

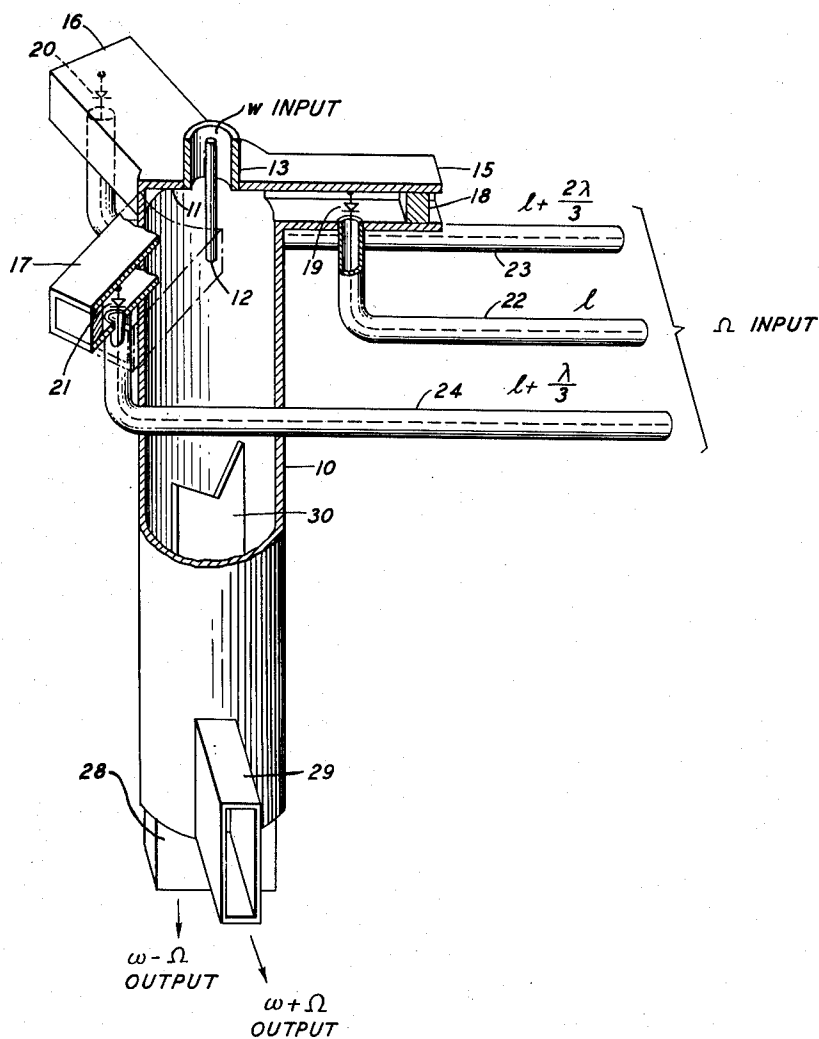
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MICROWAVE FREQUENCY CONVERTER

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MICROWAVE FREQUENCY CONVERTER
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This invention relates to electromagnetic wave modulators or frequency changing systems for wave energy in the microwave or higher frequency range and, more particularly, to a single side band modulator for said wave energy.

It is well known that when currents of two different frequencies are combined in a non-linear manner, there will be present in the output both of these frequencies together with modulation products representing the sum and difference of the original frequencies. It is equally well known that there are numerous advantages in suppressing one or more of these modulation products while producing only the one that is desired. In the past, rather complicated balancing schemes have been used to combine the undesired modulation products in cancelling phase while reinforcing the desired products to produce single side band modulation.

It is an object of the invention to generate modulation products in a form that can be directly separated into component side bands.

It is a further object to simplify and improve single side band modulators.

In accordance with the principles disclosed in my co-pending application, Serial No. 78,078, filed December 23, 1960, a wave guide capable of supporting a multiplicity of polarizations is excited with a linearly polarized wave of angular frequency ω that turns in space consecutively through successive ones of said polarizations at an angular rate of Ω . Analysis has shown that the complicated wave form thus produced includes upper and lower side bands $\omega + \Omega$ and $\omega - \Omega$ as respectively oppositely rotating circularly polarized waves. Means are provided for separating these oppositely rotating components thus producing either upper or lower single side band modulation. In accordance with the present invention, the specific means for producing the required rotating linearly polarized wave comprises a coaxial antenna or probe type radiating element positioned along the axis of a round, dominant mode wave guide. Such a radiating element is normally incapable of exciting the guide. However, when the guide is sequentially unbalanced at points around the periphery at the Ω rate, excitation takes place in a polarization that follows the unbalance.

These and other objects, features and advantages of the invention will appear more fully upon consideration of the following detailed description taken in connection with the illustrative drawing which shows a cut-away perspective view of the embodiment in accordance with the invention.

Referring more particularly to the drawing, the illustrative embodiment of the modulator in accordance with the invention is seen to comprise a section 10 of conductively bounded wave guide adapted to support linearly polarized electromagnetic wave energy in a multiplicity of polarizations and, therefore, capable of supporting circularly polarized waves. As illustrated, guide 10 is of circular cross section but it might also be square. In either case, guide 10 has transverse dimensions sufficiently small to support only the dominant mode of a linearly polarized wave in at least two cross polarizations.

The upper end of guide 10 is closed by a conducting end plate 11 having a centrally positioned aperture therein through which a coaxial antenna or radiating probe 12

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extends along the axis of guide 10. Probe 12 constitutes the extension of the inner conductor of a section of coaxial line 12-13 which is directly connected to the source of wave energy of angular frequency ω .

Surrounding guide 10 in the vicinity of probe 12 are three rectangular wave guide stubs 15, 16 and 17; each forming E-plane junctions with guide 10 at points spaced 120 degrees around its periphery. Non-linear conductive devices 19, 20 and 21 are respectively located one each in each of the stubs 15, 16 and 17. While these devices may be crystal diodes, varactors or other similar devices, they will be referred to hereinafter simply as crystals. It is preferred that crystals 19 through 21 appear identical when viewed from guide 10 so they are, therefore, preferably located in their respective guides at equal distances from the junction. Terminating conductive pistons, such as 18 in guide 15, close the end of each stub and are adjusted to equalize any inherent difference in the crystals themselves.

In the absence of bias applied to crystals 19 through 21 or with equal bias, probe 12 will not excite wave energy capable of propagation in guide 10. Recall in this connection that an axial probe such as 12 can only excite symmetrical transverse magnetic modes of the TM_{0n} series. However, since guide 10 is dominant mode, the TM_{0n} modes are beyond cut off. The presence of guides 15 through 17 does not change this situation so long as symmetry is maintained and no electric field transverse to the axis of guide 10 is produced. While the guides 15 to 17 will each be excited by probe 12, reflections from crystals 19 through 21 will be equal and symmetry will be preserved.

However, crystals 19 through 21 are suitably biased in sequential phases by waves of angular frequency Ω . As illustrated, crystals 19 through 21 are supplied with bias voltages from a common source of wave energy through coaxial wave guide sections 22 through 24, respectively, having lengths which differ by multiples of one-third wave length. Thus, guides 23 and 24 have lengths of $2\lambda/3$ and $\lambda/3$ greater than guide 22, respectively, which in effect supplies three phase bias voltage of frequency Ω to the crystals.

Therefore, at one instant of time the impedance of one crystal will be smaller than that of the remaining two and symmetry at the junction will be destroyed. The reflection from the crystal of smaller impedance at the junction will exceed the remaining two reflections and will excite a TE_{11} mode in guide 10 polarized in a plane including the crystal of smaller impedance. Because of the three phase bias applied to crystals 19 through 21, the position of the smallest impedance crystal rotates at Ω . Thus, the polarization of the radiation excited in guide 10 turns also in space at the angular frequency Ω so that the resulting wave in guide 10 is actually neither a linearly polarized wave nor a circularly polarized wave. Rather it is an extremely complicated wave which has orthogonal electric field components normal to the direction of propagation which are, respectively, the real and imaginative parts of the expression

$$\cos \omega t e^{j\Omega t}$$

This expression may be written

$$2 \cos \omega t e^{j\Omega t} = e^{j(\omega + \Omega)t} + e^{-j(\omega - \Omega)t}$$

which shows that the wave includes two circularly polarized waves of $\omega + \Omega$ and $\omega - \Omega$ angular frequencies turning in opposite directions.

The lower end of guide 10 includes means for resolving these oppositely rotating components into separate orthogonal, linearly polarized waves. Thus, guide 10 is provided with a suitable pair of polarization selective branches by which wave energy in orthogonal, linearly polarized

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modes may be separately coupled from guide 10. Specifically, guide 10 is coaxially joined by a first rectangular wave guide 28 of dimensions which will support wave energy polarized in a plane normal to the plane of the paper. At substantially the same location, guide 10 is joined by a second rectangular wave guide 29 perpendicular to both guides 10 and 28 which will accept only wave energy polarized parallel to the plane of the paper. The junction between guides 10 and 29 is illustrated as an H-plane or shunt plane junction but it could obviously be an E-plane junction as well. Conventional matching means not shown may be employed to facilitate the transition of the selected polarization of wave energy from guide 10 into either guides 28 or 29. Typical matching means are described in U.S. Patent 2,682,610, granted June 29, 1954 to A. P. King.

Disposed above guides 28 and 29 in guide 10 is suitable means for producing a conversion between circularly polarized wave energy supportable in guide 10 and linearly polarized waves. This means may be a 90 degree differential phase shift section of any of the types disclosed for example in "Principles and Applications of Waveguide Transmission" by G. C. Southworth, 1950, pages 327 to 331. By way of specific illustration, the phase shift section comprises a diametrical vane 30 of dielectric material lying in a plane which is inclined at 45 degrees to the polarizations accepted by guides 28 and 29. As is well known, if the length of vane 30 is such that a 90 degree phase shift is introduced to wave energy polarized parallel to the plane of vane 30 relative to wave energy polarized perpendicular to the plane of the vane, circularly polarized wave energy rotating in one sense in guide 10 is converted into linearly polarized wave energy in the proper polarization to be accepted by guide 28. Similarly, circularly polarized wave energy rotating in the opposite sense in guide 10 is converted into linearly polarized energy of the proper polarization to be accepted by guide 29.

Thus, when the composite wave in guide 10 is applied to vane 30 it is resolved into two orthogonal components which are received in guides 28 and 29, representing, respectively, the upper and lower sideband products of single sideband modulation, that is, the original wave ω increased in frequency by Ω and decreased in frequency by Ω . Either the upper or lower sideband may be utilized separately, the other being terminated, or they may be used simultaneously as required in some double detection systems.

Three crystal branches have been illustrated for producing the desired sequential unbalance around the periphery of guide 10. This, of course, represents the simplest configuration. It should be noted, however, that any number of crystal branches, excited sequentially in the proper phase, may be employed. Furthermore, the use of E-plane wave guide stubs is only illustrative of the manner in which these crystals may be coupled to the multipolarization guide.

In all cases it is to be understood that the above-described arrangement is merely illustrative of a small number of the many possible applications of the principles of the invention. Numerous and varied other arrangements in accordance with these principles may readily be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. In combination, first and second sources of electromagnetic wave energy of first and second frequencies, principal supporting means for supporting said energy of said first frequency in a multiplicity of linearly polarized polarizations, a plurality of auxiliary supporting means positioned about and electromagnetically coupled to said principal supporting means each with an axis orthogonal to the axis of said principal supporting means for sup-

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porting said energy of said first frequency, radiating means axially positioned within said principal supporting means for directing linearly polarized energy of said first frequency orthogonally to the propagation axis of said principal supporting means from said first source toward said auxiliary supporting means, nonlinear conducting means located within said auxiliary supporting means and energized by said second source with phase differences directly related to the angular separation of said auxiliary supporting means about said principal supporting means for reflecting energy of said first frequency of a polarization that rotates at said second frequency from said auxiliary supporting means into said principal supporting means, means within said principal supporting means for converting said reflected energy into two mutually orthogonal linearly polarized waves one of which has a frequency equal to the sum of said first and second frequencies and the other of which has a frequency equal to the difference of said first and second frequencies, and means within said principal supporting means on the opposite side of said converting means from said auxiliary supporting means for separating said linearly polarized waves.

2. In combination, a source of electromagnetic wave energy of frequency ω , a source of electromagnetic wave energy of frequency Ω , a principal section of electromagnetic wave guide of circular cross-section, a plurality of auxiliary wave guide sections joined to and spaced about said principal section with axes orthogonal to the axis of said principal section and reflectively terminated, a dipole radiating element axially positioned within said principal section in the vicinity of said auxiliary sections and energized by said source of frequency ω , a plurality of nonlinear conducting elements located within said auxiliary sections and energized by said source of frequency Ω with phase differences proportional to the angular separation of said auxiliary sections about said principal section, a pair of orthogonal polarization-selective connections to said principal section, and a quarter-wave differential phase shift section interposed within said principal section between said auxiliary section and said connections.

3. In combination, first and second sources of electromagnetic wave energy of first and second frequencies respectively, wave energy supporting means for supporting said energy of said first frequency in a multiplicity of linearly polarized polarizations, a plurality of nonlinear impedances coupled to said supporting means at locations about the axis thereof, radiating means located in said supporting means for radiating energy from said first source toward said plurality of impedances in a first wave mode which is beyond cut-off in said supporting means, means for varying said impedances in synchronism with said second frequency with phase differences that produce reflections which are nonsymmetrical with respect to the axis of said supporting means to couple energy of said first frequency into said supporting means in a second wave mode with polarization that rotates in space in synchronism with said second frequency, means within said supporting means for converting said coupled energy into two mutually orthogonal linearly polarized waves with frequencies proportional to the sum and difference of said first and second frequencies respectively, and means for separating said mutually orthogonal linearly polarized waves.

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