Feb. 6, 1962 R. S. COLE ET AL 3,020,501

WAVEGUIDES

Filed May 10, 1957 2 Sheets-Sheet 1

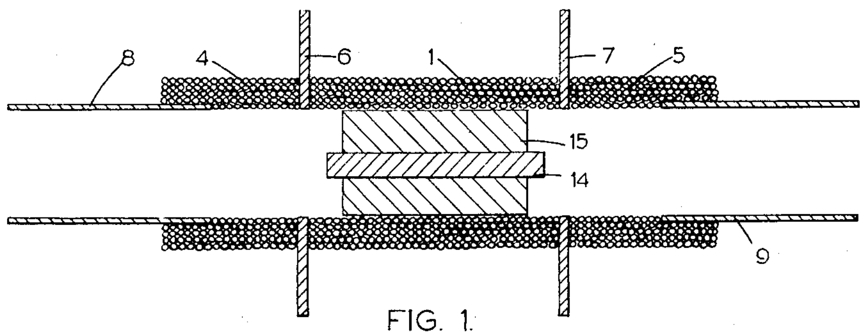

FIG. 1.

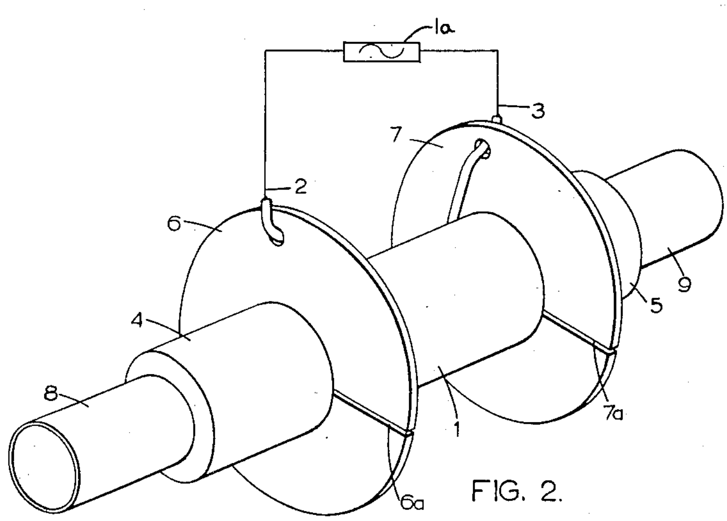

FIG. 2.

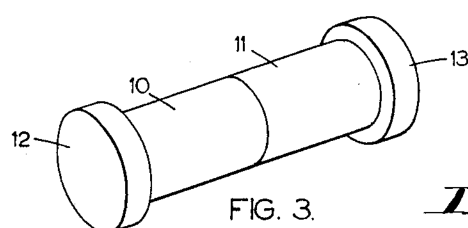

FIG. 3.

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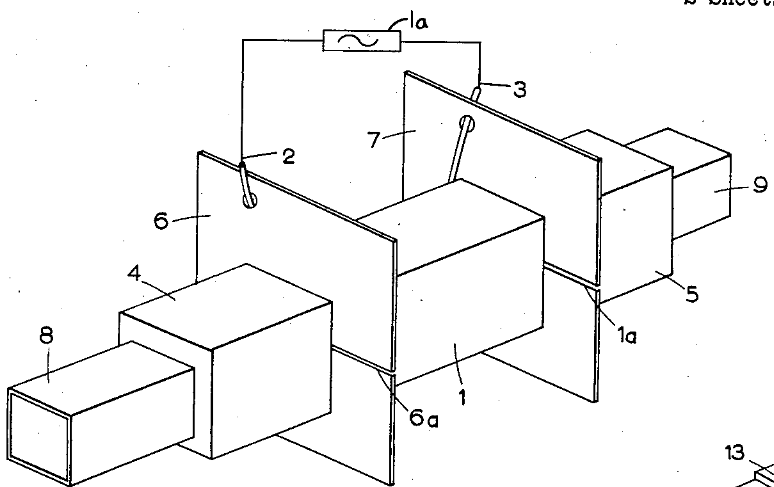


FIG. 4.

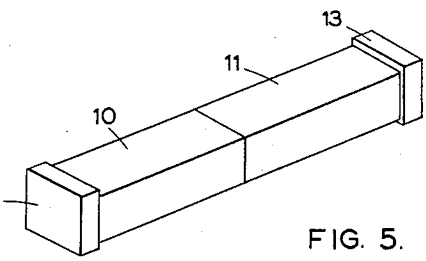
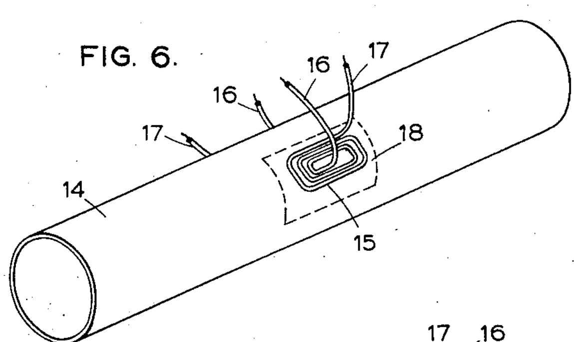


FIG. 5.

FIG. 6.



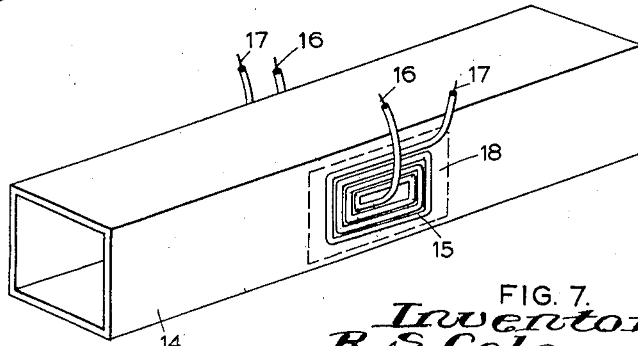


FIG. 7.

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WAVEGUIDES

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Filed May 10, 1957, Ser. No. 658,389
Claims priority, application Great Britain May 12, 1956
8 Claims. (Cl. 333—98)

This invention relates to waveguides.

Microwave ferromagnetic materials such as ferrites can be employed in a waveguide to provide a high speed amplitude or phase modulator or a high speed switch. Ferrite switches have many useful applications resulting from the fact that they can be operated at considerably higher frequencies than many other forms of switches. The permeability of microwave ferromagnetic materials is controlled by introducing into the waveguide alternating magnetic fields. The introduction of such a field through the waveguide wall, however, is impeded by eddy current losses within said wall. It is known to reduce eddy current losses in a waveguide by splitting the waveguide wall to cut the path of the eddy currents, or by reducing the thickness of the waveguide wall, but both of these methods become less effective as the frequency of the magnetic field increases. Thus if a slot is provided in the wall of the waveguide the slot will tend to radiate power and if the thickness of the waveguide wall is decreased transmission losses are increased and furthermore with such a reduced thickness of wall it may be necessary to form the wall as a thin conducting coating on a dielectric support which is difficult to prepare.

The object of the present invention is to provide an improved waveguide including a microwave ferromagnetic material whereby an alternating magnetic field can be introduced to control the permeability of said material in such a manner that eddy current losses in the waveguide wall are substantially reduced.

According to the invention there is provided a waveguide, microwave ferromagnetic material arranged in said waveguide, said waveguide having a wall which comprises a coil having a plurality of turns insulated from one another and wound sufficiently closely so that the capacity between adjacent turns is such as to conduct electromagnetic energy propagated through said waveguide, and means for applying an alternating current to said coil to set up an alternating magnetic field in said waveguide to control the permeability of said material.

The invention can be employed to set up an alternating magnetic field within the waveguide either in a longitudinal or a transverse direction and the wall of said waveguide can either be constituted by said coil or said coil can form a part of said wall.

In order that the present invention may be clearly understood and readily carried into effect, the same will be more fully described with reference to the accompanying drawings, in which:

FIGURE 1 is a sectional view of a waveguide in accordance with one embodiment of the invention,

FIGURE 2 is a perspective view of said waveguide, and

FIGURE 3 shows a former which may be used for the construction of coils forming a part of said waveguide.

Reference will also be made to the accompanying drawings in which:

FIGURE 4 shows a perspective view of a further embodiment of the invention,

FIGURE 5 shows a perspective view of a former which may be used for the construction of the coils employed in FIGURE 4 and,

FIGURES 6 and 7 show perspective views of further embodiments of the invention.

Referring to FIGURES 1 and 2 of the drawings, the invention is shown, by way of example, as applied to a circular waveguide in which a longitudinal alternating magnetic field is required to be set up in microwave ferromagnetic material arranged in said waveguide so as to control the permeability of said material. As shown the waveguide comprises a solenoidal coil **1** the ends **2** and **3** of which are connected to a source *1a* of alternating current, so as to set up an alternating magnetic field within said wave-guide. The frequency of said alternating current can be of the order of 100 kilocycles per second and the magnetic field set up within the waveguide is conveniently of the order of 50 gauss. The ferromagnetic material is indicated at **14** and is of rod form supported coaxially in the coil **1** by means of polystyrene foam **15**. Alternatively said material can be provided in any other convenient form and may for example be arranged to fill the waveguide or a section thereof. At the ends of said coil **1** are provided further coils **4** and **5** separated from the coil **1** by aluminium spacers **6** and **7** each having a gap in the form of a radial slot, *6a* and *7a*, therein to prevent a short circuited turn. The turns of the coils **1**, **4** and **5** are insulated from one another such as by employing insulated wire and said turns are arranged sufficiently closely together to prevent the escape of high frequency energy transmitted along the waveguide whilst the capacity between adjacent turns is sufficient to enable the high frequency currents to be conducted along the guide. The further coils **4** and **5** are so constructed that the end portions thereof can surround the ends of brass cylindrical waveguide sections **8** and **9**. The internal diameter of the coil **1** is made substantially identical with that of the sections **8** and **9**, and the further coils **4** and **5** also have the same internal diameter with the exception of said end portions thereof the internal diameter of which is made substantially equal to the external diameter of the sections **8** and **9**. The further coils **4** and **5** through which no current is passed are included for the purpose of preventing the short circuited turn effect of a circular waveguide by preventing the end turns of the coil **1** from being short circuited by the waveguide sections **8** and **9**.

The coils **1**, **4** and **5** may be formed by winding lengths of insulated wire on a waxed former of the shape shown in FIGURE 3, the former being provided at each end with a collar **12** and **13**. The central portion of the former has a diameter substantially equal to the internal diameter of the sections **8** and **9** whilst the collars **12** and **13** each have a diameter equal to the external diameter of said sections **8** and **9**. Thus the coil **1** is wound on said central portion of the former whilst the further coils **4** and **5** are each wound partly on said central portion and partly on one of the collars **12** and **13** so that the sections **8** and **9** can subsequently be fitted into the ends of the further coils **4** and **5** as shown in FIGURE 1. The former is constructed in two portions **10** and **11** so that it can readily be withdrawn after formation of the coils **1**, **4** and **5**. Removal of the former is facilitated by the layer of wax with which it is provided and the coil can be made self supporting by impregnation with a suitable insulating material such as an epoxy resin, for example Araldite (registered trademark). A six inch length of the coil **1** having an internal diameter of approximately one inch may be constructed by layer winding say, 1,000 turns of 25 S.W.G. wire onto the waxed former.

A waveguide such as described above comprising a six inch length of coil **1** has been found to have substantially the same impedance as a similarly dimensioned solid walled waveguide with a loss of approximately 1 db along its length when used to propagate electro-magnetic energy of approximately 3 cm. wavelength.

The coil may in some cases be supported on a low loss dielectric substance such as polystyrene or polythene, for example.

The invention can also be employed with rectangular waveguides. Such a waveguide is shown in FIGURE 4 and is similar in construction to the waveguide shown in FIGURE 2 apart from the cross sectional shape. Reference numerals identical to those used in FIGURE 2 are used in FIGURE 4. The solenoid coils **1**, **4** and **5** shown in FIGURE 4 can be wound on a former such as the one shown in FIGURE 5. The external dimensions of said former correspond to the internal dimensions of the sections **8** and **9** whilst the external dimensions of the collars **12** and **13** correspond to the external dimensions of said sections **8** and **9**. Thus the waveguide shown in FIGURE 4 can be constructed in a similar manner to that already described with reference to the waveguide shown in FIGURE 2. It will be appreciated that a longitudinal sectional view of the waveguide of FIGURE 4 will be identical with the view shown in FIGURE 1.

The spacers **6** and **7** are employed as described above for the purpose of convenience in the case in which the coils **1**, **4** and **5** are each wound separately. If desired, however, the three coils may be wound as one composite coil and tappings can be taken for the coil **1** and the composite coil cut to provide the three separate coils **1**, **4** and **5**. For this purpose the layers of the composite coil may be wound in such a manner that a few, say three turns, are first wound and then subsequent turns are wound on those few turns until a sufficient depth of winding is built up and then the subsequent turns of the coil can be wound superimposed on one another adjacent to or side-by-side with the initial turns. This enables the complete composite coil to be built up during winding from one end thereof to the other so that said composite coil may be cut to form the three separate coils **1**, **4** and **5**.

The coils **1** shown in FIGURES 1, 2 and 4 serve to set up when energised with an alternating current a longitudinal alternating magnetic field in the ferromagnetic material **14**. In some cases it may, however, be desired to set up a transverse alternating magnetic field. FIGURES 6 and 7 illustrate arrangements for this purpose as applied respectively to circular and rectangular waveguides. In the case of a circular waveguide the coils which are to be energised can be provided in the form of spiral coils wound in circular or rectangular form and bent to arcuate shape so as to have the radius of curvature of the required waveguide. As shown in FIGURE 6 the coils **15** are wound in rectangular form and are inserted in oppositely disposed apertures in the wall **14** of a waveguide. Only one coil **15** is shown in the drawing but a second diametrically opposite coil is similarly provided. Alternating current is applied to the coils **15** via terminal leads **16** and **17**. If desired a further coil may be associated with each of the coils **15** said further coil through which no current is passed being adapted to surround the terminal winding or windings of the respective coil **15** so as to have the effect of preventing a short circuited turn of said coil **15** in a manner similar to that described in connection with the coils **4** and **5**. The position of said further coil is indicated by the dotted line **18**.

In the case of a rectangular waveguide into which a transverse alternating magnetic field is required to be introduced, the coils which are to be energised to produce said field are oppositely disposed and can be in the form of a spiral of circular or rectangular form. As shown in FIGURE 7 the coils **15** are flat rectangularly wound spiral coils which are provided in apertures in opposite walls of the waveguide **14**. Alternating current is applied to said coils **15** via terminal leads **16** and **17** thereof so as to set up a transverse alternating magnetic field within said waveguide. As in FIGURE 6 a dotted line **18** is shown in FIGURE 7 indicating the position of a further coil which can be provided to prevent short circuiting of the outer turns of the coil **15**.

Where a further coil is provided to surround a spiral coil such as the coil **15** in FIGURE 6 or 7, said further coil can be separately wound or can be wound with the coil **15** so as to form a composite coil which can subsequently be cut to separate said coils and tapped to provide means for feeding alternating current to said coil **15**. If desired a spacer can be provided between the coil **15** and further coil said spacer having a gap so as to prevent the formation of a short circuited turn. If the coil **15** is a flat spiral circularly wound coil the spacer can be provided in the form of a split ring whilst if the coil **15** is flat and rectangularly wound as shown in FIGURE 7 the spacer can be of similar form but having a substantially rectangular cross section. Where the coil **15** is of other shape the spacer will be provided of suitable shape to surround the terminal turn or turns of the coil **15**.

If desired microwave ferromagnetic material can be arranged in a waveguide in which a transverse alternating magnetic field is set up such as the waveguide in FIGURE 6 or 7, said alternating magnetic field serving to control the permeability of said microwave ferromagnetic material.

Waveguides as described above can be employed to provide a high speed amplitude or phase modulator or switch or to control the permeability of a microwave ferromagnetic material for any other purpose.

What we claim is:

1. A waveguide, microwave ferromagnetic material arranged in said waveguide, said waveguide having a wall portion which is a coil having a plurality of turns insulated from one another and wound sufficiently closely so that the capacity between adjacent turns is such as to conduct electromagnetic energy propagated through said waveguide, and means for applying an alternating current to said coil to set up an alternating magnetic field in said waveguide, to control the permeability of said material.

2. A waveguide, microwave ferromagnetic material arranged in said waveguide, said waveguide having a wall portion which consists of a solenoid coil having a plurality of turns insulated from one another and wound sufficiently closely so that the capacity between adjacent turns is such as to conduct electromagnetic energy propagated through said waveguide, and means for applying an alternating current to said coil to set up an alternating longitudinal magnetic field in said waveguide to control the permeability of said material.

3. A waveguide having wall portions which are oppositely disposed spiral coils each having a plurality of turns insulated from one another and wound sufficiently closely so that the capacity between adjacent turns is such as to conduct electromagnetic energy propagated through said waveguide and to set up an alternating magnetic field in said waveguide when alternating current is fed to said coil, which field is transverse to the axis of said waveguide.

4. A waveguide according to claim 3, and microwave ferromagnetic material arranged in said waveguide, said alternating magnetic field controlling the permeability of said material.

5. A waveguide, microwave ferromagnetic material arranged in said waveguide, said waveguide having a wall portion which consists of a solenoid coil having a plurality of turns insulated from one another and wound sufficiently closely so that the capacity between adjacent turns is such as to conduct electromagnetic energy propagated through said waveguide, and means for applying an alternating current to said coil and to set up an alternating longitudinal magnetic field in said waveguide to control the permeability of said material, and two further coils insulated from and adjacent respective ends of said solenoid coil to prevent short circuiting of the turns of said solenoid coil at said ends, and wound to conduct

electromagnetic energy propagated through said waveguide.

6. A waveguide according to claim 5 comprising a conducting spacer disposed between said solenoid and each of said further coils, said spacer having a gap to prevent said spacer from constituting a short circuited turn.

7. A waveguide having wall portions which are oppositely disposed spiral coils each having a plurality of turns insulated from one another and wound sufficiently closely so that the capacity between adjacent turns is such as to conduct electromagnetic energy propagated through said waveguide and to set up an alternating magnetic field in said waveguide when alternating current is fed to said coils, which field is transverse to the axis of said guide, and a further coil insulated from and adjacent the terminal turn of each of said spiral coils to prevent short circuiting of the terminal turns, and wound to conduct electromagnetic energy propagated through said waveguide.

8. A waveguide according to claim 7 comprising a

conducting spacer disposed between said terminal turn and said further coil, said spacer having a gap to prevent said spacer from constitutnig a short circuited turn.

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