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SURFACE WAVE DEVICE

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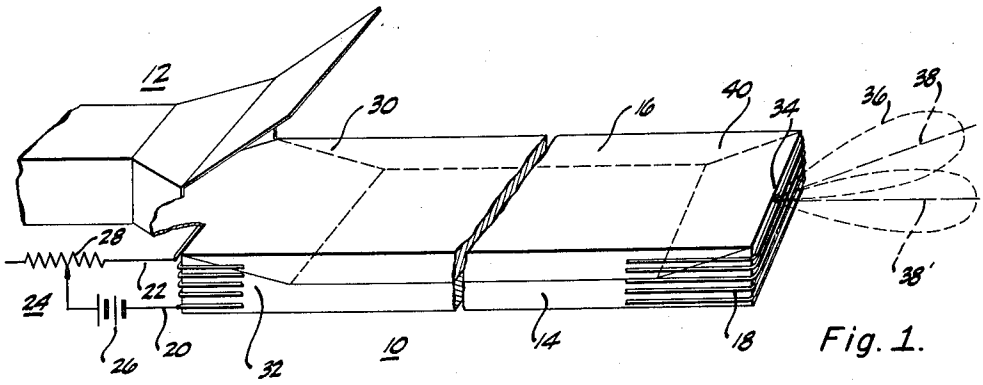


Fig. 1.

Fig. 2.

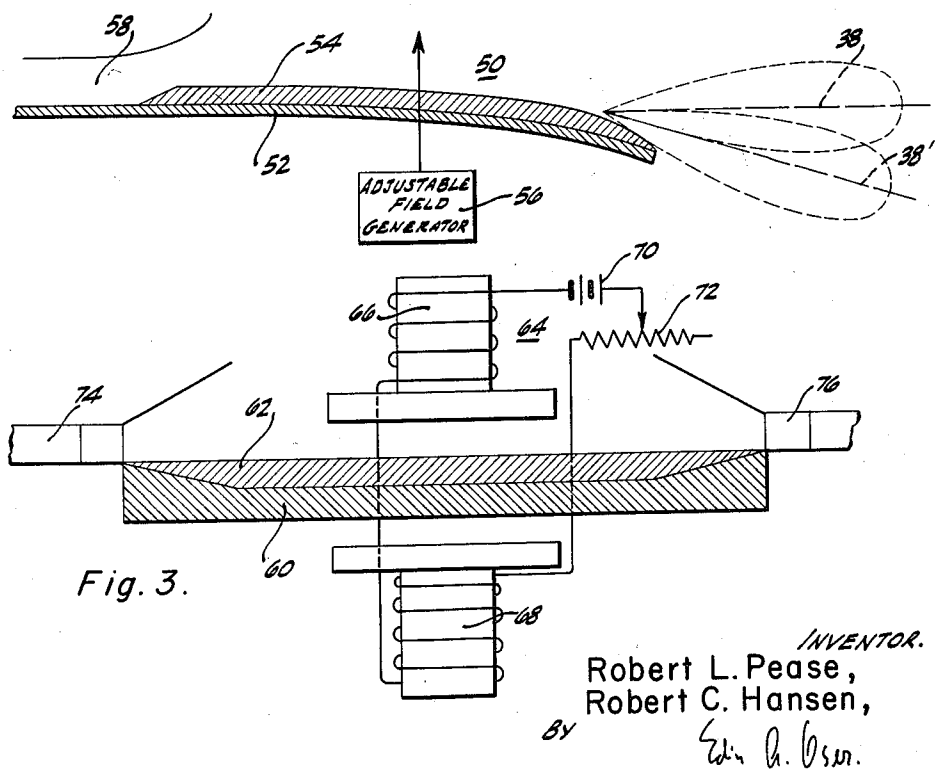


Fig. 3.

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SURFACE WAVE DEVICE

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This invention relates to surface wave structures, and more particularly to a surface wave device wherein the velocity of propagation of surface waves is controllable.

As is well known to those skilled in the art, electromagnetic wave energy may be propagated over a metallic ground plane as a surface wave. The wave energy so propagated is confined to the ground plane by affixing thereto a suitable trapping agent such as a coating of a low-loss dielectric or a plurality of transverse metallic corrugations.

The velocity of propagation of surface waves over surface wave structures depends entirely on the electrical or mechanical characteristics or both of the trapping agent. For example, in corrugated surface wave structures the velocity of propagation depends on the height and width of the grooves and the distance between grooves. In dielectric-clad surface wave structures the velocity of propagation depends on the thickness of the dielectric coating and the transmission characteristics thereof such as the permeability μ and the dielectric constant ϵ. Consequently, if the above named properties of the trapping agent remain unchanged along the direction of propagation, the velocity of propagation of the surface wave likewise remains constant.

Generally speaking, prior art surface wave structures are essentially devices providing constant velocity surface wave propagation. The only exception thereto known to the applicants is a corrugated surface phase shifter wherein the depth of the corrugation is mechanically adjustable. Such a phase shifter has been used to feed an antenna array to provide beam scanning. One disadvantage of such a phase shifter is the inherent limitation associated with all mechanical motion devices, namely slow scan speeds. Another disadvantage is great mechanical complexity.

The major application of surface wave structures is found in the antenna field. One of the characteristics of a surface wave is that its phase velocity is always less than the corresponding phase velocity in free space. For this reason surface waves are often referred to as slow waves. As a result of this characterisitc, surface wave antennas radiate end-fire wave energy beams. The reason that an end-fire wave energy beam is radiated may be understood physically by noting that since the waves are slow, there is no real angle at which radiation could emerge in phase. The angle at which the wave energy beam is radiated into space should theoretically be independent of the velocity of propagation. However, it has been found that this requires an infinite ground plane. In practice, short ground planes are used and the angle of the radiated beam, called the tilt angle, is not zero. It has also been found that the tilt angle is a function of the velocity of propagation of the surface waves.

One great disadvantage of such surface wave antennas is their inability to scan. For a given trapping agent, a constant tilt angle is obtained. As is well known, many applications of microwave antennas require beam scanning or tracking so that the direction of a distant object

may be determined without physically moving the antenna.

It is therefore an object of this invention to provide a surface wave structure of the dielectric-clad type in which the velocity of propagation of surface waves may be altered.

It is another object of this invention to provide a surface wave antenna of the dielectric-clad surface wave structure type adapted to scan the radiated beam, by changing the tilt angle.

It is still another object of this invention to provide an electrically scanning surface wave antenna, in which the magnitude and the rate of change of the tilt angle is a function of the magnitude and periodicity of an applied magnetic or electric field.

It is a further object of this invention to provide a surface wave phase shifter of the dielectric-clad surface wave structure type adapted to provide a predetermined phase shift as a function of an externally applied magnetic or electric field.

In accordance with one embodiment of this invention a surface wave of electromagnetic energy is confined to a low-loss dielectric trapping agent adjacent to a metallic ground plane. The trapping agent is made of such a material that upon being subjected to an external field either the permeability μ or the dielectric constant ϵ is altered. The effect of such a change of the transmission characteristics of the trapping agent results in a change of the velocity of propagation of the surface wave over the metallic ground plane. If the trapping agent is a ferromagnetic material, a magnetic field will change the permeability μ. Similarly, if the trapping agent is a ferroelectric material an electric field changes the dielectric constant ϵ.

The terminology which is used in the description of the invention has been adopted from "The International Dictionary of Physics and Electronics" published by the Van Nostrand Co., Inc., 1956. The term ferrite is generic and includes ferromagnetic and ferroelectric materials. Also the term field includes electric and magnetic fields.

The above mentioned phenomena are successfully employed in a surface wave antenna where a change of the velocity of propagation of a surface wave produces a change in the tilt angle of the radiated beam of wave energy. Likewise this phenomenon is also advantageously employed in phase shifters using the surface wave structure of this invention wherein a change of the propagation velocity of the surface wave provides a change in the relative phase between an input and an output wave.

The novel features which are believed to be characteristic of the invention, both as to its organization and method of operation, together with further objects and advantages thereof, will be better understood from the following description considered in connection with the accompanying drawing in which several embodiments of the invention are illustrated by way of example. It is to be expressly understood, however, that the drawing is for the purpose of illustration and description only, and is not intended as a definition of the limits of the invention.

Figs. 1 and 2 are respectively a perspective view and a cross-sectional view of two different surface wave antennas each of which embodies a surface wave device in accordance with this invention; and

Fig. 3 is a cross-sectional view of a phase shifter which embodies the surface wave device in accordance with this invention.

Referring now to the drawing wherein like or corresponding parts are designated by like reference characters throughout the several views, there is shown in

Fig. 1 a surface wave antenna constructed in accordance with the principles of this invention. The surface wave antenna comprises a surface wave structure **10**, and an H-plane sectoral horn **12** coupled thereto. The surface wave structure **10** includes a finite metallic ground plane such as the plane member **14** one surface of which has affixed thereto, for example, by bonding, a low-loss dielectric trapping member **16**. Surrounding the combination of the ground plane **14** and the trapping member **16** is a coil of wire **18** shown broken away for purposes of clarity. The coil **18** is excited by coupling respective wire terminals **20** and **22** across an adjustable current source **24** which may include a battery **26** and a rheostat **28** as shown.

When a voltage is impressed upon the end terminals **20** and **22** of the coil **18**, a current will flow. As is well known, the current will set up an axial magnetic field inside the coil **18** extending vertically through the ground plane **14** and trapping member **16**. If the ground plane **14** is made of some non-ferrous metallic material such as copper, the magnetic field will penetrate through the ground plane **14** and impress a magnetic field upon the dielectric member **16**.

The low-loss dielectric member **16** is composed of some material which changes one or more of its transmission characteristics when subjected to a magnetic field. For example, if the dielectric member **16** is made of a ferromagnetic material, its permeability μ is some function of the applied magnetic field.

Consequently, a change of the setting of the potentiometer **28** causes a change in the magnitude of the magnetic field penetrating the ferromagnetic element **16** which in turn produces a corresponding change in the permeability μ. As indicated hereinabove a change in the permeability μ will result in a change of the velocity of propagation of surface waves which travel substantially inside the member **16** over the ground plane **14**.

The operation of the invention of Fig. 1 will now be explained. Wave energy from horn **12** which is coupled to some wave energy source not shown in Fig. 1 is transferred by the flared mouth of the horn **12** onto the surface wave structure. To provide smooth transition between the horn **12** and the surface wave structure **10** it has been found desirable to taper the end portion **30** of the dielectric member **16**. From the point of view of providing a good impedance match it is immaterial whether the ground plane **14** is provided with a matching tapered end portion **32** as shown in Fig. 1 to fit the dielectric member flush to the ground plane **14** or whether a dielectric member having tapered end portions is affixed to the top of a ground plane having a planar surface. From a practical point of view it may be more desirable to imbed the dielectric member **16** into the ground plane **14** to provide additional mechanical strength to the bond therebetween.

The surface wave is propagated over the ground plane **14** towards the radiation edge **34** where the surface wave is radiated into space in the form of a beam **36** having a beam axis **38**. The angle between the beam axis **38** and the plane determined by the surface of the ground plane **14** is usually referred to as the lead angle. If the length of dielectric member **16** is much greater than the working wavelength and if an infinite ground plane extension is provided instead of the radiation edge **34** the lead angle of the resulting beam would be equal to zero. Without such a ground plane extension radiation will take place at the sharp radiation edge **34**, and the lead angle of the resulting beam **36** is a function of the length of the surface wave structure **10** and the velocity of propagation of the surface wave therein. Changing the strength of the magnetic field and thereby altering the value of the permeability μ results in a change of the velocity of propagation of the surface waves.

For a surface wave structure of given length it has been found that a change of the strength of the magnetic field produces an appreciable change in the lead angle. In other words, by respectively increasing or decreasing the magnetic field the lead angle decreases or increases. The effect resulting from a change of the magnetic field strength upon the lead angle was found to be most pronounced when the ground plane **14** and the dielectric member **16** terminated together upon the sharp radiation edge **34**. This may be explained by observing that in the absence of a field the lead angle is greatest when termination of the dielectric member and the ground plane are upon a single sharp edge. The effect of the field is to tilt the beam to a position of zero lead angle.

The tapered section **40** of the dielectric member **16** is not essential to the operation of this invention but provides a smooth transition between the surface wave structure **10** and free space and minimizes reflected waves from being set up and disturbing the beam pattern.

It has been found that for a surface wave structure of the type shown in Fig. 1 being approximately 10 working wavelengths long and having affixed thereto a ferrite slab having a thickness of approximately 0.025 working wavelength, a change of the tilt angle from about 14° to 0° could be obtained with the application of the magnetic field having a strength of 100 oersteds. Fig. 1 shows this change by superimposing a second beam having a beam axis **38'**.

Referring now to Fig. 2 there is shown a surface wave structure **50** comprising a curved ground plane such as member **52**, a dielectric member **54** affixed thereto and an adjustable field generator **56**. A source means such as the horn **58** provides a convenient way of exciting a trapped surface wave within the surface wave structure **50**. The adjustable field generator **56** is an adjustable field means adapted to impress upon the dielectric means **54** either an electric or a magnetic field to effect a change in the transmission characteristics thereof. The field generator **56** may be coupled to a programming unit to produce variation in the field in a predetermined manner or may be provided with a manually operated adjustment means. Furthermore, the field generator may comprise an electromagnet or a combination of a permanent magnet and electromagnet or it may be a large capacitor creating an electrostatic field between its plates.

The dielectric member **54** is usually a ferrite but may be some other substance whose transmission characteristics are a function of an applied field. If a ferromagnetic material is selected, the generator **56** must provide a magnetic field to alter the permeability μ thereof. If a ferroelectric material is selected the generator **56** must provide an electric field to alter the dielectric constant thereof.

The operation of the surface wave antenna of Fig. 2 is the same as the operation of the surface antenna of Fig. 1. The beam axis **38** obtains when the generator **56** is inactive whereas the beam axis will assume the position shown at **38'** when the generator **56** is energized.

Fig. 3 shows a surface wave phase shifter having a ground plane **60** to which is bonded or otherwise affixed a low-loss dielectric member **62** whose transmission characteristics are a function of an applied field means **64**. The field means **64** are shown by way of example as comprising two electromagnets **66** and **68** serially connected to one another and excited by battery **70** connected to a variable resistor **72** in the manner shown in Fig. 3. It will be obvious to those skilled in the art that electromagnet **66** may be entirely eliminated so that the field is generated by electromagnet **68**. Also if both electromagnets **66** and **68** are employed, the pole piece of electromagnet **66** must be placed at such a distance from the surface wave structure as not to physically interfere with the surface wave propagation. The combination of the ground plane member **60**, the dielectric member **62**, and the adjustable field means **64** is the surface wave structure of this invention. Coupled to the ends of the ground plane **60** are input and output terminals

74 and 76 respectively. Such input and output terminals may comprise H-plane sectoral horns similar to the horn 12 shown in Fig. 1.

The operation of the phase shifter of this invention of Fig. 3 is again similar to the operation of the wave energy antenna of Fig. 1 except that instead of radiating the surface wave in the form of a beam, a second sectoral horn or some other means are provided to utilize the energy in some other way. As indicated above, the dielectric member 62 is composed of a material whose transmission characteristics are a function of an applied field. If a magnetic field is provided the dielectric selected is preferably a ferromagnetic substance or at least one exhibiting the property of changing its permeability with the application of a magnetic field. The adjustable field means 64 is shown in Fig. 3 by way of example only and it is to be understood that other known ways of establishing a magnetic or an electric field may be substituted therefor.

There has been shown and described a surface wave structure which is adapted to change the velocity of propagation of the surface wave progagated therethrough. This change in the velocity of propagation is accomplished by impressing upon a dielectric trapping agent either an electric or a magnetic field. What is essential to the successful operation of this invention is that the dielectric member has transmission characteristics which are functions of an externally applied electric or magnetic field.

What is claimed is:

1. A surface wave antenna adapted to scan a beam of electromagnetic wave energy and comprising: a metallic ground plane; a ferroelectric member bonded to said ground plane, the dielectric constant ϵ of said member being a function of an externally applied electric field; adjustable electric field means disposed for impressing an adjustable electric field upon said ferroelectric member; and source means disposed for exciting a surface wave within said ferroelectric member.

2. A surface wave antenna adapted to scan a beam of electromagnetic wave energy and comprising: a metallic ground plane having a radiation edge; a ferromagnetic member of substantially uniform thickness bonded to said ground plane, said member having a tapered portion at one end thereof to provide a smooth free-space transition, the thin edge of said tapered portion terminating upon said radiation edge, the permeability μ of said member being a function of an externally applied magnetic field; adjustable magnetic field means disposed for impressing a magnetic field upon said ferromagnetic member; and source means disposed for exciting a surface wave within said ferromagnetic member.

3. A surface wave transmission line adapted to shift the phase of electromagnetic wave energy propagated therein and comprising: a metallic ground plane; a ferromagnetic member of substantially uniform thickness bonded to said ground plane, said member having two tapered end portions defining respectively input and output terminals and providing smooth transitions, the permeability μ of said member being a function of an externally applied magnetic field; adjustable magnetic field means disposed for impressing a magnetic field upon said ferromagnetic member; source means coupled to said input terminal for exciting a surface wave within said ferromagnetic member; and a load device coupled to said output terminal for abstracting said surface wave from said ferromagnetic member.

4. A surface wave antenna for providing a scanning beam of electromagnetic wave energy and comprising: a substantially planar metallic ground plane having a radiation edge; a planar surfaced ferromagnetic member bonded to said ground plane and substantially coextensive therewith, said ferromagnetic member having a tapered portion at the radiation edge of said ground plane to provide a smooth free-space transition, the thin edge of said tapered portion terminating upon said radiation edge, said ferromagnetic member having a length along a longitudinal axis substantially normal to said radiation edge which is approximately ten working wavelengths of the electromagnetic wave energy employed; adjustable means including a plurality of windings around the periphery of the structure defined by said ground plane and said ferromagnetic member which is substantially normal to the planar surface thereof; and electromagnetic wave energy source means disposed adjacent an edge of said ground plane and said ferromagnetic member and operatively associated therewith for exciting a surface wave within said ferromagnetic member.

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