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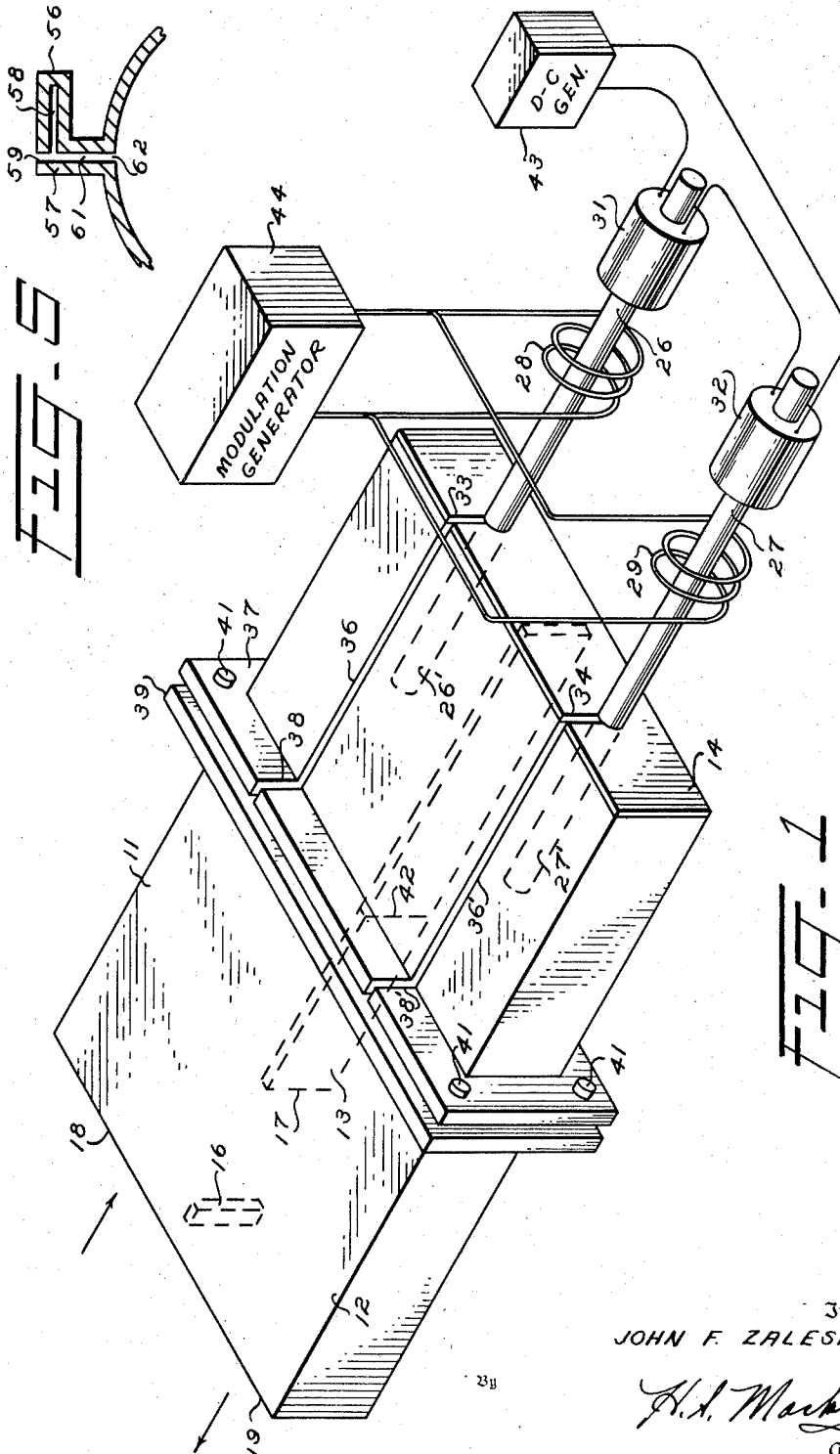
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2,847,647

MICROWAVE MODULATOR

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2 Sheets-Sheet 1



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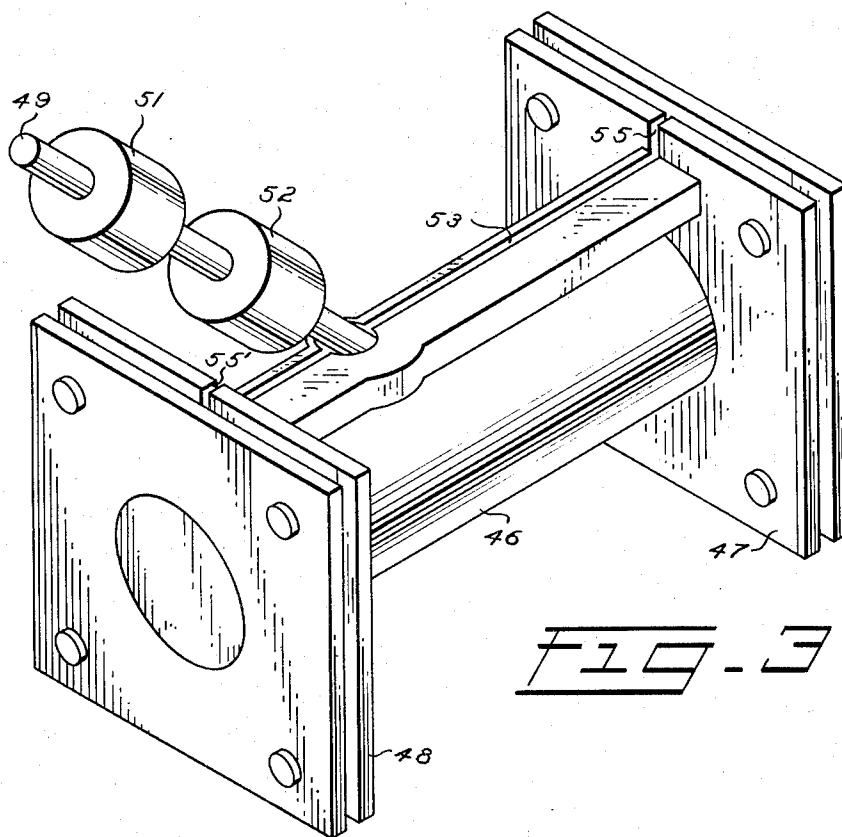
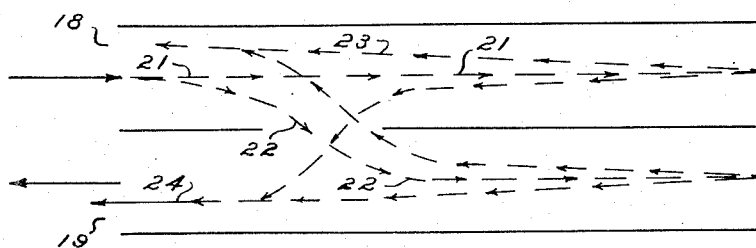
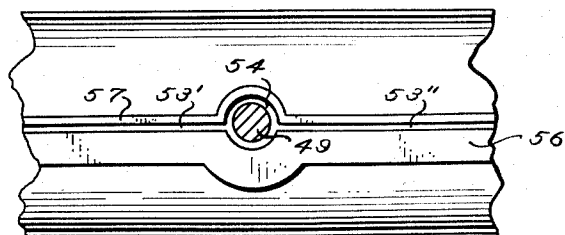


FIG. 2

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2,847,647

MICROWAVE MODULATOR

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7 Claims. (Cl. 332-17)

This invention relates to devices for modulating microwave energy in waveguides and more especially to ferrite modulators which operate to vary waveguide impedance and which are effective at very high modulation frequencies.

The conventional microwave modulator employing a crystal diode is limited in power capacity, is non-linear at all but very small powers, and is inherently noisy. For these reasons such a modulator leaves something to be desired in fulfilling the purposes of this invention, at both low and high powers. On the other hand, the ferrite rotator employed as a modulator is inherently quiet. It is capable of fairly high power modulation, and when employed as taught herein can be used for very high frequency modulation.

Ferrite elements employed in microwave field rotators and modulators are usually composed of polyoxides of two, three or more metals such as iron, manganese, magnesium, copper, nickel, cobalt and zinc. Such ferrites are described by E. Albers-Schoenberg in the Journal of Applied Physics, volume 25, No. 2, on pages 152-154. Their use to rotate the plane of polarization of a microwave field is fully described in Patent No. 2,644,930 dated July 7, 1953, and Patent No. 2,719,274 dated September 27, 1955. It is not, therefore, necessary to describe this device further. However, for the purposes of this invention, it should be understood that the ferrite properties of high high-frequency resistance and high permeability, and the peculiar property of rotating a polarized guided microwave field are important.

As described in Patent No. 2,719,274 one method of employing ferrite to rotate a microwave field consists of positioning a ferrite rod axially in a round waveguide which can transmit a microwave field in a radially non-symmetrical mode such as the TE₁₁ mode. The rod is magnetized by direct current passed through a coil coaxially positioned around the outside of the waveguide at the position of the rod, and the direction of the microwave field polarization is rotated in amount and sense depending upon the amount and sense of ferrite magnetic induction, among other factors, and independent of the magnitude or direction of propagation of the microwave energy. When this arrangement is employed as a modulator the direct current excitation is replaced by alternating or varying modulating current excitation, and the waveguide is arranged with an outlet which then emits microwave energy having its amplitude, and usually its phase also, varied in accordance with the modulating current.

This modulating arrangement can be employed with modulating frequencies in the kilocycle range or even up to about one megacycle, but is not satisfactory with increasing modulating frequency. This is because the metallic waveguide absorbs increasing amounts of power from the magnetizing solenoid as the frequency is increased, and at frequencies above, say, five mc. p. s. it serves as a virtually complete shield between the magnetizing coil and the ferrite rod. It is not desirable to

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insert the magnetizing coil inside the waveguide around the ferrite rod because the metal of the solenoid would greatly interfere with the propagation of the microwave field energy through the waveguide. This is particularly true because at high frequencies, such as at 20 mc. p. s., the solenoid takes the form of a single-layer helix having widely spaced turns and, if carrying large amounts of power, is made of heavy wire or rod. Such a mass of metal within the waveguide would cause a microwave impedance discontinuity so large as not to be tolerated. Moreover the effect on the modulating circuit of the capacitance of the waveguide walls would be highly undesirable because it would shunt most of the modulating energy to ground.

For these and other reasons the instant invention extends the ferrite rod outside the waveguide and applies the modulating current coil to that portion of the rod which extends outside the waveguide. The modulating current magnetizes the ferrite rod, the magnetic induction following the modulating current amplitude and extending along the rod to that portion inside the waveguide. The resulting modulated magnetic induction field within the waveguide interacts with the microwave field to rotate its polarization direction.

When the ferrite rod is employed in a rectangular waveguide the field rotation force cannot cause rotation of the direction of polarization away from the single direction permitted by the waveguide, but does cause a change in amplitude of the field, with a consequent change in the effective waveguide impedance.

In employing a ferrite rod extending through the waveguide wall with a modulating coil around the external end, the waveguide wall would constitute a single closed turn about the ferrite rod which at high frequencies would absorb all of the modulating power and would completely prevent any modulation whatever of the magnetic induction within the waveguide. It is a feature of the invention therefore to split the waveguide wall so that it does not form a closed turn about the ferrite rod. In some forms of the invention this split or slot is inherently non-radiating, while in other forms the slot must be protected by a wavetrap in the manner well understood to prevent leakage of microwave energy out of the waveguide. When the modulator is thus constructed the frequency of the modulating current is in no way limited by the construction of the modulator. Specifically, the frequency of the modulating current may range up to and beyond 500 mc. p. s., a value so much above the limits of all existing microwave modulators as to indicate that the instant modulator is qualitatively different from previously existing modulators.

The purpose of this invention, then, is to provide an improved microwave modulator for both low and high modulation frequencies.

Another purpose of this invention is to provide a microwave modulator comprising a waveguide containing a ferrite rod passing through the slotted wall thereof and provided with an external magnetizing coil.

Another purpose of this invention is to provide a modulator comprising a rectangular microwave guide short-circuited by a conductive plate, and having a ferrite rod axially positioned in the waveguide, passing through a central hole in the plate, and surrounded outside of the waveguide by a coil carrying modulating current. The end plate and waveguide walls are split in the longitudinal plane of the maximum electric field so as not to load the magnetic induction field.

Still another purpose of this invention is to provide a modulator comprising a microwave guide having a ferrite rod passing diagonally through at least one side wall of the waveguide which is split to prevent its form-

ing a short-circuited turn around the rod. A modulating current coil surrounds the rod outside the waveguide.

A further understanding of this invention may be secured from the detailed description and accompanying drawings, in which:

Figure 1 is an isometric sketch, partly schematic, of one embodiment of the invention employing a 3 db coupler.

Figure 2 schematically illustrates part of the operation of the device depicted in Fig. 1.

Figure 3 depicts another embodiment of the invention.

Figures 4 and 5 illustrate design details of the embodiment depicted in Fig. 3.

Referring now to Fig. 1, two rectangular microwave hollow waveguides 11 and 12 are positioned parallel with each other so as to have one common narrow side 13. The right ends of the waveguides are closed and short-circuited by a conductive metal plate 14. The common narrow side 13 is provided with a gap, window, or discontinuity, the edges thereof being designated 16 and 17. The length of this gap has such dimension that the two waveguides so connected constitute a three-decibel directional coupler. This well-known construction is described by H. J. Riblet in Proceedings of the Institute of Radio Engineers for February 1952, entitled The Short-Slot Hybrid Junction. The left ends of the waveguides are depicted as open, it being understood that in operation either one of them, as for example, end 18 of the right waveguide as shown, is connected to a source of microwave power, and end 19 of the left waveguide constitutes the output of the microwave modulator, and is to be connected to utilization apparatus.

The directional coupler as so far described transmits all of the energy applied at input 18 to output 19, and does not reflect any energy back to the source, as is well known. This is effected, briefly, as indicated in Fig. 2. The input energy divides equally at the window as indicated by dashed lines 21 and 22, the energy 22 experiencing 90° phase advance relative to energy 21. Both are reflected and each is equally divided, that energy passing through the window again experiencing 90° phase advance. The combined energies 23, being 180° apart, completely cancel each other but the energies 24, being in phase, reinforce each other, and constitute the output containing all of the input energy.

In order to modulate the energy as it passes through this directional coupler, two identical ferrite rods 26 and 27, Fig. 1, are inserted through two holes in the end plate 14 and protrude equal distances axially and centrally within the two hollow rectangular waveguides 11 and 12. Each rod is surrounded outside of its associated waveguide by a coil, helix or solenoid 28 and 29. These coils are identical and are designed for the frequency at which they are to be used. For example, as depicted each has 2½ turns of heavy wire, widely spaced, suitable for high frequencies as, for example 10 to 50 mc. p. s. In accordance with good practice these coils are somewhat spaced from the rods and somewhat separated from the end plate 14, as well as from solenoids 31 and 32 the functions of which are to be described later. This isolation of the coil turns by spacing from all conductive objects reduces losses by induced currents and by capacitive shunting.

In order to prevent the metal of the waveguides and of the end plate 14 from acting as a single short-circuited turn around each of the rods, the end plate 14 is provided with two slots 33 and 34. These slots are continued as a slot 36 in the median line of the upper broad side of the waveguide 11 and as a similar slot 36' in the median line of the upper broad side of the waveguide 12. These two slots are further continued in the coupling plate 37 as two vertical slots 38 and 38'. This plate 37 contains a choke groove entirely surrounding both waveguides so that, with plane plate 39, it constitutes a choke coupling. Such coupling flanges are de-

scribed in Principles and Applications of Waveguide Transmission, by G. C. Southworth, on page 201. The plates 37 and 39 are separated by spacing insulators thick enough to insulate them electrically from each other, a space of one thirty-second inch being satisfactory, and are mechanically secured together at their corners by insulating bolts 41. The common side 13 of the waveguides is provided with a butt joint 42. As is well known, choke flanges when thus separated prevent microwave field leakage out of the waveguide and also provide low impedance for transmission of the microwave field energy through the wave guide. Additionally, this construction prevents short-circuiting of the gaps 36 and 36' either by flange 37 or by flange 39.

If modulation is effected by impedance increase as in this case, when the ferrite rods 26 and 27 are initially unmagnetized, any magnetization by the coils 28 and 29 in either sense will produce an impedance increase, thus producing modulation in the waveguides at double the frequency of the modulating current. It therefore is necessary to bias the ferrite rods by magnetizing them equally to one-half of the maximum amount by which they are to be magnetized during modulation. That is, a constant magnetization equal to one-half of the peak-to-peak maximum modulation should be applied. This is conveniently effected, for example, by applying direct current either to the same coils 28 and 29, or to separate coils 31 and 32 from a source 43.

In the operation of the microwave modulator of Fig. 1, suitable direct-current bias being applied to coils 31 and 32, microwave energy is applied to the left end 18 of waveguide 11 and modulation current is applied from modulation generator 44 to the two modulating coils 28 and 29 equally. To effect this these coils may be connected either in series or in parallel as depicted, so that the modulations of the magnetic induction of the ferrite rods 26 and 27 inside the waveguides, along their free ends 26' and 27' therein, respectively, will be equal in amplitude and phase. The energies reflected inside the respective waveguides from the end plate 14 will then be modulated in accordance with the magnetic induction modulation, the amount of modulation and hence reflected energy being equal in the two waveguides in all respects. The energies reflected toward the source end 18 will then cancel each other at all instants exactly as in the absence of modulation, and the energies reflected to the output end 19 will then add at all instants exactly as in the absence of modulation, so that the modulation of the output is effected to the same degree as it is in each of the individual waveguides at the ferrite rods.

The modulating components including the ferrite rod, modulating coil and biasing coil, may be applied in several other microwave devices to modulate microwave energy. In all cases, by application of the principles exemplified in the description of Fig. 1 including placement of the modulating coil outside of the waveguide and slotting of the waveguide wall where the ferrite rod passes through it, the microwave modulator is made suitable for modulation at all frequencies without upper limit. When a magnetized ferrite rod causes rotation of a guided microwave field or exerts a rotative effort upon the field, it is principally that portion of the ferrite which extends longitudinally in the waveguide which causes the effect or exerts the rotative effort. It is not necessary for the ferrite rod to be axially or even longitudinally positioned in the waveguide, but only to be positioned so as to have a longitudinal component. That is, the rod should preferably extend in other than a transverse direction. It therefore is satisfactory to position the rod obliquely in the waveguide and this position is convenient when the microwave modulator requires the ferrite rod to be placed in a waveguide which is not short-circuited by an end plate. The waveguide may be either round or rectangular, in accordance with the modulating method employed.

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An example of a ferrite rod obliquely positioned in a round waveguide is illustrated in Fig. 3. A round waveguide 46 is provided with choke couplings 47 and 48 at its ends, each coupling comprising a choke flange and a plane flange separated by insulating spacers, as before described, so as to prevent electrical current conduction between the flanges while permitting field transmission in the waveguide passing through them. A ferrite rod 49 is positioned obliquely in the round waveguide to intersect its axis at a 45° angle, and is provided with a direct-current bias coil 51 and a modulating coil 52, the latter being depicted as a multilayer solenoid but in each case being designed for the frequency to be used as previously described. The round waveguide is slotted by slot 53 throughout its length along a line including the entrance point of the ferrite rod 49, so as to prevent metallic continuity around the rod. The slot is continued as slots 55 and 55' in the flanges 47 and 48 terminating the round waveguide in the manner previously described.

In order to prevent radiation from slot 53 and also to prevent interference with microwave current flow in the inner surface of the waveguide, the slot 53 is preferably protected by a choke coaming. Such a choke coaming is depicted in Figs. 4 and 5. In Fig. 4 the ferrite rod 49, shown sectioned, passes through the hole 54 in the wall of the waveguide. The hole 54 is extended longitudinally in two narrow slots 53' and 53'' protected by the choke coaming 56 and the plain coaming 57, these coamings being illustrated in section in Fig. 5. The coaming 56 contains a quarter-wave slot 58 which presents high impedance at the external lips 59, thus preventing radiation, and the coaming contains an additional slot 61 having such length that the inner lips 62 are one-half wavelength from the closed end of slot 58, thus presenting low impedance at the inner surface of the waveguide.

What is claimed is:

1. A microwave modulator comprising, a waveguide section, a ferrite rod extending through a wall of said waveguide section having one end thereof positioned internally of said waveguide section and extending longitudinally therealong with its other end projecting externally of said waveguide section, a slot interrupting the peripheral wall of said waveguide section extending along the entire longitudinal length thereof, choke coupling means for said waveguide section, said choke coupling means comprising a pair of flanges insulated from each other, one of said flanges being affixed to an end of said waveguide section and being provided with a slot forming an extension of the slot in the wall of said waveguide section, and means coupled to the end of the rod exterior to said waveguide section for modulatingly magnetizing said rod.

2. A microwave modulator in accordance with claim 1 in which said microwave guide is rectangular.

3. A microwave modulator in accordance with claim 1 in which said microwave guide is round.

4. A microwave modulator comprising, a waveguide section, a ferrite rod extending through a wall of said waveguide section having one end thereof extending into the interior thereof at an acute angle as respects the longitudinal axis thereof with its other end projecting

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exteriorly of said waveguide section, a slot extending through the wall of said waveguide section and extending along the entire length thereof through the point of juncture of said rod and said waveguide section, choke couplings for each end of said waveguide section, each of said choke couplings comprising a pair of flanges insulated from each other, one of each of said pair of flanges being affixed to a respective end of said waveguide section and being provided with a slot forming extensions of the slot in said waveguide section, and means coupled to the end of the rod exterior to said waveguide section for modulatingly magnetizing said rod.

5. A microwave modulator in accordance with claim 4 in which said microwave guide is round and in which said slot is protected by a choke coaming.

6. A microwave modulator comprising, an input microwave rectangular waveguide adapted to be energized at one end by microwave energy for transmission there-through in the TE₁₀ mode, an output microwave rectangular waveguide positioned in juxtaposition to said input waveguide and parallel thereto, one narrow side of each waveguide being common to both waveguides, a window in said common side adapted to transmit one half of microwave energy in either waveguide to the other, a conductive plate closing and short-circuiting the other end of said input waveguide and the adjacent end of said output waveguide, two ferrite rods, each passing through said plate axially into a respective one of said input and output waveguides, said plate and said waveguides being provided with slots extending radially from said respective rods thereby interrupting the circumferential continuity of the conductive plate and waveguide around each of said two rods, means magnetically biasing said rods in equal amounts and senses and means modulatingly magnetizing said rods in instantaneously equal magnitudes, frequencies and phases.

7. A microwave modulator comprising, a rectangular waveguide section having a conductive plate closing one end thereof, a ferrite rod projecting through said conductive plate with one end thereof extending interiorly and longitudinally along said waveguide section, a slot cut through a broad wall of said waveguide section along the entire length thereof and through said conductive plate to the juncture of said rod and plate, a choke coupling for the other end of said waveguide section, said choke coupling comprising a pair of flanges insulated from each other with one of said flanges affixed to the end of said waveguide section and provided with a slot forming an extension of the slot in said waveguide section, said rod having an end projecting exteriorly of said waveguide section, a coil surrounding the end of said rod exterior to said waveguide section, and a variable current supply for said coil.

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