Referring now to the drawings in detail, wherein like reference characters designate like or corresponding parts throughout the several views, there is shown in FIG. 1 an electronic phase shifter in the form of a tube **10** which may be made of metal, glass, or the like, mounted on a waveguide **12**, with the waveguide having a longitudinal slot **14** and windows **15** at each end. Tube **10** and waveguide **12** may be made as a single unit, but the preferred embodiment is to affix the top and bottom portions of the tube to waveguide **12** and completely evacuate the air from both components. The waveguide may be of any size or shape and can be of the L, S, or X band type, with both ends of the waveguide being provided with a sealed window, with slot **14** preferably being one wavelength long, but may be of any length, depending on the specific design requirements and uses.



Tube **10** is essentially a typical, standard electron gun having a cathode **18**, control grid **20**, anode **22**, focusing electrode **24**, a second anode **26**, deflection plates **28** and a collecting anode **30**. Cathode **18** is connected to the collecting anode **30** through a current source such as a battery or the like, while deflection plates **28** have a voltage source impressed thereon in order to deflect the electron beam. By establishing a circuit between cathode **18** and anode **30**, a difference of potential exists and a beam of electrons will be projected from the cathode to the anode and thus through slot **14** and across waveguide **12**. If the intensity is made large enough, microwave energy projected into the waveguide will be reflected at the point where the electron beam crosses the slot, and will thereby be reflected back along the waveguide to an external R.-F. output.

By impressing a deflection voltage on deflection plates **28**, the electron beam is shifted in slot **14** either forwardly or rearwardly of the midpoint of the slot, thereby effecting a phase shift of the reflected energy, to an external R.-F. output. At all times it is necessary that the electron beam be parallel to the electric field vector.

In order to accomplish a phase shift the electron beam density must be such that it behaves as a metallic conductor, i.e., a short circuit. In order to compute the density, etc., the following equations are set forth and the construction of the device is dependent upon the choice of parameters used and the amount of microwave energy which is required to be projected to the outside R.-F. output.

(1) Electron beam density:

$$n=\frac{\epsilon_0 m\omega_p^2}{e^2}$$

where:

$\epsilon_0$ is the permittivity of free space
$m$ is the electron mass
$e$ is the charge of an electron
$n$ is the number of electrons per unit volume

$$\omega_p=\sqrt{\frac{ne^2}{m\epsilon_0}}$$

where:

$\omega_p$ is the plasma frequency which is the frequency at which the electrons oscillate about their rest positions

(2) Power requirement:

$$P=\frac{2A\epsilon_0 v^{3/2}\omega_p^2}{\sqrt{2e/m}}$$

where:

A is the cross sectional area of the electron beam
V is the beam voltage

(3) Beam current for the electron gun is:

$$I=KV^{3/2}$$

where:

$K$=beam perveance which is the quotient of the space charge-limited cathode current by the 3/2 power of the anode voltage

(4) Available beam power is:

$$P \text{ available}=KV^{5/2}$$

FIG. 2 shows a typical block diagram arrangement, comprising a signal generator **32** which transmits a signal to a hybrid junction or directional coupler **34**, to the electronic phase shifter **10**, the instant invention, to a termination point **38** which may be an antenna, direct short, or a standard waveguide load. The signal is transmitted via an R.-F. transmission line **36** such as a wave-

guide, coaxial cable, or the like. If phase shifter **10** is not emitting an electron beam across the waveguide **12**, the R.-F. energy transmitted continues through the phase shifter to the termination point **38**. However, if the phase shifter is emitting an electron beam across the path of the R.-F. energy, the energy will be reflected back to the junction point **34** and then to an R.-F. output **40** which may be an antenna, feedboard matrix, or the like. Since the phase angle is directly proportional to the length of path the R.-F. energy must travel, all that is required to shift the phase angle of the microwave energy to R.-F. output **40** is that the electron beam be deflected by means of deflection plates **28**, thereby varying the length of path and thus effecting a phase change at the output. It is apparent, therefore, that if the junction **34** were not present, and microwave energy were required at termination point **38**, phase shifter **10** could be used as an on-off switch simply by having the phase shifter emit, or not emit, electrons across the path of the R.-F. energy generated by the signal generator **32**.

Referring now to FIG. 3, a system in block diagram arrangement is shown which has two phase shifters **10** in the path of the microwave energy generated by a signal generator **32** through a T network **42** to antennas **44** and **46**. By varying the position of the electron beam in phase shifter **10**, the phase in antennas **44** and **46** would likewise be shifted so as to provide a scanning arrangement. As can be seen, any number of the above combinations may be connected together to provide a very desirable scanning antenna. The scan rate would be governed only by the time required to deflect the almost inertialess electron beam emitted by phase shifter **10**.

In summary, the invention encompasses an electron gun across a waveguide, with the electron gun being controlled by an external source separate from that of the microwave energy. Since the phase of the microwave energy (R.-F.) output is proportional to the position of the shorting beam, the desired energy (R.-F.) phase variation amplitude variation, or both, are accomplished by electrically moving the electron shorting beam, emitted by the electron gun, along a longitudinal slot in the waveguide. The time required to move the shorting beam is in the order of millimicroseconds ($10^{-9}$ secs.). Because the speed of moving the shorting beam is in millimicroseconds, the slow response time of the prior devices is overcome, and further, there is no limitation in the scan angle, or the number of targets which can be tracked, when used in a scanning antenna.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood, that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

What is claimed is:

**1.** A phase shifting device comprising:

electron beam producing means,

transmission means having said electron beam producing means mounted upon a portion thereof,

said transmission means having a plurality of elongated slots oriented so as to allow said beam producing means to project a beam of electrons through said slots and across said transmission means, microwave signal means providing a signal into said transmission means, and

means to vary the path length of energy traveling within said transmission means including electron beam deflection means operative to move said electron beam along the length of said slots in a direction parallel to the path of said energy so that said energy impinges upon said beam of electrons at varied points along said transmission means thereby shifting the phase of said energy while maintaining the frequency of said energy at a constant value.



**2.** The device as described in claim **1** wherein said electron beam deflection means includes deflection plates having a deflection voltage impressed thereon.

**3.** A microwave system including at least one phase shifting device comprising:

electron beam producing means,

transmission means having said electron beam producing means mounted upon a portion thereof to provide a beam unit,

said transmission means having elongated slots, one each in the top and bottom, so as to allow said beam producing means to propel a beam of electrons through said slots and across said transmission means,

microwave signal means providing a signal into said beam unit,

means to vary the path length of said signal, said means including electron beam deflections means operative to move said electron beam along the length of said slots in a direction parallel to the path of said signal so that said signal impinges upon said beam of electrons at varied points along said transmission means thereby shifting the phase of said signal while maintaining the frequency of said signal at a constant value,

sealing means on each end of said portion of transmission means thereby permitting said unit to be evacuated, and

termination means, distinct from said microwave signal means, coupled to said transmission means whereby upon the signal intersecting said beam of electrons, said signal is reflected to said termination means.

**4.** The system of claim **3** wherein the electron beam producing means is mounted across said slots and wherein the longitudinal axis of said electron beam producing means is parallel to the electric field vector created by said microwave signal transmitted into said beam unit.

**5.** The system of claim **3** further including:

a plurality of said phase shifting devices,

a plurality of scanning antennas each coupled to a separate one of said phase shifting devices to provide phase differences to radiation emanating from said scanning antennas by introducing said beam of electrons into each of said phase shifting devices at different positions relative to their respective slots at the same instant of time.


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