

[54] **FREQUENCY TRANSLATOR USING
GYROMAGNETIC MATERIAL**

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[51] Int. Cl.² **H01P 1/40; H02M 5/02**

[58] Field of Search **333/24.1; 332/51 W;
321/69 NL, 69 W**

[56] **References Cited**

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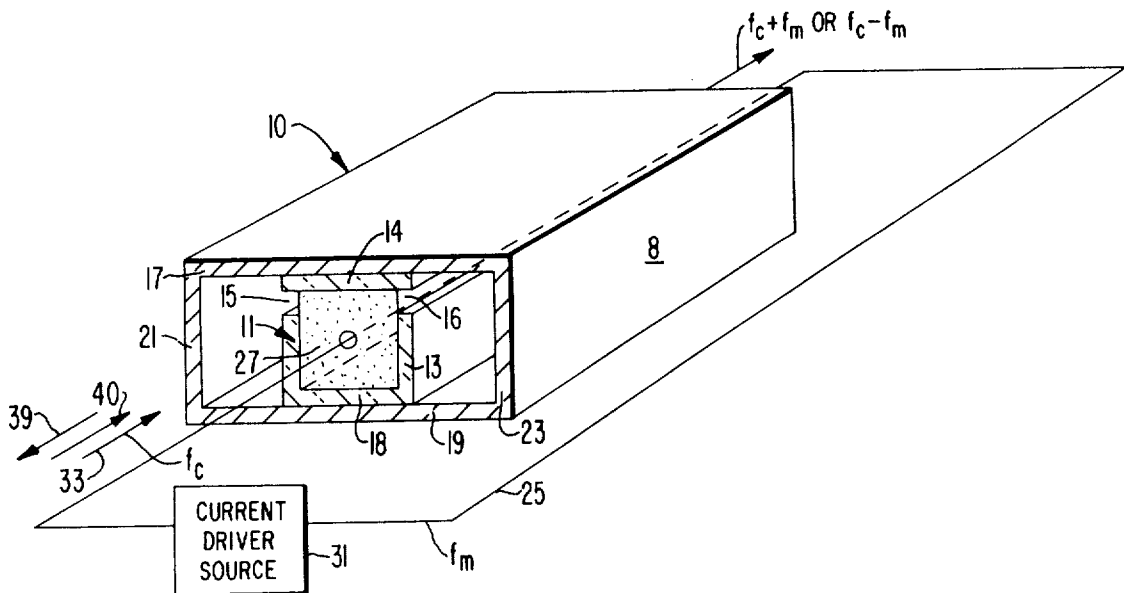
Primary Examiner—Paul L. Gensler

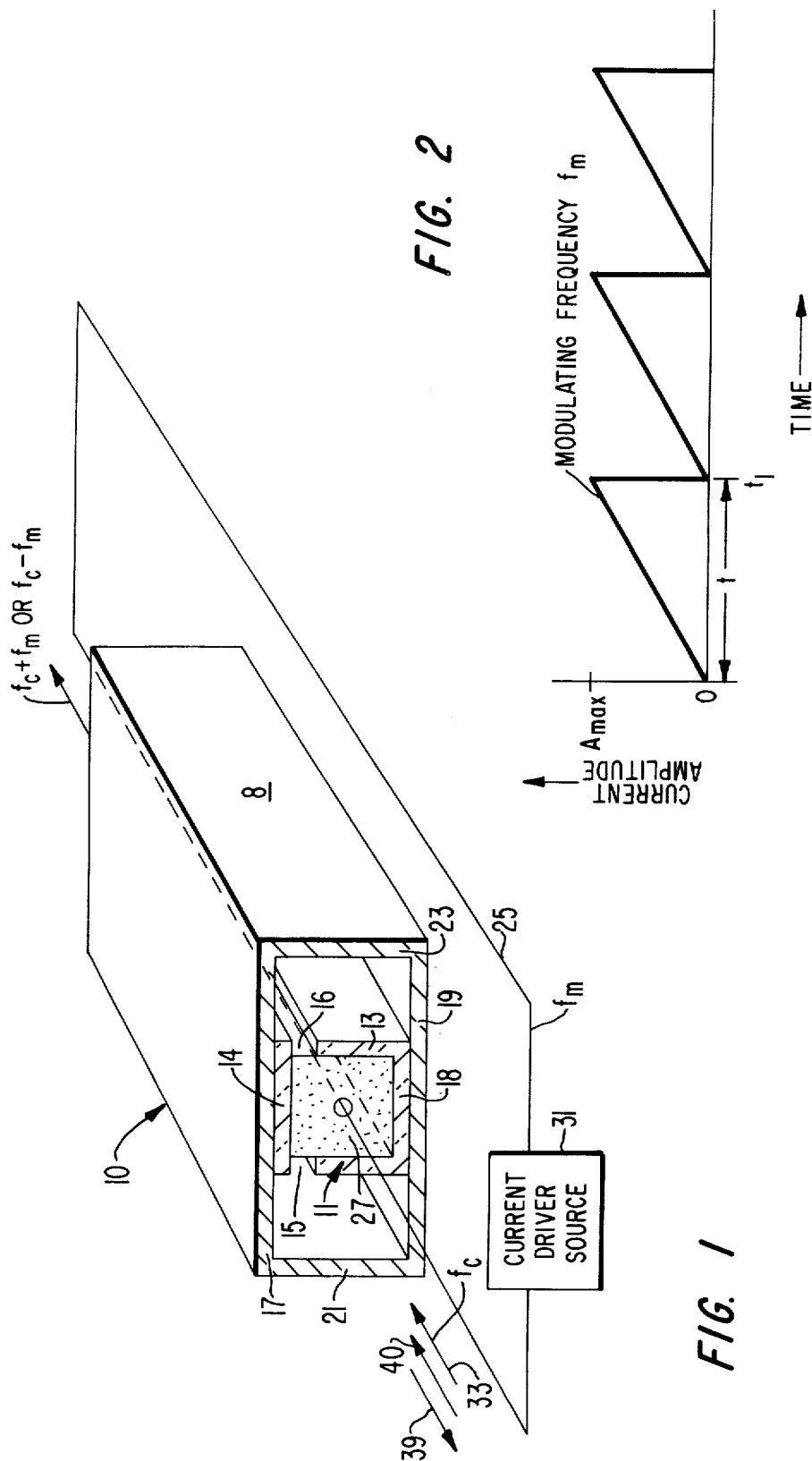
Attorney, Agent, or Firm—Edward J. Norton; Robert L. Troike

[57] **ABSTRACT**

A frequency translator is described that includes a toroid of gyromagnetic material extending along a length of waveguide. The toroid has demagnetizing gaps along its length. RF signals propagating along the waveguide are frequency deviated by the application of sawtooth current coupled through and along the toroid as modulating signals therefor.

6 Claims, 8 Drawing Figures





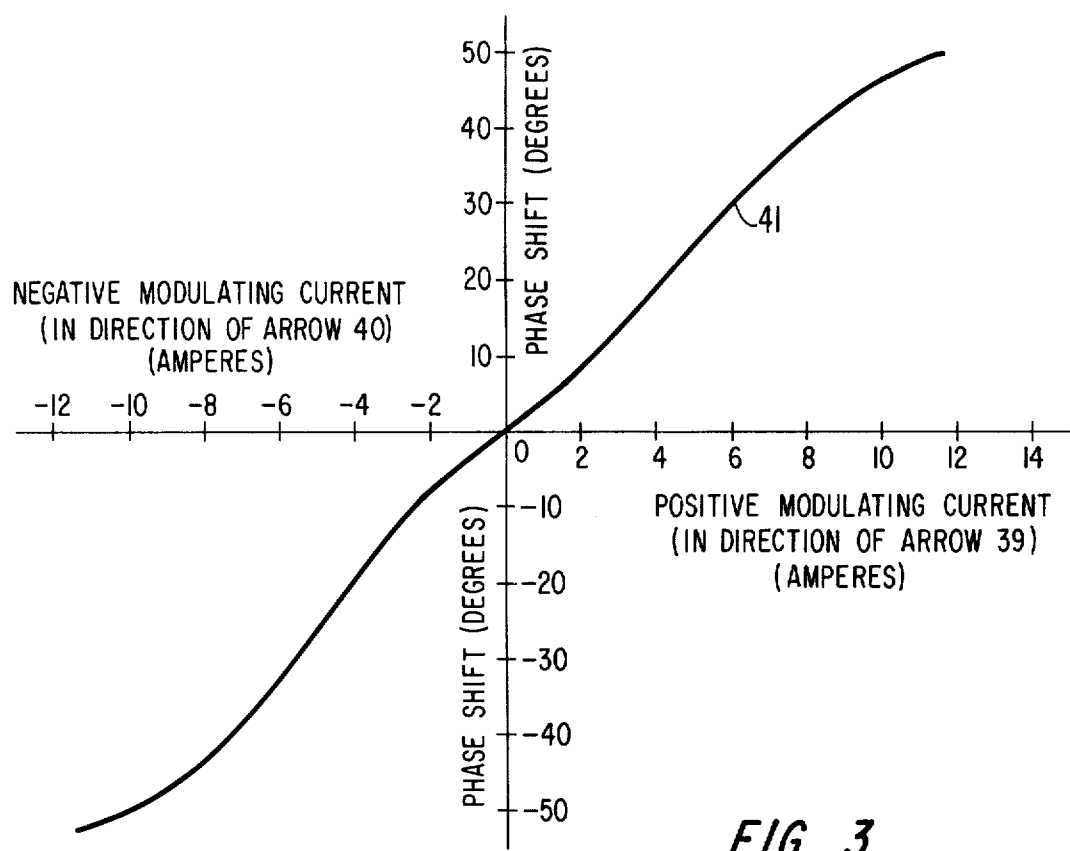


FIG. 3

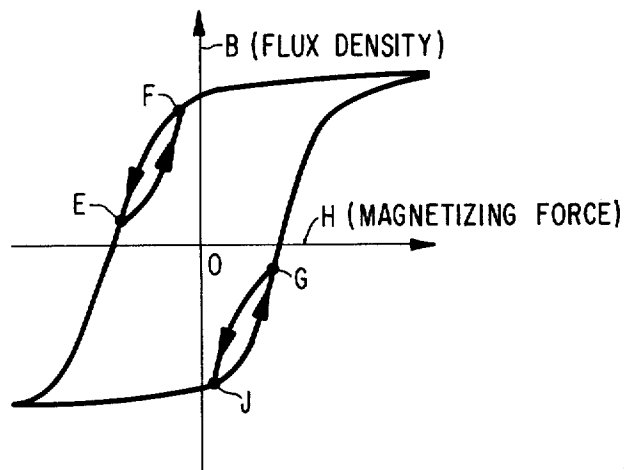


FIG. 4

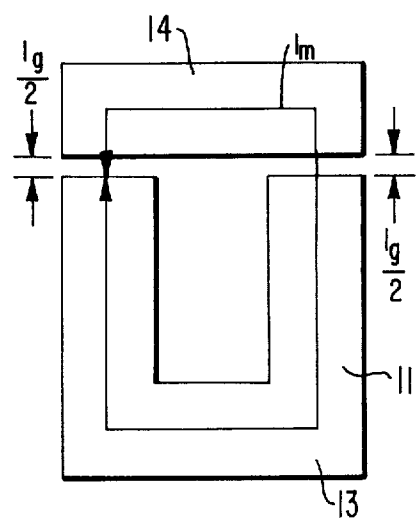
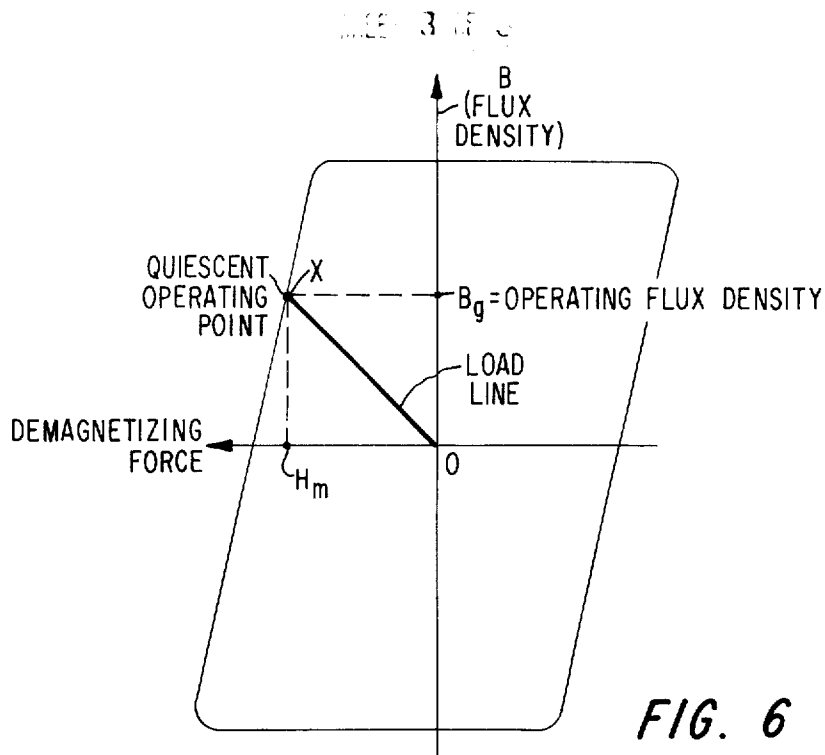
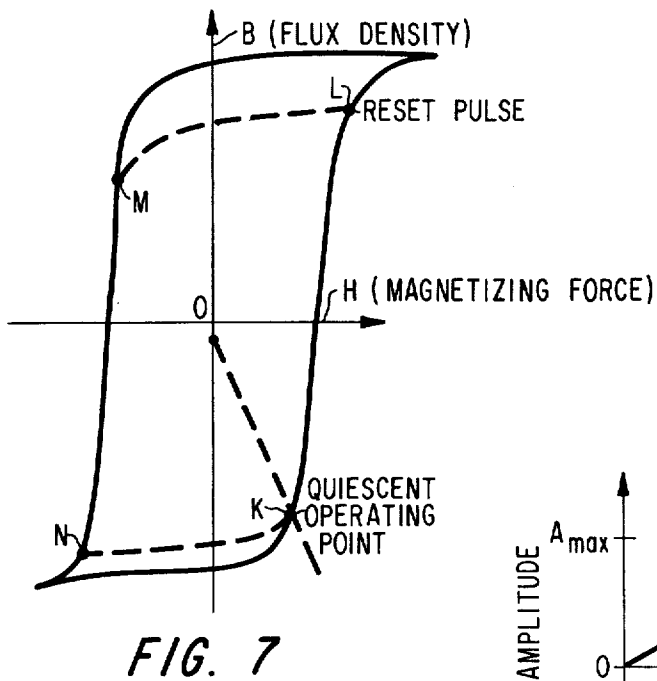
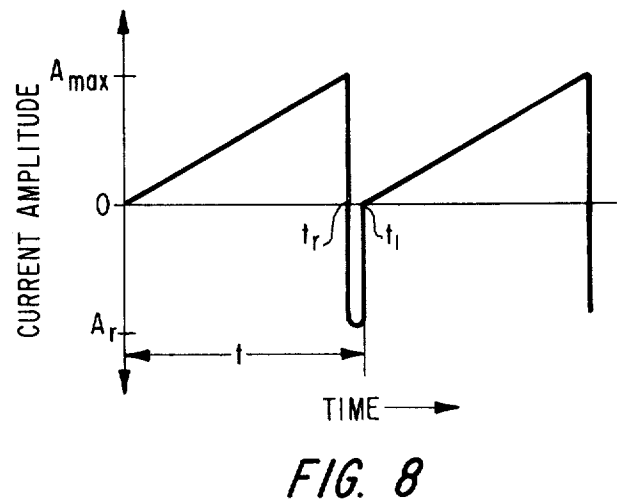


FIG. 5



FREQUENCY TRANSLATOR USING GYROMAGNETIC MATERIAL

BACKGROUND OF THE INVENTION

This invention relates to frequency translation and more particularly to the achievement of frequency translation by the use of gyromagnetic material.

The term "gyromagnetic" material refers to ferromagnetic, ferromagnetic and antiferromagnetic material, which material exhibit a phenomena associated with the motion of dipoles in these materials in the presence of a D.C. magnetic field and a superimposed RF magnetic field that is similar in many respects to the classical gyroscope. These materials and their properties are discussed by Lax and Button in Chapters 1 thru 6 in a book entitled "Microwave Ferrites and Ferrimagnetics," a McGraw-Hill publication.

While it is known that toroids made from these gyromagnetic materials when placed in a rectangular waveguide with a source of current passed through the toroid produce a microwave phase shift, such devices have not been known to provide frequency translation. In the prior art phase shifters the current passed through the toroid is pulsed with a square wave and operation takes place either at remanence or when operated at a minor hysteresis loop where there is no demagnetizing force.

BRIEF DESCRIPTION OF INVENTION

Briefly, frequency translation of radio frequency (RF) signals is provided in a waveguide having a toroid of gyromagnetic material mounted therein. The toroid has at least one small demagnetizing gap extending its length. Modulating signals in the form of sawtooth current are applied through the toroid to cause the toroid to track a minor hysteresis loop whereby frequency translation of the RF (radio frequency) signals traveling along the waveguide is achieved.

DETAILED DESCRIPTION

A detailed description follows in conjunction with the following drawings wherein:

FIG. 1 is a sketch of a frequency translator according to one embodiment of the present invention.

FIG. 2 illustrates the modulating signal as a plot of current amplitude versus time.

FIG. 3 is a plot of phase shift versus current amplitude.

FIG. 4 illustrates a B-H loop (hysteresis loop) for a toroid as used in FIG. 1.

FIG. 5 is a sketch of a toroid illustrating the dimensions 1_m and 1_p .

FIG. 6 illustrates a B-H loop (hysteresis loop) of a toroid with an air gap illustrating the demagnetizing force H_m and the flux density B_g across the air gap.

FIG. 7 illustrates a B-H loop for a toroid operating over the first and fourth quadrants.

FIG. 8 illustrates the modulating signal when operating a toroid over the first and fourth quadrants.

Referring to FIG. 1, there is shown a frequency translator 8 including a rectangular waveguide 10 having therein a toroid 11 of gyromagnetic material and a current driver source 31. The toroid 11 is made of a U-shaped section 13 and a flat plate section 14. The flat plate section 14 is separated by small demagnetizing air gaps 15 and 16 from the free ends of the U-shaped section 13. The flat plate section 14 is fixed adjacent to top

wall 17 of waveguide 10, and the bottom base 18 of the U-shaped section 13 is mounted adjacent to bottom wall 19 of waveguide 10. The toroid 11 is centered midway between narrow walls 21 and 23 of waveguide 10. A biasing wire 25 passes through the center of the toroid 11 as shown in FIG. 1. This wire is centered within the toroid 11 by a body 27 of dielectric material filling the inside of the toroid 11.

The current driver source 31 is coupled between the ends of the biasing wire 25 for providing along the wire the modulating signal current (at frequency f_m) which is a sawtooth driving current as illustrated in FIG. 2. Radio frequency signals at (original carrier frequency) (f_c) coupled to the waveguide 10 in the direction of arrow 33 are shifted in frequency in either a positive or negative direction according to the direction of the modulating current passed along wire 25. (See FIG. 3). For modulating current in the direction of arrow 39, opposite to the direction of propagation of the radio frequency signals (f_c), a positive phase and frequency shift is produced, as illustrated by curve 41 at the upper right of FIG. 3. The toroid operates with a quiescent point in the second quadrant of the B-H loop as shown in FIG. 4. As the current amplitude from the driver source 31 increases linearly (as illustrated in FIG. 2 between time 0 and just prior to time t_1), the flux density increases and the phase shift increases as illustrated in FIGS. 3 and 4. The phase shift is proportional to the flux density B, and the magnetizing force H is proportional to the modulating current. With zero modulating current the translator 8 operates at quiescent point E on the B-H loop of FIG. 4. As the modulating current increases from the current driver source 31 to a maximum of A_{max} in FIG. 2, the magnetizing force H increases and the flux density B increases causing an increase in phase shift produced to the carrier frequency signals at frequency f_c propagating along the waveguide 10 in the direction of arrow 33. When the maximum current amplitude (A_{max}) of the sawtooth is reached, the translator 8 operates at point F on the B-H loop of FIG. 4. At time t_1 in FIG. 2, the modulating current from the driver source 31 rapidly drops to zero and due to the demagnetizing gaps (15 and 16), the B or flux density flies back to the quiescent point E. A phase shift of 360° may, for example, be provided over each cycle (time t) with a maximum current of A_{max} . The toroid 11 is operated at a point where the sawtooth modulating current illustrated in FIG. 2 will cause the tracing of a minor hysteresis loop in that portion of the second quadrant that produces essentially a linear phase-time characteristic.

For magnetizing current in the direction of arrow 40 (in the direction of propagation of the signals at f_c), a negative phase and frequency shift is produced, as illustrated by curve 41 at the lower left of FIG. 3. The toroid under this condition operates with a quiescent point in the fourth quadrant of the B-H curve as shown in FIG. 4. As the current amplitude increases in the direction of arrow 40, the amount of phase shift in a negative direction increases and the flux density increases from quiescent point G in FIG. 4 to a maximum phase shift at a current amplitude A_{max} at point J. The current rapidly drops to zero by time t_1 and due to the demagnetizing gaps (gaps 15 and 16) the flux density changes back to the quiescent point G.

For one example where toroid 11 is made of a U-shaped section 13 and plate section 14, as shown in

FIG. 1, the toroid may be of a ferrite material having a ferrite remanence of 750 gauss such as ferrite G-1001 sold by Trans Tech of Gathersburg, Md. The dimension of the toroid 11 is 0.19 inch [0.48 centimeters (cm)] wide and 0.4 inch (1.02 cm) high with the area filled by dielectric body 27 being 0.030 inch (0.076 cm) wide and 0.24 inch (0.61 cm) high. The gaps 15 and 16 in this example are each about 0.005 inch (0.0127 cm). The axial length (length in the direction of propagation of the RF signal) of the toroid for one example is 2.88 inches (7.32 cm). The waveguide in this example is 900 mils (2.38 cm) wide and 400 mils (1.2 cm) high. The center of the toroid in this example is filled with a dielectric body 27 having a dielectric constant relative to air of 16. With a maximum driving current A_{max} of 15 amperes, the device in the above example produces each cycle about 49° phase shift per inch. For 360° phase shift per cycle of the sawtooth a toroid axial length of about 7.2 inches (18.05 cm) is needed. With the dielectric body in the center having a dielectric constant of 80, a toroid axial length of 2.9 inches (7.36 cm) will produce 360° phase shift per cycle of the sawtooth. The approximate relationships between the total air gap l_a , the mean length of the toroid l_m , the magnetic flux density in air B_a and the corresponding demagnetizing force H_m is as follows:

$$\frac{H_m}{B_a} = \frac{l_a}{l_m}$$

In this equation the external magnetic leakage is neglected for simplicity. FIG. 5 illustrates where the dimensions l_a and l_m are measured. The term l_a is equal to the sum of the two gaps. For a given quiescent operating point, x , FIG. 6 illustrates the demagnetizing force H_m and flux density B_a provided in the gaps.

For operation in the second quadrant of the B-H loop and using the G-1001 ferrite discussed above, the demagnetizing force (H_m) was very nearly 1 oersted and the operating flux density (B_a) was 100 gauss. For translation of 9 GHz (gigahertz) RF (radio frequency) signals, the mean path length l_m of a typical toroid is very nearly 1 inch (2.54 cm). Substitution of these values in the previous equation gives a total air gap l_a of

$$\text{Total } l_a \approx \frac{1}{100} \times 1 = 0.010 \text{ inch (10 mils) or } 0.0254 \text{ cm.}$$

For operation in FIG. 1 with two gaps, each gap was 5 mils (0.0127 cm). The frequency deviation of Δf_r is proportional to the phase shift per cycle of the sawtooth (ϕ_m) and the frequency of the sawtooth f_m as represented by: $\phi_m f_m / 2\pi$. If for example, the phase shift per cycle (ϕ_m) is 360° (2π radians) then the frequency deviation Δf_r equals the frequency of the sawtooth modulating current (at frequency f_m). The phase shift per cycle need not be 360° . The frequency of the modulating current (f_m) may be increased to achieve increased frequency deviation without changing the phase shift per cycle. Also the phase shift per cycle may be increased by operating over the first and fourth quadrants of the B-H loop as illustrated in FIG. 7.

To operate over the first and fourth quadrants, the structure may be like that of FIG. 1, but the demagnetizing gaps are of a different size and the modulating

current from the current driver source 31 includes, in addition, a reset signal in an opposite direction each cycle. The modulating signal current as illustrated in FIG. 8 is characterized by a linearly increasing current from 0 to A_{max} in a first positive direction followed by a reverse resetting pulse. The linearly increasing current causes the operating point of the toroid to change along the B-H loop of FIG. 7 from point K in the fourth quadrant of FIG. 7 to point L in the first quadrant. In this case, for example, this linearly increasing current is applied in the direction of arrow 39 of FIG. 1. The modulating signal current from the source 31 over the time period t (each cycle) further includes a reset pulse at time t_r which is a reverse pulse after the current reaches A_{max} . Near the end of each cycle at about the time t_r , the reset pulse is applied in the direction of arrow 40 in this example. This pulse is of a magnitude A_r and time such that with the gap the operation of the translator will return (when this resetting pulse is removed) to point K at time t_1 via a retrace along point LMNK of the B-H loop. It is desirable to keep the time duration of the reset pulse down to less than 10 percent of the time period t . For operation in the first and fourth quadrants of the B-H loop, as shown in FIG. 7 and using the same materials and arrangement as shown in FIG. 1, the corresponding parameters are:

$B_a \approx 600$ gauss, $H_m \approx 0.5$ oersted, $l_m \approx 1$ inch (2.54 cm). Therefore the total gap size is

$$l_a \approx \frac{0.5}{600} \times 1 = 0.0008 \text{ inch (0.8 mils) (0.0021 cm)}$$

Although the toroid illustrated above had two magnetizing gaps, the toroid could also have been made of a single gap but with total gaps equal to l_a . Other gyromagnetic materials found useful in phase shifters, such as yttrium iron garnet could also be used for the toroid material.

What is claimed is:

1. A translator for providing a frequency deviation of radio frequency signals in accordance with a modulating signal comprising:

a waveguide having a toroid of gyromagnetic material extending along a length of the waveguide, said toroid having at least one demagnetizing gap along the length of said toroid,

said waveguide being dimensioned to support given radio frequency signals propagated along said waveguide,

means for applying a sawtooth current through said toroid to translate according to said current the frequency of said given signals.

2. The combination claimed in claim 1 wherein said means for applying a sawtooth current includes a conductor extending through the center of said toroid.

3. The combination claimed in claim 1 wherein said waveguide is rectangular with the toroid centered between the broad and narrow walls of the waveguide.

4. The combination claimed in claim 1 wherein said toroid is filled with a body of dielectric material.

5. The combination claimed in claim 1 wherein the total size of the demagnetizing gap l_a in the toroid is determined by

$$l_a = l_m \frac{H_m}{B_a}$$

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where l_m is the mean length of the toroid, H_m is the demagnetizing force, and B_m is the magnetic flux density in the demagnetizing gap.

6. A translator for providing a frequency deviation of radio frequency signals in accordance with a modulating signal comprising:

- a waveguide having a toroid of gyromagnetic material extending along a length of the waveguide, said toroid having at least one demagnetizing gap along the length of said toroid, said waveguide being dimensioned to support given radio frequency signals coupled into and out of said waveguide,

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- a conductor extending through the center of said toroid, and
 - a source of sawtooth current coupled to said conductor, said sawtooth current characterized by the current amplitude each cycle going linearly from a reference potential to a first maximum amplitude in a first direction through said toroid and to a resetting potential in a second opposite direction through said toroid, whereby operation takes place in two quadrants of the B-H loop for said toroid in a manner to alter the frequency of said given signals.
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