

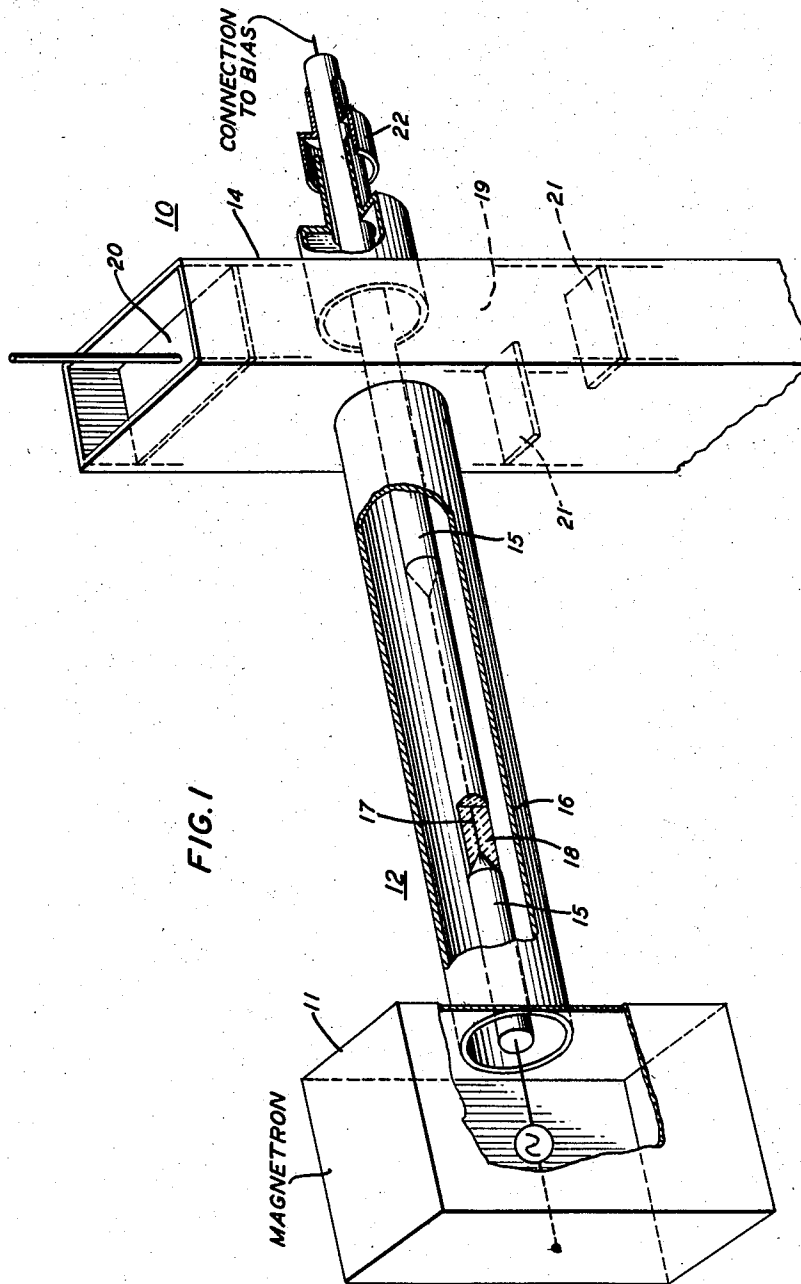
July 28, 1959

G. C. SOUTHWORTH
NONLINEAR TRANSMISSION MEDIA

2,897,452

Filed May 14, 1956

3 Sheets-Sheet 1



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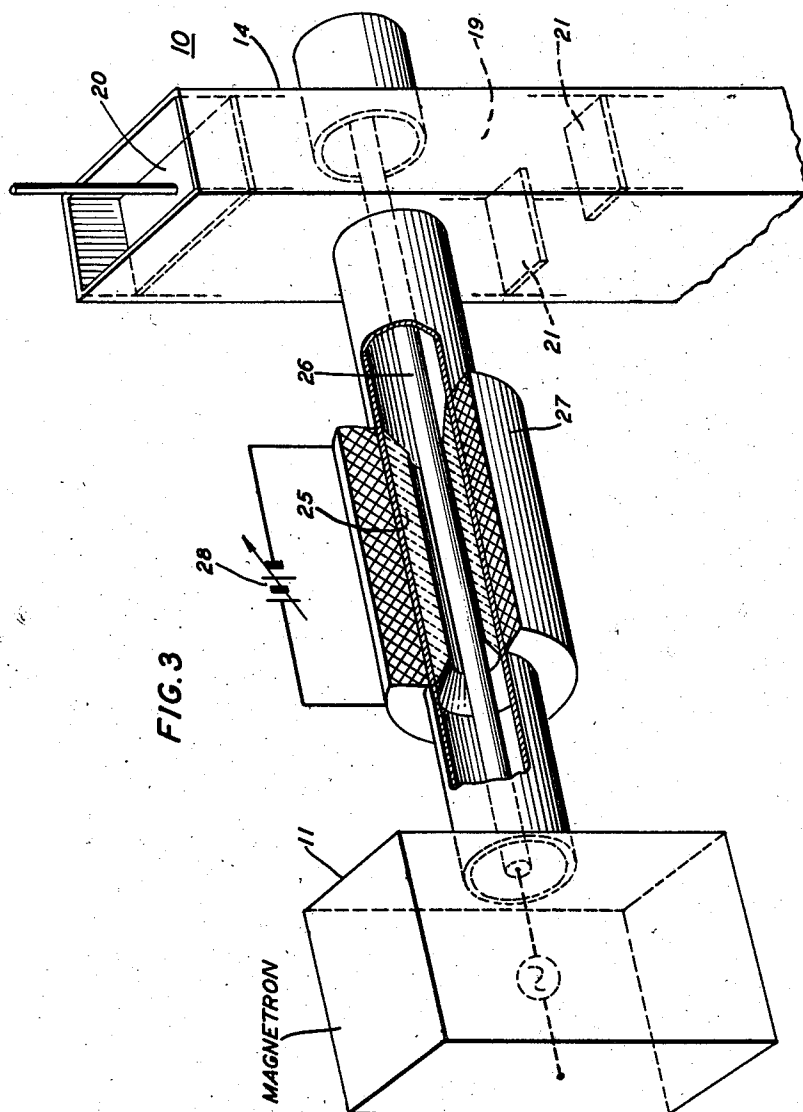
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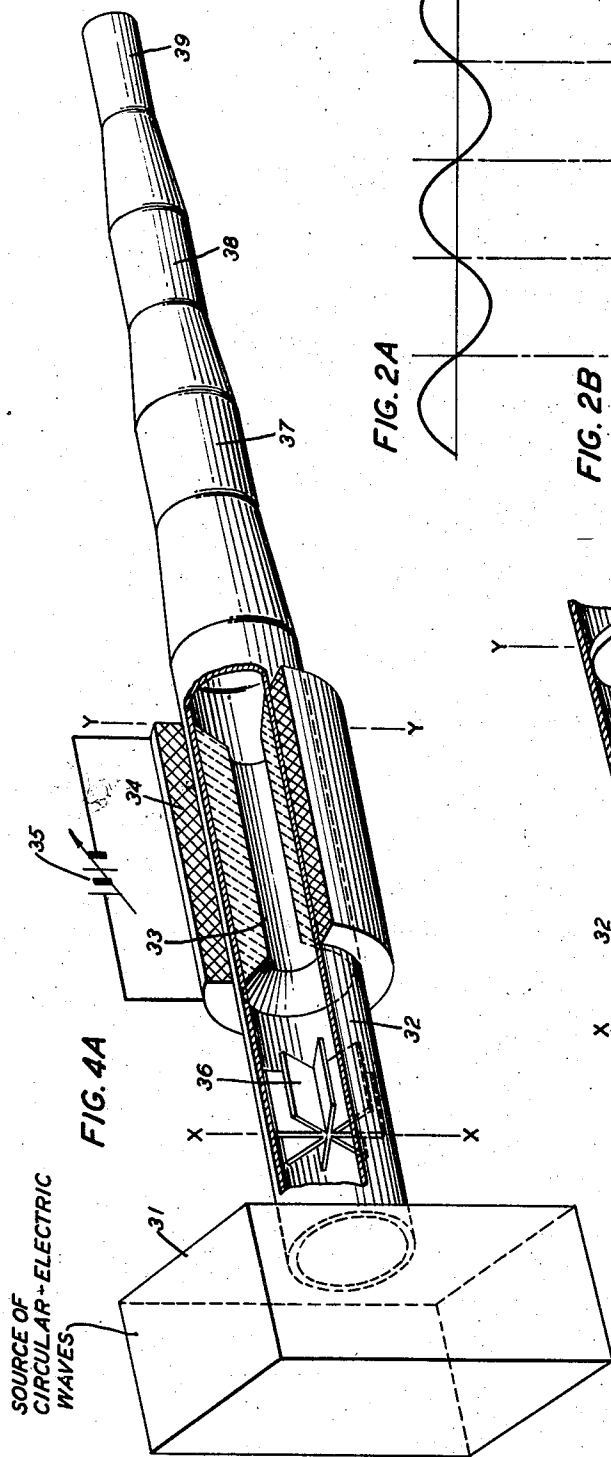


FIG. 4A

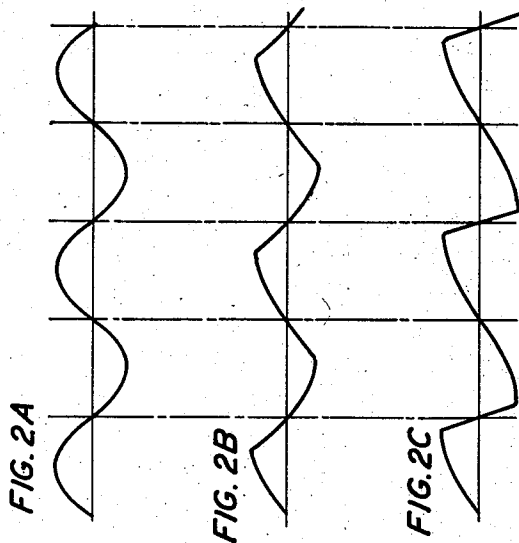


FIG. 2A

FIG. 2B

FIG. 2C

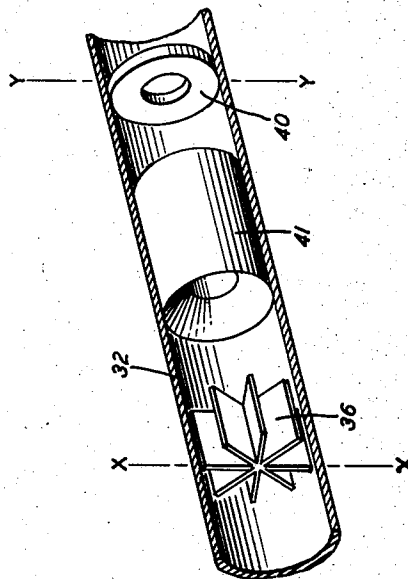


FIG. 4B

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2,897,452

NONLINEAR TRANSMISSION MEDIA

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Application May 14, 1956, Serial No. 584,565

14 Claims. (Cl. 331-76)

This invention relates to media exhibiting non-linear propagation constant versus signal amplitude characteristics and more particularly to the use of such media in electromagnetic wave transmission systems for the purpose of generating harmonics of the operating frequency.

It is an object of this invention to convert a substantial portion of the power in an electromagnetic wave of a given frequency into useful higher order harmonics of that frequency.

It is an additional object of this invention to derive from an electromagnetic wave of a given frequency any frequency which is an integral multiple of said given frequency.

It is known in the art that certain media exhibit characteristics of dielectric constant and magnetic permeability which vary nonlinearly with the amplitude of radio frequency energy transmitted through the media. For example, it is known that the dielectric constant of barium titanate varies in such a manner. Similarly, various non-conductive ferromagnetic materials such as the ferrites exhibit characteristics of magnetic permeability which also vary nonlinearly with signal amplitude. Heretofore, these nonlinear characteristics inherent in these materials have been considered an undesired distortion in the applications in which they were utilized.

In accordance with the invention, this inherent non-linearity is utilized advantageously for the purpose of generating and utilizing harmonic frequencies from a fundamental. More generally, it may be used for transforming a given but inappropriate harmonic content of a wave into a harmonic content which is useful and utilized for a desired purpose. Consider an element exhibiting the nonlinear characteristic either with respect to dielectric constant or magnetic permeability whose electrical length is several wavelengths of a given radio-frequency wave. If a pure sinusoidal wave is propagated through such a nonlinear medium, the large amplitude portions of the wave, that is, the peaks of the wave above and below the zero axis, will see a dielectric constant or magnetic permeability of different value than the smaller amplitude portions of the waves (that is, those portions of the waves closer to the zero axis). Now, the velocity of wave propagation is inversely proportional to the square root of the product of the dielectric constant and magnetic permeability. Therefore, it may be seen that the velocity of propagation will be different for the high signal level components than for the low signal level components of the waves. Accordingly, this results in the peaks of the waves above and below the zero axis, i.e., the crests and troughs, traveling at a different speed than intermediate portions. As a consequence, the wave becomes distorted from its original sinusoidal shape with the amount of distortion being dependent upon the length of nonlinear medium through which it passes and the degree of nonlinearity inherent in the medium. The shape of the distortion may be controlled by an electric biasing field applied to the medium in the cases where the medium

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is nonlinear with respect to its dielectric constant or with a direct-current magnetic biasing field in the cases where the medium is non-linear with respect to its permeability. It is well known in the art, and Fourier analysis demonstrates clearly, that any periodic non-sinusoidal wave form comprises an infinite series of sinusoidal waves whose frequencies are each an integral multiple of the fundamental frequency. The sharper and more discontinuous the portions of the wave are, the more of the wave's energy is concentrated in the higher frequency sinusoidal components. In accordance with the invention, a nonlinear medium, several wavelengths of the operating frequency in length, is utilized to produce the distorted wave and in conjunction therewith a linear receiving device receptive at a frequency substantially greater than the operating frequency impressed on the medium is coupled to the transmission line supporting the medium to extract the desired harmonics.

In one embodiment of the invention, a coaxial wave-guiding structure is utilized as the transmission line. The nonlinear material is located within the coaxial line and a means for biasing the medium is coupled thereto. At the input end of the coaxial structure, a wave energy generating device is located which launches a sinusoidal signal on the coaxial line. At the output end a hollow metallic wave guide receiver is coupled to the coaxial line and is proportioned below cut-off for the fundamental and lower order harmonics of the distorted wave. At the region of coupling, the hollow wave guiding structure comprises a variable resonant chamber so that any of the desired harmonics may be selectively coupled to the wave guide receiver.

In another embodiment in accordance with the invention, the nonlinear medium is located in a transmission line of the hollow metallic wave-guide type. The receiver in this arrangement comprises a hollow wave guide whose dimensions are proportioned so as to be below cut-off for all but the desired higher order harmonics. Alternatively, in this arrangement, the nonlinear medium may be shorter in length than would ordinarily be the case, since it may be located between two reactive elements so that wave energy propagating through the medium is multiply reflected therethrough. This results in an electrical transmission path through the nonlinear element whose length is equal to that of the longer nonlinear medium.

It may be noted that the shape of the distorted wave may be varied by the strength of the biasing field. Consequently the harmonic content of the wave and, therefore, the harmonics and amplitudes thereof available to the receiver, may be varied electrically by varying the strength of the biasing field.

These and other objects and features of the present invention, the nature of the invention and its advantages, will appear more fully upon consideration of the various illustrative embodiments shown in the accompanying drawings and of the following detailed description.

In the drawings:

Fig. 1 is a perspective view for the purposes of illustration in accordance with the invention wherein a medium nonlinear with respect to dielectric constant is located within a coaxial structure;

Fig. 2A, given by way of explanation, is a graphic representation of a sinusoidal wave such as that impressed upon the nonlinear material;

Fig. 2B, given by way of explanation, is a graphic representation of a wave such as that in Fig. 2A which has been distorted by an unbiased nonlinear medium;

Fig. 2C, given by way of example, is a graphic representation of a distorted wave resulting from propagation through a biased nonlinear medium;

Fig. 3 is a perspective view of an illustrative embodi-

ment in accordance with the invention wherein the medium in the coaxial structure is nonlinear with respect to magnetic permeability;

Fig. 4A is a perspective view of an illustrative embodiment in accordance with the invention wherein a medium nonlinear with respect to magnetic permeability is disposed within a hollow pipe metallic wave guide; and

Fig. 4B is a perspective view of an illustrative embodiment in accordance with the invention similar to that of Fig. 4A wherein a nonlinear medium is located in a chamber having a reactive component at each end thereof.

In more particular, Fig. 1 is a transmission system given by way of example, for purposes of illustration, which in accordance with the invention includes three major components. The first component is a source of sinusoidal wave power of a given frequency represented by a magnetron 11. The second component is a section of coaxial transmission line 12 which contains a nonlinear or wave-distorting medium 18. The third component is a linear receiver 10 comprising a hollow metallic wave guide 14. The receiver selects from the distorted wave the desired harmonic components and translates them into useful form.

Let us consider now the transmission line component of the system. The transmission line comprises a section of coaxial line 12 of the type well known in the art wherein an inner metallic conductor 15 is located along the longitudinal axis of and coaxial to an outer metallic cylindrical conductor 16. In one region extending for several wavelengths of the operating frequency that the coaxial line supports, the diameter of the inner conductor is much smaller than elsewhere in the section. In this region the inner conductor is a small diameter wire 17 which tapers gradually into a wider diameter at each end of this region so as to form a continuous conductive path with the inner conductor 15 disposed on either side of this region. Disposed about the narrow wire 17 and co-extensive therewith is a solid cylindrical element 18 of dielectric material exhibiting nonlinear dielectric properties. In particular, this element may be of material such as barium titanite. The narrow inner conductor 17 in this region lies along the longitudinal axis of the dielectric cylinder. Cylinder 18 need not and, as represented in the drawing, does not fill the entire volume of outer conductor 16. However, the diameter of cylinder 18 is substantially greater than that of inner conductor 17 which it encompasses but need not be greater than the diameter of inner conductor 15.

The sinusoidal wave power generator 11 is coupled to the coaxial line 12 at its left-hand end. Generator 11 is a magnetron depicted in schematic form and may be coupled to coaxial line 12 in manner well known in the art so as to launch electromagnetic wave energy upon coaxial line 12.

Receiver 10 comprises a hollow metallic rectangular wave guiding structure 14 coupled to coaxial line 12 on the right thereof. The inner conductor 15 of coaxial line 12 enters wave guide 14 through an aperture in the wide dimensioned wall thereof. Inner conductor 15 then passes through wave guide 14 parallel to its narrow dimensioned walls and passes out through another aperture in the second wide dimensioned wall. Outer conductor 16 terminates at the first wide dimensioned wall of the receiver and reappears external to the receiver at the second wide dimensioned wall. This type of coaxial-to-metallic wave guide coupling arrangement is well known in the art and is treated in greater detail, for example, in my book, "Principles and Applications of Wave Guide Transmission," D. Van Nostrand Company, Inc., 1950, at page 284. Inner conductor 15 which penetrates wave guide receiver 10 is located therein in an adjustable resonant chamber 19. Chamber 19 is formed by having within wave guide 14, on one side of inner conductor 15,

a movable piston 20 having a smooth, flat, metallic face which is disposed transverse to the longitudinal axis of wave guide receiver 10. On the other side of inner conductor 15 are two septa 21 disposed in the same transverse plane and separated from each other to form a rectangular inductive iris. Each is disposed in its long dimension parallel to the narrow dimension of guide 14 and in its short dimension perpendicular to the narrow dimension of guide 14. Septa 21 are also disposed transverse to the longitudinal axis of guide 14 and each has one edge contiguous respectively to different wide dimensioned walls. The dimensions of wave guide 14 are appropriately proportioned so as to be below cut-off for the frequency generated by magnetron 11 and for some lower order harmonics of said frequency. Conductive piston 20 may be moved longitudinally within the wave guide so as to change the length of cavity 19 formed by it and septa 21. Consequently, any particular harmonic may be coupled from coaxial line 12 to wave guide receiver 10 by appropriate adjustment of piston 20. Inner conductor 15 appearing outside receiver 10 and to the right thereof is coupled through a by-pass condenser 22 to a direct-current source, not shown, so as to provide an electric biasing field for wave distorting cylinder 18 within the coaxial line 12.

In considering the operation of the embodiment of Fig. 1, let us first direct attention to the mode of operation of wave distorting cylinder 18 located within coaxial line 12. Fig. 2A represents a pure sinusoidal wave such as might be generated by magnetron 11. The actual electromagnetic wave propagating along coaxial line 12, which is represented by the sinusoidal curve, will have its greatest concentration of electric field radially disposed in a region close to inner conductor 15. As a consequence, upon reaching distorting cylinder 18 the wave will interact therewith. The nature of the material of cylinder 18, namely barium titanite, is such that the dielectric constant it exhibits to wave energy transmitted through it is nonlinear. Specifically, cylinder 18 will exhibit a smaller dielectric constant to large amplitude components of the waves than it will to small amplitude components. As a result, the different amplitude components will propagate through cylinder 18 at different velocities. Since it is known that the velocity of propagation in this arrangement is inversely proportional to the square root of the product of the dielectric constant and magnetic permeability, it may be seen that the velocity of propagation will be greater for high level components than for low level components. This is graphically depicted in Fig. 2B which shows the crests and troughs of the sinusoidal wave of Fig. 2A advanced relative to the regions therebetween. As a consequence, Fig. 2B shows the type of distortion that occurs from wave energy propagating through the nonlinear medium when no biasing field is imposed. It is well known from Fourier analysis that a wave of this type comprises, in addition to the fundamental sine wave of Fig. 2A, an infinite series of pure sinusoidal components whose frequencies are integral multiples of the fundamental frequency. Consider now what happens when nonlinear cylinder 18 is biased electrically by virtue of the biasing source coupled through by-pass condenser 22 to inner conductor 17 extending through the center of cylinder 18. An intense electric field is set up thereby throughout the region of nonlinear cylinder 18 which is also the radial region wherein the greatest concentration of electric field from the radio frequency wave exists. In such an arrangement the crests of the sinusoidal waves travel faster through cylinder 18 than the troughs, thereby converting the distorted wave of Fig. 2B into a saw-tooth type wave which is therefore even more distorted. This configuration is depicted in Fig. 2C. As is well known, the saw-tooth configuration may be resolved by

the Fourier method into a series of harmonic terms of the

$$\text{type I} = \frac{V}{2\pi} \left(\cos \omega t - \frac{1}{2} \cos 2\omega t + \frac{1}{3} \cos 3\omega t - \frac{1}{4} \cos 4\omega t \dots \right)$$

where $\omega = 2\pi f$. It may be seen, therefore, that a substantial portion of the power of the initial sinusoidal wave having a given frequency is transferred to higher frequencies as the wave propagates through nonlinear cylinder 18. Effectively, Fig. 2A represents an input wave to nonlinear cylinder 18 while Figs. 2B and 2C represent the output from cylinder 18 when cylinder 18 is unbiased and biased respectively.

The over-all operation of Fig. 1 may now be properly comprehended. Magnetron 11 launches a sinusoidal wave upon coaxial transmission line 12. Upon passage through the biased nonlinear cylinder 18 contained in coaxial line 12 the sinusoidal wave is distorted to an extent dependent upon the biasing field afforded by cylinder 18, the length of cylinder 18 and the inherent nonlinear property of cylinder 18. The distorted wave containing harmonics of the input sinusoidal frequency propagates on to wave guide receiver 10, whereupon only those harmonics, whose frequency is above the cut-off dimension of wave guide 14 can be launched therein. More particularly, a specific desired harmonic may be isolated from the composite distorted wave by appropriately moving adjustable piston 20 so as to make resonant chamber 19 resonant at the frequency of that harmonic. The desired frequency or frequencies may then propagate down wave guide 14 to be utilized as desired. The unwanted harmonics see receiver 10 as a reactive or nondissipative load and hence their power is reflected back toward the source where it will be reflected in turn and thus ultimately converted into the desired harmonic form.

For the purposes of clarity of exposition, the wave prior to passage through the distorting element has been described as sinusoidal. This need not be the case. A wave having any harmonic content which is not useful for a desired purpose may be passed through the distorting element, thereby transforming the harmonic content into a form which may be appropriate for the purpose at hand.

Although a wave guide configuration has been depicted in Fig. 1, as a receiving device, it is not essential to the invention that the receiver be of the wave guide type. Any linear receiving means would be appropriate and selection of a receiver may be based upon other considerations. For example, in an alternative form, a coaxial conductor may replace the wave guide. In this arrangement, iris discontinuities may be spaced along the line at distances appropriate for passing the desired harmonic frequency while rejecting unwanted frequencies.

It may be desirable to include in this transmission system a means for controlling the amplitude of the wave energy generated from the magnetron. This may be readily achieved by disposing an attenuator in the coaxial line between the magnetron and the nonlinear system. The attenuator may, for example, be a cylinder of semiconducting material such as porcelain containing a suitable amount of silicon carbide. The attenuating cylinder will be disposed inside the coaxial line 12 surrounding the inner conductor 15. The end faces of the cylinder may be appropriately tapered so as to reduce reflections of wave energy. An attenuator of this type will be appropriate for reducing power to suitable levels for efficient operation.

Fig. 3 is a modified form of the embodiment of Fig. 1 in accordance with the invention. In this arrangement, the transmission system as a whole is similar. However, the nonlinear element 18 of Fig. 1 is replaced by an element 25 which is nonlinear with respect to magnetic permeability rather than dielectric constant. Also, the bias-

ing means rather than being electric is appropriately magnetic. Specifically, a hollow cylindrical element 25 of ferrite material is disposed within coaxial line 12. The outside surface of ferrite cylinder 25 is contiguous to the inside surface of outer coaxial conductor 16. The ferrite material 25 will react with the magnetic field components of wave energy transmitted through it, unlike the barium titanite element which reacts with the electric field components. Since it is the case, that the greatest concentration of the magnetic field components will be disposed in this coaxial arrangement close to the inside surface of outer conductor 16, the central longitudinal section of cylinder 25 may be hollow and a substantial air space may exist between inner conductor 26 and the inner surface of ferrite cylinder 25. The ends of ferrite cylinder 25 may be tapered toward the inner surface of outer conductor 16 so as to minimize reflections. Disposed about outer conductor 16 in the region of ferrite cylinder 25 and coextensive thereto is a solenoid 27 supplied by a direct-current source 28. Solenoid 27 serves to provide a magnetic field parallel to the longitudinal axis of ferrite cylinder 25 which provides a magnetic bias for the ferrite. The operation of this embodiment then would be the same as that of Fig. 1, except that the distortion of the sinusoidal wave passing through the nonlinear element in this case would be due to the difference in magnetic permeability exhibited to different amplitude components of the wave by the ferrite.

The embodiment in accordance with the invention represented by Fig. 4A is one which utilizes hollow metallic wave guides to the exclusion of coaxial lines. In this arrangement a source 31 of circular-electric waves is coupled to a round hollow-pipe metallic wave guide 32 at one end thereof in a manner well known in the art. Round wave guide 32 constitutes an electromagnetic wave transmission line and is suitably proportioned to support circular-electric waves of the TE_{01} mode in round guides. Disposed within wave guide 32 is a hollow, cylindrical ferrite element 33 whose outside surface is contiguous to the inside surface of round guide 32. Ferrite element 33 constitutes a wave-distorting medium in the system and to appropriately perform this function extends along round guide 32 for several wavelengths of the operating frequency. Ferrite element 33 is tapered at each of its ends from its inside surface through narrower dimensions to its outside surface wherein the inside surface and the outside surface meet along a circle transverse to round wave guide 32 and contiguous with its inside surface. The type of tapering, well known in the art, is for the purpose of reducing from impedance mismatch due to irregularities. Circumscribing round wave guide 32 in the region of ferrite element 33 and co-extensive therewith is a solenoid 34 connected to a direct-current source 35 which may be, for example, a battery. Solenoid 34 serves to provide ferrite 33 with a biasing magnetic field in a direction longitudinal to the axis of ferrite cylinder 33 and parallel to the direction of wave energy propagation therethrough. Interposed between ferrite 33 and wave energy source 31 on the left is a mode-filtering element 36 made up of thin sheets of resistive material extending longitudinally along the round wave guide and which appear radially in transverse cross section like the spokes of a wheel with the center of the spokes coincident with the center of the transverse cross section of round wave guide 32. The function of mode-filtering element 36 is to remove by dissipation any modes other than the circular-electric mode which may develop due to inadvertent irregularities in the transmission system. A mode filter of this type is treated in greater detail in a copending application by A. P. King, Serial No. 222,006, filed April 20, 1951. The end of round wave guide 32 opposite to that coupled to source 31 tapers gradually into a narrower diameter round wave guide 37 which, because of its higher cut-off frequency dimension, will only support wave energy of a frequency higher than the operating frequency

generated by source 31. This round wave guide 37 is then successively tapered to narrower and narrower dimension guides 38 and 39 so that wave guide 39 will selectively receive only those harmonics of the fundamental operating frequency which are desired.

In operation, source 31 generates a sinusoidal electromagnetic wave of the circular-electric type which is launched in round wave guide 32 in the form of TE_{01} mode energy. This mode is kept uncontaminated by virtue of mode-filtering element 36 which removes any noncircular electric mode energy which may inadvertently have developed. As is known, the TE_{01} mode has its magnetic field components most heavily concentrated at the periphery of the wave guide (that is adjacent the inside surface of round guide 32) and consequently ferrite element 33 will be intimately coupled to the radio-frequency magnetic field since it too is disposed at the periphery of wave guide 32. Wave energy in this form, therefore, becomes subject to the distortion provided by the nonlinear ferrite medium as discussed and explained with respect to Figs. 2A, 2B and 2C. The distorted wave leaving ferrite cylinder 33 is in a saw-toothed configuration due to the biasing effect of solenoid 34 on the ferrite, and will therefore contain an infinite series of harmonics. Upon reaching the linear receiver comprising wave guide sections 37, 38 and 39, only those harmonics above cut-off for the tapered sections will continue to propagate down the transmission line. As a consequence the output of the tapered section receiver will not contain the fundamental frequency nor the lower harmonics previously selectively rejected by the preceding tapered sections.

Although a linear receiver in this embodiment has been depicted as a simple tapered wave guide, a receiver of the type depicted in the embodiment of Fig. 1 may be appropriately utilized when only a specified harmonic is needed or desired.

From the above discussion, it is apparent that the generation and utilization of harmonics is dependent upon the amount of distortion the nonlinear medium provides the radio frequency wave. As a consequence the electrical path length through the nonlinear medium must be substantial, that is several wavelengths of the operating frequency, in order to provide the requisite amount of distortion. In each of the embodiments thus far described, this extended electrical path has been achieved by utilizing a distorting medium which physically extends several wavelengths of the operating frequency. In the embodiment now to be described in accordance with the invention in Fig. 4B, the same electrical path length and consequently the same magnitude of distortion, is accomplished with a shorter physical length of distorting medium. This is very directly achieved by inserting an iris across the round wave guide transverse to the guide's longitudinal axis. This iris is disposed on the opposite side of the ferrite cylinder from source 31 and mode filter 36. In Fig. 4B a section of wave guide transmission line 32 is depicted in this arrangement with the source 31 (not shown) and mode filter 36 of Fig. 4A on the left, a circular metallic iris 40 on the right and a ferrite cylinder 41 located therebetween. It may be noted that ferrite cylinder 41 is only a fraction of the length of its counterpart 33 in Fig. 4A. In the operation of this embodiment, wave energy propagated through the ferrite will be multiply reflected between reactive iris 40 and source 31. As a consequence the wave energy will propagate back and forth through ferrite cylinder 41 and will experience the same electrical path length as previously experienced through the longer ferrite element 33. Therefore, this embodiment could most appropriately be utilized where economy in apparatus dimension is called for.

In all cases it is understood that the above-described arrangements are simply illustrative of a small number of many possible specific embodiments which can represent applications of the principles of the invention.

Numerous and varied other arrangements can readily be devised in accordance with said principles by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A harmonic generating system comprising a source of electromagnetic wave energy signals of given frequency, a section of coaxial transmission line for supporting said signals connected at one end to said source, a wave-distorting element of material having a nonlinear dielectric constant versus signal amplitude characteristic for given levels of signal intensity included within said coaxial line, said distorting element extending along said coaxial line for several wavelengths of said given frequency, the intensity of at least portions of said signals from said source being sufficient to drive said material into its nonlinear operating region, and a linear frequency selective receiving means coupled to the other end of said coaxial line receptive to frequencies substantially higher than said given frequency.

2. A combination as recited in claim 1 including means for electrically biasing said nonlinear distorting element.

3. A harmonic generating system comprising a source of electromagnetic wave energy signals of given frequency, a section of coaxial transmission line for supporting said signals connected at one end to said source, a wave-distorting element of material having a nonlinear permeability versus signal amplitude characteristic for given levels of signal intensity included within said coaxial line, said distorting element extending along said coaxial line for several wavelengths of said given frequency, the intensity of at least portions of said signals from said source being sufficient to drive said material into its nonlinear operating region, and a linear frequency selective receiving means connected to the other end of said coaxial line receptive to frequencies substantially higher than said given frequency.

4. A combination as recited in claim 3 including means for magnetically biasing said nonlinear distorting element.

5. A harmonic generating system comprising a source of electromagnetic wave energy signals of given frequency, a section of hollow circular cylindrical metallic wave guide for supporting said signals connected at one end to said source, a wave-distorting element of material having a nonlinear permeability versus signal amplitude characteristic for given levels of signal intensity included within said wave guide, said distorting element extending along said wave guide section for several wavelengths of said given frequency, the intensity of at least portions of said signals from said source being sufficient to drive said material into its nonlinear operating region, and a linear frequency selective receiving means connected to the other end of said wave guide section receptive to frequencies substantially higher than said given frequency.

6. A combination as recited in claim 5 including means for magnetically biasing said wave-distorting element.

7. A combination as recited in claim 5 wherein said selective receiving means comprises at least one section of wave guide having a higher cut-off frequency dimension than said wave guide section containing said wave-distorting element.

8. A combination as recited in claim 5 wherein said source of electromagnetic wave energy produces waves of the circular electric type and said wave-distorting element comprises a hollow ferrite cylinder longitudinally and coaxially disposed in said wave guide.

9. A combination as recited in claim 8 including means for dissipatively filtering all modes of wave energy other than said circular electric type, said filtering means being disposed between said source of circular electric energy and said wave-distorting ferrite cylinder.

10. In combination, a source of electromagnetic wave

signals having a fundamental frequency; a section of wave guiding transmission line for supporting said signals coupled at one end to said source; an element of material characterized by the parameters of dielectric constant and permeability, at least one of said parameters of said material having a nonlinear response relative to applied signal strength for a given region of signal strength; said element being coupled to said section of said line in the path of said signals; the strength of said signals from said source being sufficient to drive said material into its nonlinear region; and a linear signal receiving means selectively receptive to a frequency substantially different from said fundamental frequency coupled to the other end of said section of transmission line.

11. A combination as recited in claim 10 wherein said nonlinear element is elongated in the direction of propagation of said wave signals over a distance of several wavelengths of said fundamental frequency.

12. A combination as recited in claim 10 including means for biasing said nonlinear element.

13. A combination as recited in claim 10 including means for propagating said wave signals through said nonlinear element along a path having an electrical length equal to several wavelengths of said fundamental frequency.

14. A combination as recited in claim 13 wherein said transmission line comprises a hollow circular cylindrical metallic wave guide and said means comprises a circular metallic iris disposed transverse to the longitudinal axis of wave guide on the side of said nonlinear element opposite from said source.

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