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3,001,154 9/1961 Reggia..... 333/73
 3,212,018 10/1965 Amoss et al. 333/73 UX

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[54] **RESONANT RING VARACTOR CIRCUIT**
 9 Claims, 4 Drawing Figs.

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321/69, 333/73

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[50] Field of Search..... 325/445;
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[56] **References Cited**

UNITED STATES PATENTS

2,530,691 11/1950 Fox 333/73

ABSTRACT: A waveguide has disposed coaxially therein and perpendicular to the axis of microwave propagation a resonant ring structure including a varactor bridging an electrical discontinuity in the ring. The structure is used as a switch, tunable filter or up-converter by suitably biasing the varactor from an outside biasing source. For use as a frequency multiplier or limiter the varactor generally needs no external biasing source.

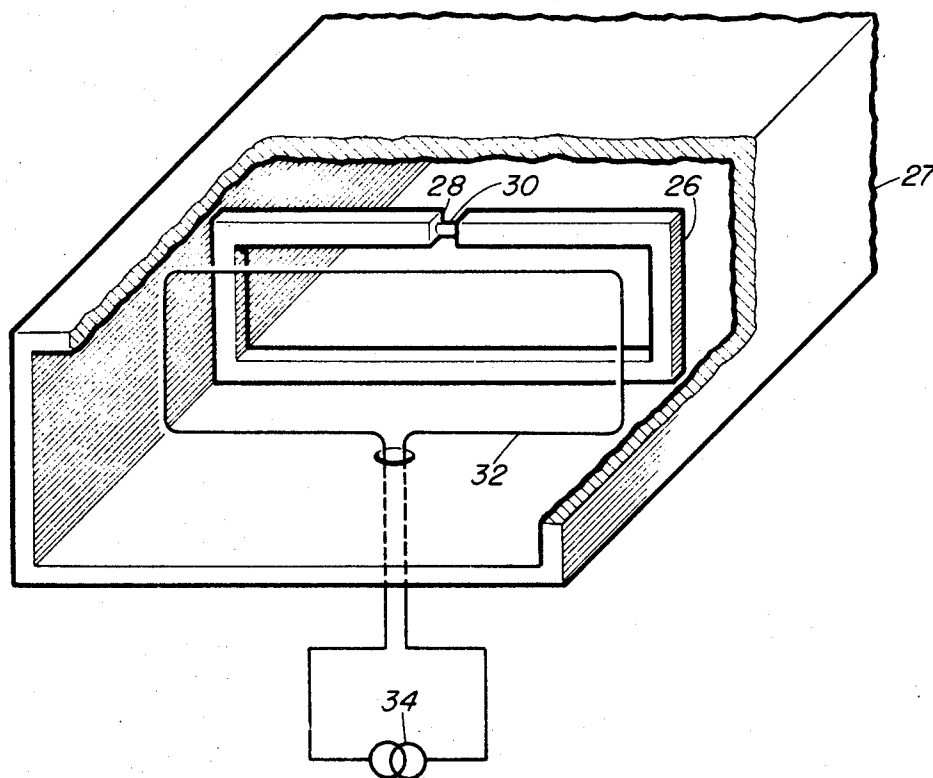


FIG. 1.

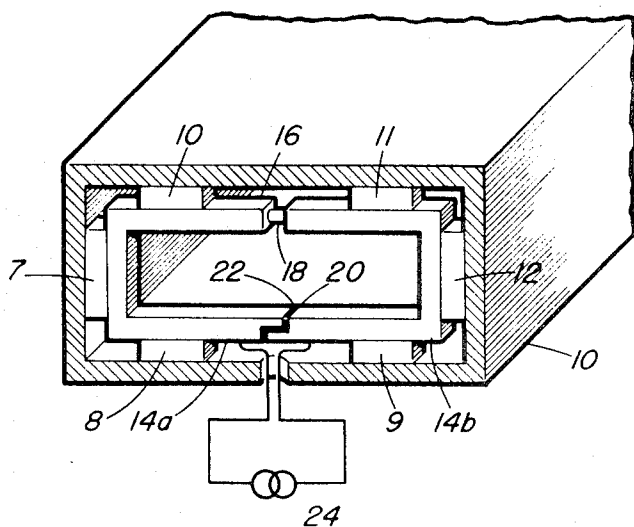
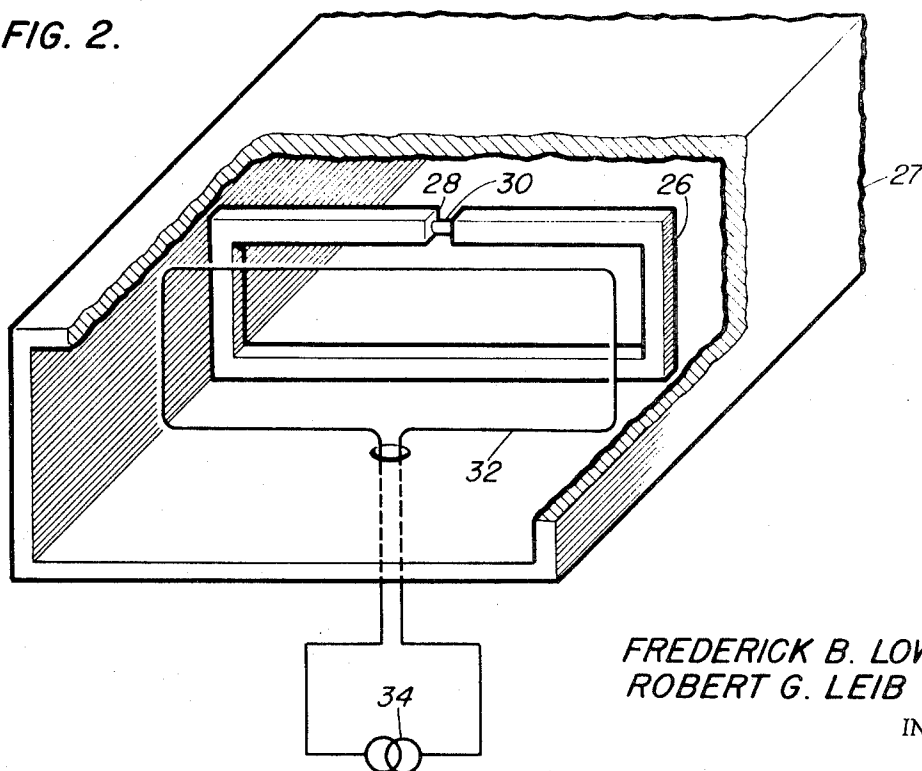


FIG. 2.



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FIG. 3

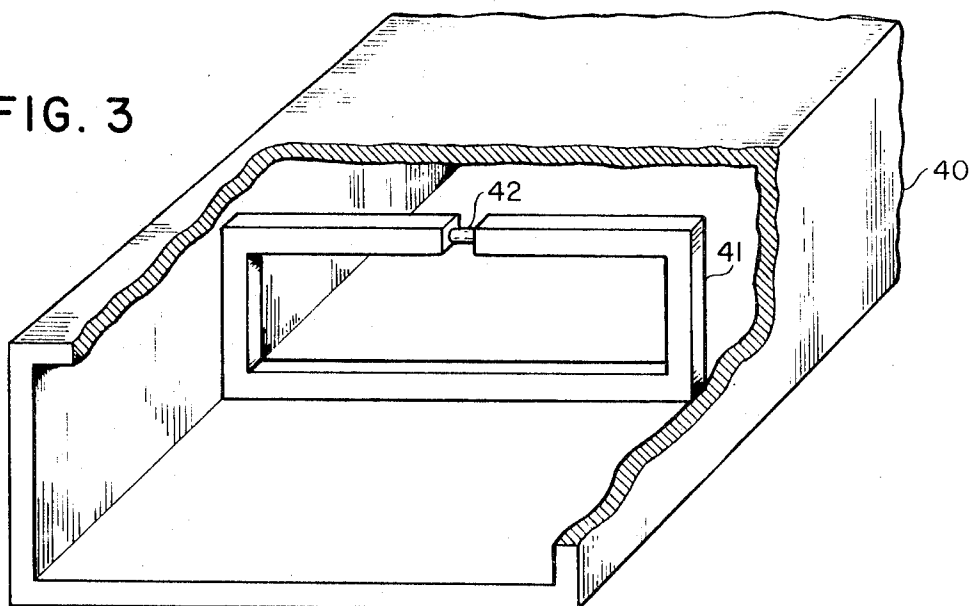
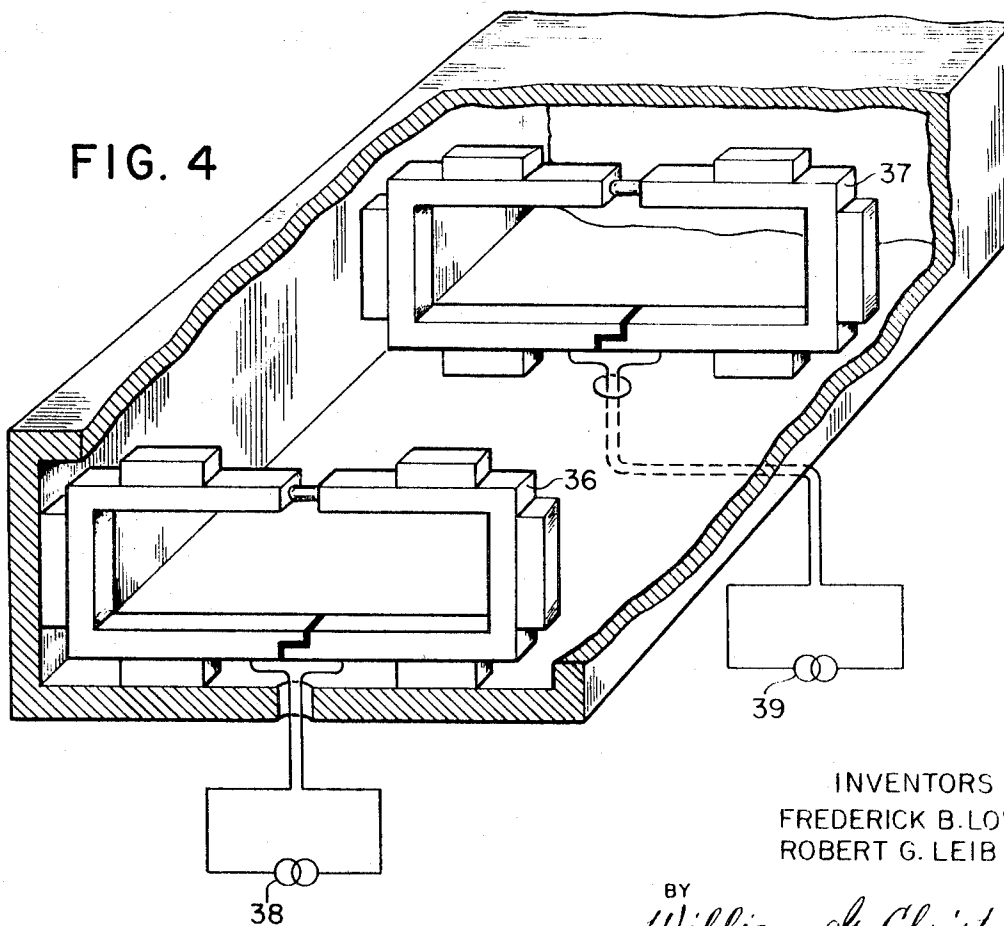


FIG. 4



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RESONANT RING VARACTOR CIRCUIT

This invention relates to solid-state microwave devices and particularly to waveguides having resonant obstacles of the resonant ring type disposed therein.

It is known that certain metallic structures when located in a waveguide exhibit resonant phenomena similar to a series resonant circuit which shunts an equivalent circuit transmission line. For example a conducting ring structure coaxially located within a waveguide and perpendicular to the direction of microwave propagation will become a series resonant shunt when the mean circumference of the ring is somewhat longer than a free-space wavelength of the propagating microwaves. In other words, under these conditions, that is, where the mean circumference of the conducting ring is slightly longer than a free-space wavelength of the electromagnetic energy which is propagating within the waveguide, no electromagnetic energy which is propagating within the waveguide can propagate past the ring structure. Since the resonant ring structure resonates in response to only a narrow band of frequencies predetermined by the physical dimensions of the ring, the device up to now has been limited to use mainly as basically a fixed notch filter.

A new type of resonant ring structure has been devised wherein a discontinuity in the resonant ring structure is electrically bridged by a varactor to reestablish the ring structure. When mounted in this manner the varactor capacitance becomes a part of the ring equivalent circuit so that when the varactor is biased the capacitance in the series resonant equivalent circuit is increased thus causing the frequency at which the ring will resonate to be decreased. In like manner, of course, decreasing the varactor bias will cause the ring equivalent capacitance to decrease thus causing the ring resonant frequency to increase.

Briefly, a varactor is a PN junction diode crystal having substantially zero current leakage in the reverse bias direction while exhibiting the nonlinearly capacitive characteristics of junction diodes generally. The varactor is inserted into the resonant ring discontinuity so that the crystal is unshielded by the material of the ring and exposed to the energy propagating in the waveguide. The crystal-contacting elements which may extend into the wave path act only to increase the inductive portion of the series resonant equivalent circuit. Of course, since the discontinuity need by only wide enough to allow the crystal wafer to be exposed to the electromagnetic wave energy, the crystal-contacting elements may be suitably recessed into the metallic structure of the resonant ring, thus effectively shielding these contacting elements from the microwave energy. All spurious reactances are thus completely eliminated. The basic equivalent circuit of the resonant ring structure with the varactor inserted is identical to the equivalent circuit of a simple resonant ring structure, that is, a simple series LC circuit shunting the equivalent transmission line circuit, except that now the series capacitance can be tuned by variation of the varactor capacitance. The varactor capacitance may vary due to the power level of the signal in the guide or by other signals coupled to the resonant ring.

By adjusting the low signal LC resonant frequency to a frequency above the signal frequency propagating in the waveguide, the circuit will perform as a limiter. That is, as the signal power increases the voltage across the varactor increases causing the capacitance of the varactor to increase, thus lowering the LC series resonant frequency. This tends to short circuit the waveguide to the signal thus limiting the signal power which will propagate along the guide.

It is thus an object of this invention to provide a new type of limiter for electromagnetic energy propagating through waveguides.

Another object of this invention is to provide a limiter of the type described using resonant ring structures which incorporate a nonlinear capacitor semiconductor device such as a varactor.

By coupling signals to the resonant ring, bias on the varactor is varied and the circuit can be made to function as a switch, up-converter or frequency multiplier. For use as a switch, the resonant ring need only be designed to have a resonant frequency somewhat higher than the frequency of the signal which is a propagating through the waveguide and which signal it is desired to switch. Subsequently, merely by biasing the varactor to increase the capacitance in the series resonant equivalent circuit so that the ring is now resonant at the propagating frequency, the equivalent transmission line circuit is shunted thus preventing propagation of the microwave energy past the resonant ring structure. For use as an up or down converter it is merely necessary to introduce as biasing to the varactor a modulating frequency and to extract from the waveguide either the sum or difference frequency, as desired, of the propagating frequency with the modulating frequency. The ring will, of course, have a low resonant frequency that, if harmonically related to the waveguide equivalent circuit resonant frequency, will aid in the generation of harmonic frequencies and keep the fundamental and harmonic frequencies separated due to the different propagation modes in the waveguide. When the ring resonant frequency is so related to the fundamental frequency a frequency multiplier results. The frequency multiplier output frequency may now be varied over a somewhat limited range, which range is generally dependent upon the band of frequencies propagating in the waveguide, by the simple expedient of varying the bias on the varactor so as to vary its resonant frequency.

Another object of this invention is thus to provide a microwave switch operating on resonant ring principles.

A still further object of this invention is to provide up or down frequency converters for microwave energy operating on resonant ring principles.

One more object of this invention is to provide a frequency multiplier operating on resonant ring principles.

Where several rings of the type described are properly spaced down a waveguide the device may now be used as a tunable filter by the simple expediency of varying the bias of the various varactors, so as to allow passage or blockage of the frequencies desired. A tunable band-pass filter is constructed, for example, by providing rings resonant to frequencies above and below the desired pass band. The filter may be tuned by increasing the bias on all varactors so as to shift the pass band down while decreasing the bias on all the varactors will shift the pass band frequency up. Of course, the bandwidth can be increased or decreased by suitably increasing the bias on the high frequency resonant rings and decreasing the bias on the low frequency resonant rings when it is desired to decrease the pass band and by varying the bias in the opposite sense when it is desired to increase the pass band.

Thus another object of this invention is to provide a tunable waveguide filter of the type described.

These objects and features of the invention will be better understood from a reading of the following description of the preferred embodiment, as well as making obvious to the reader other objects of this invention.

FIG. 1 shows the resonant ring structure of the invention with low frequency or DC biasing means.

FIG. 2 shows a method of biasing the resonant ring structure through a loop coupling.

FIG. 3 illustrates the invention when used as a limiter.

FIG. 4 illustrates the invention when used as a tunable filter.

Referring more specifically to FIG. 1, there is seen in section a waveguide 10 having mounted coaxially therein on spacers 7 to 12, suitably of Teflon rexolite or other microwave window material, a ring 14 of electrically conductive material. Ring 14 has an electrical discontinuity 16 into which is inserted a varactor 18 electrically bridging the discontinuity. A second ring discontinuity 20 has a dielectric material 22 inserted therein to capacitively couple the two halves 14a and 14b of ring 14. Biasing source 24 applies voltage across second discontinuity 20 which is a short circuit to microwave frequencies propagating in waveguide 10 and induced in ring 14 but

which comprises an open circuit to bias voltage frequencies. In this manner the varactor is quite simple biased from an external source so long as the bias voltage is unidirectional or a relatively low frequency.

Another means of biasing the varactor is seen in FIG. 2 and is applicable when the frequency of the biasing source is higher than can be blocked by capacitive coupling on the resonant ring structure such as shown in FIG. 1. Referring to FIG. 2, as before a ring structure 26 is coaxially mounted in waveguide 27, by spacers not shown, perpendicular to the direction to the microwave energy propagation. Ring structure 26 has a single discontinuity 28 which is bridged by varactor 30. A loop antenna 32 is also mounted coaxially in the waveguide 27 perpendicular to the direction of microwave propagation and in close proximity to ring structure 26. Loop antenna 32 is energized from biasing source 34 having an output frequency which will cause electrical energy to radiate from the loop. Bias voltages oscillating at the loop antenna frequency are thus induced into ring structure 26, thus biasing varactor 30 at the bias source 34 frequency.

As has been previously discussed, the resonant ring structure acts as an equivalent LC series shunt across the waveguide equivalent transmission line circuit with the equivalent LC shunt being resonant when the mean perimeter of the ring is somewhat greater than a free-space wavelength of the energy propagating in the waveguide. The varactor provides the means of varying the equivalent circuit series capacitance so as to change the ring resonant frequency. With this teaching it should be obvious to one skilled in the art how various microwave devices could be made using a resonant ring varactor circuit. Briefly, the device shown in FIG. 1 may be used as a microwave switch if the resonant frequency of the unbiased ring varactor circuit is somewhat higher than the frequency of the energy propagating within the waveguide. The varactor is then biased to increase the series capacitance of the equivalent shunt circuit so as to lower the ring resonant frequency to the waveguide propagating frequency. The device can also operate as a tunable notch filter merely by tuning the ring varactor circuit with the biasing source.

In like manner, a tunable band-pass filter can be made by arranging a number of resonant ring varactor structures along the guide and biasing each to remove a different portion of the frequency spectrum propagating within the waveguide. The invention employed as a tunable filter is illustrated in FIG. 4, reference to which should now be made. In this figure, the elements of each resonant ring structure 36 and 37 are essentially identical to the resonant ring structure shown in FIG. 1. In this case, each resonant ring structure is biased by a separate biasing source, 38 and 39 respectively for resonant ring structures 36 and 37. Again, the filter is tuned by varying the bias of the varactors.

For microwave devices requiring high frequency bias voltages the biasing means shown in FIG. 1 is not applicable since the high frequency voltages will be shorted by the capacitor comprised of discontinuity 20 and dielectric material 22. Thus, when the resonant ring varactor circuit is used as an element in, for example, an up or down converter the loop antenna biasing means shown in FIG. 2 is more suitable since the modulating frequency will normally be fairly close to the propagating frequency. Biasing source 34, in this case, a modulating frequency generator, excites loop antenna 32 at the modulating frequency which is thus induced in ring 26 to bias varactor 30 at the modulating frequency. The resultant waveguide frequency will be the sum and difference of the propagating frequency with the modulating frequencies. Known means can now be utilized to select the desired resultant frequency.

When it is desired to use the resonant ring varactor circuit as a limiter it is merely necessary to design a ring structure to have a resonant frequency slightly higher than the frequency

of the signal it is desired to limit, as previously discussed. Additionally, in the case of a limiter, no external bias source is required, varactor bias being extracted from the waveguide in the following manner. The invention employed as a limiter is illustrated in FIG. 3 reference to which should now be made and wherein a structure identical to that shown in FIG. 2 except without a separate biasing means is seen. When the power of the signal propagating within waveguide 40 is low, only slight voltage is induced in ring structure 41, varactor 42 is only slightly biased and the ring structure is not resonant at the propagating frequency. As signal power increases, however, the voltage across the varactor increases causing the varactor capacitance to increase, lowering the LC series resonant frequency. This tends to short circuit the waveguide signal thus limiting the signal power which can propagate past the resonant ring structure.

Having thus described the preferred embodiment of my invention and the various means of taking advantage thereof, I hereby claim the subject matter including modifications and alterations thereof encompassed by the true scope and spirit of the appended claims.

The invention we claim is:

1. Means for processing electromagnetic microwaves comprising:

a waveguide through which said microwaves propagate;
a nonlinear voltage variable capacitor means; and,
a resonant ring structure including a ring of electrically conductive material having an electrical discontinuity, said capacitor means being mounted in said ring to bridge said discontinuity so as to comprise a portion of said resonant ring structure, the peripheral shape of said resonant ring structure approximating the cross-sectional shape of said waveguide but of smaller size, said resonant ring structure being disposed coaxially within said waveguide and being normal to the direction of propagation of said microwaves.

2. Means as recited in claim 1 wherein said nonlinear voltage variable capacitor means comprises a varactor.

3. Means as recited in claim 2 with additionally means for biasing said varactor.

4. Means as recited in claim 2 with additionally:
second capacitor means for bridging a second discontinuity in said resonant ring and,
a source of bias voltage connected across said varactor and said second capacitor means.

5. Means as recited in claim 2 wherein the mean perimeter of said resonant ring is somewhat longer than a free-space wavelength of said propagating microwaves.

6. Means as recited in claim 2 wherein the resonant frequency of said resonant ring structure is greater than the frequency of said propagating microwaves.

7. Means as recited in claim 3 wherein said biasing means comprises:

a source of biasing frequencies;

a loop disposed within said waveguide in spaced relationship with said resonant ring structure and connected to receive said biasing frequencies for electromagnetically coupling said biasing frequencies to said resonant ring structure.

8. Means as recited in claim 1 wherein said resonant ring structure including said nonlinear voltage variable capacitor comprises a voltage variable series resonant LC equivalent circuit shunting the equivalent transmission line.

9. Means as recited in claim 3 with additionally at least a second resonant ring structure including at least a second varactor and means for biasing said second varactor, said second resonant ring structure being mounted within and coaxially to said waveguide normal to the direction of propagation of said microwaves a predetermined distance from said resonant ring structure.