July 5, 1949. R. A. HEISING 2,474,898

ELECTROMAGNETIC RESONATOR OF THE MAGNETRON TYPE

Filed April 5, 1944 2 Sheets-Sheet 1

FIG. 1

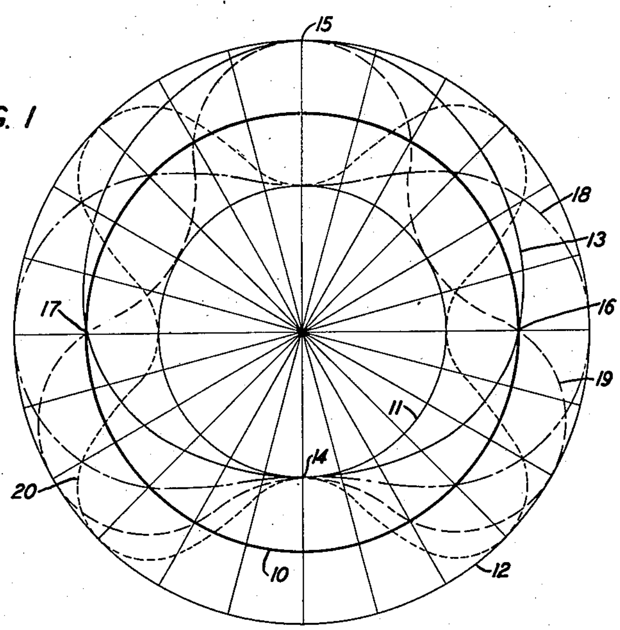
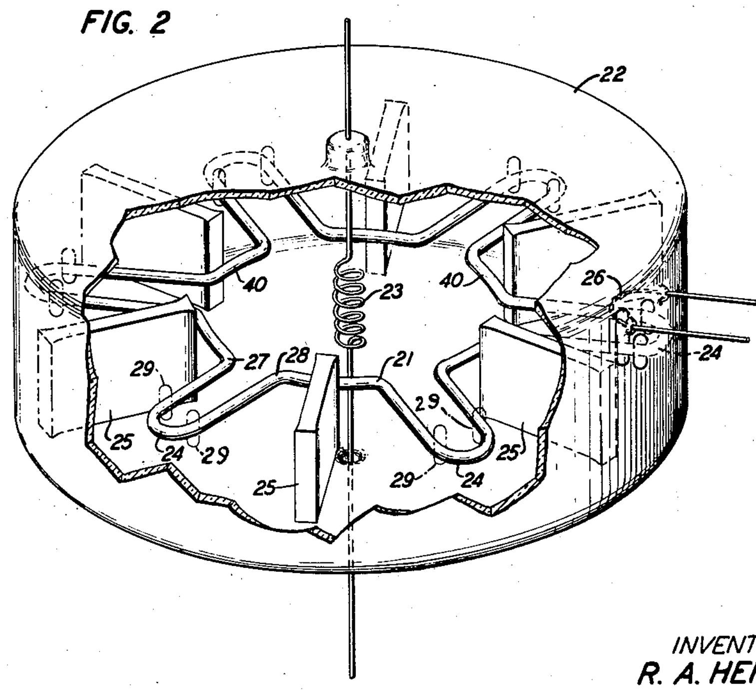


FIG. 2



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Filed April 5, 1944 2 Sheets-Sheet 2

FIG. 3

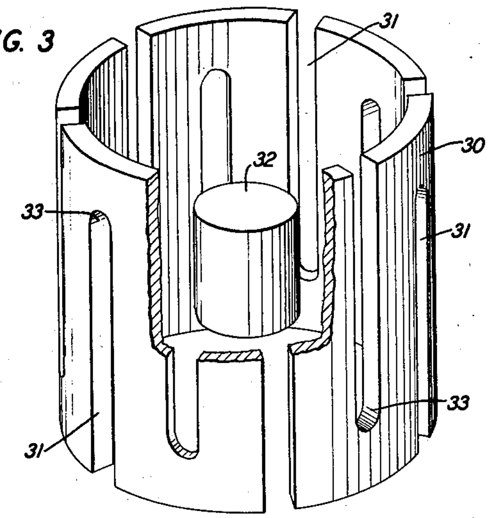


FIG. 4

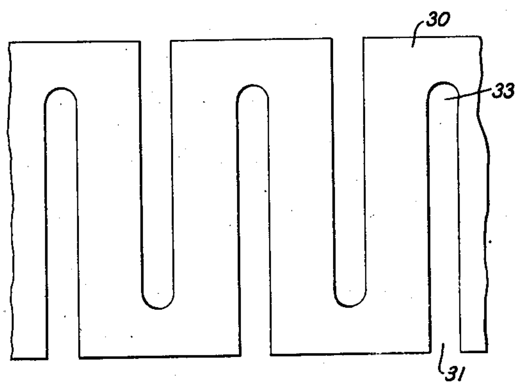
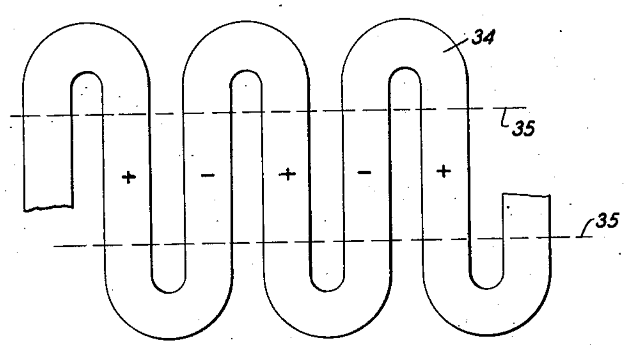


FIG. 5



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ELECTROMAGNETIC RESONATOR OF THE MAGNETRON TYPE

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4 Claims. (Cl. 315—40)

1

This invention relates to multiply-resonant electromagnetic systems and to arrangements for operating a plurality of resonant elements in unison.

In microwave oscillation generating systems it has become customary, particularly where magnetron oscillators are concerned, to employ a resonant system comprising a plurality of coupled resonant conductors, conductive structures, or resonating cavities excited in unison by an excitation system, usually electronic, which is common to all the resonators. Resonators of this type have come into use at increasingly high frequencies, reaching at the present time to 3,000 to 10,000 megacycles per second, or higher. Difficulty has sometimes arisen due to the tendency of a system to generate different frequencies from time to time and, upon occasion, to shift erratically and unpredictably from one frequency to another.

This difficulty has its origin in a well-known property of coupled oscillatory systems, namely, that a plurality of elements, even if all are resonant at one and the same frequency, form, when coupled together, a multiply-resonant system having a plurality of resonant frequencies, which are generally as numerous as the individual resonators comprising the system. The multiple resonant frequencies are distributed over a band of frequencies in the neighborhood of the resonant frequency of the individual resonators when the latter are tuned alike or nearly so. The amount of spreading apart of the resonant frequencies depends upon the degree of coupling, the band becoming wider as the coupling is increased. A slight amount of coupling will be required in order to maintain a definite phase relationship between the individual oscillations but in general either the coupling should be reduced to a minimum in order that the neighboring resonant frequencies may be to all intents and purposes indistinguishable, the system then having essentially but one operating frequency, or the coupling should be made sufficient to separate the resonant frequencies to an extent that operating conditions will be conducive to oscillation at one frequency only.

It is well known that a uniform linear conductor or transmission line of fixed length may be excited to oscillate in one or more sections in a system of standing waves either of a fundamental frequency or of a harmonic multiple of the fundamental frequency. An endless conductor or ring will likewise support harmonic standing waves. Uniform lines, being characterized by smoothly distributed reactance, do not exhibit the relatively close grouping of resonant frequencies found in the systems of coupled resonators or lumped or relatively concentrated reactances hereinbefore considered.

2

A ring type resonator may be folded or bent into a shape to favor the substantially exclusive production of one of the harmonic modes of oscillation. Such bending may, however, introduce coupling between points or separated regions in two or more of the oscillating sections of the ring, which coupling will tend to by-pass the normal transmission of waves along the line from one point to the immediately adjacent point. If such coupling appears, its effect is to destroy the uniform distribution of reactance and introduce multiple resonances in a relatively narrow band adjacent to the selected harmonic frequency exactly as in the case of the coupled resonators or systems with separated regions of relatively concentrated reactance.

An object of the invention is to reduce coupling irregularities, particularly of the magnetic type, between the individual resonating elements of an otherwise uniformly distributed system of reactances.

In accordance with the invention, an initially substantially uniformly distributed system of reactances is modified in shape and employed as a resonating system operable at a harmonic frequency by virtue of standing waves produced in the system and a separate return path is provided for the magnetic flux in each harmonic section of the system so that the magnetic flux in each harmonic section has a return path substantially free from magnetic linkage with any other harmonic section, whereby magnetic coupling between currents in the respective harmonic sections of the system is minimized.

A feature of the invention is the use of a resonating system comprising an endless ring capable of supporting harmonic standing waves and deformed by shaping or folding to favor the substantially exclusive production of one particular harmonic mode of oscillation.

In the drawings, Fig. 1 is a graphical representation of a harmonic system of standing waves such as may be supported upon an endless conductive ring;

Fig. 2 is a view in perspective, partially broken away, showing an embodiment of the invention in a magnetron oscillator;

Fig. 3 is a perspective view partially broken away showing the electrode structure of another embodiment of the invention in a magnetron oscillator;

Fig. 4 is a developed plan view of the anode in the system of Fig. 3; and

Fig. 5 is a developed plan view of a modification of the anode shown in Fig. 3.

In Fig. 1 there is represented graphically an endless conductor 10 in the form of a circular turn of wire or a metallic ring or the like. Such a conductor is capable of supporting standing waves in harmonic relation. The ring may vibrate electromagnetically either as a whole or in a number of sections. In Fig. 1, there are indicated graphically a number of possible standing wave patterns, the amplitude of oscillation being indicated by radial coordinates extending inwardly and outwardly from the ring 10. A circle 11 is shown to indicate an arbitrarily selected maximum amplitude in one sense and another circle 12 to represent the maximum amplitude in the opposite sense. The curve 13 shows the distribution of amplitude along the ring when the standing wave is of the fundamental frequency. The wave represented by the curve 13 has maximum amplitude at a point 14, minimum amplitude at a point 15 diametrically opposite the point 14 and zero amplitude at intermediate points 16 and 17 each separated from the points 14 and 15 by 90 degrees. The curve 18 represents a standing wave of the second harmonic frequency and has two maxima, two minima and four points of zero amplitude. The curve 19 represents a standing wave of the third harmonic frequency and the curve 20 the fourth harmonic. An oscillator of the ring type capable of supporting harmonic standing waves as represented in Fig. 1 is employed with certain modifications in the following preferred embodiments of the invention.

Fig. 2 illustrates an embodiment of the ring type oscillator in a magnetron type of oscillating system. An endless conductor 21 or continuous band of conductive material which may be formed from metallic wire or rod or bar is supported in any suitable manner within a vacuum tight envelope 22. The configuration of the conductor 21 preferably has circular symmetry as shown in Fig. 2 and a cathode 23 such as a helical coil capable of thermionic emission is supported in any suitable manner in the axis of symmetry as shown. The conductor 21 is preferably formed with a plurality of reentrant portions or poles 40, alternating with salient portions or folds 24 and between these may be placed respective barriers or shielding means 25 which may be conductive plates or screens or the like. As an output coupling device there may be provided in conjunction with one of the loops 24 a coupling loop 26 magnetically coupled with the loop 24 and having terminals extended through seals in the envelope 22 to permit external connection to the loop 26.

The conductor 21 may be viewed as having been formed by collapsing a ring, such as the ring 10 of Fig. 1, so as to encourage standing waves of one particular harmonic frequency. In the arrangement shown in Fig. 2, the third harmonic is favored. The conductor 21 may be utilized as the anode of the magnetron in conjunction with the cathode 23. Electric and magnetic steady operating fields may be provided in any suitable manner in accordance with well-known practice for the operation of magnetrons.

It will be observed that in the absence of non-

uniformly distributed couplings the conductor 21 can oscillate only at its fundamental frequency and at the comparatively widely separated harmonic frequencies. By virtue of the shaping of the conductor in Fig. 2, however, the third harmonic will appear to the substantial exclusion of the other harmonic modes. A small amount of non-uniform capacitive coupling is unavoidably introduced by the folding of the conductor 21 bringing portions, such as indicated at the points 27 and 28, for example, into proximity to form a lumped or relatively concentrated capacitance. There are also introduced by the shaping a plurality of regions of relatively concentrated inductance, namely in the salient portions or nearly closed inductive loop portions 24. These loops give rise to individual portions of magnetic flux which may interlink adjacent loops and thereby introduce a concentrated coupling between discrete portions or separated regions with a resulting introduction of band-pass filter behavior as above described. A few individual flux lines are indicated as at 29. To avoid non-uniform coupling it is desirable that the flux linkages in any one loop 24 shall not pass within, or take a return path through, any other of the loops 24. A few illustrative flux lines are indicated as at 29 with return paths free of linkage with more than one loop 24. The barriers 25 or other shielding means may be used when necessary to compel the magnetic fields in the individual loops 24 to return separately as in the case of the flux lines 29. The desirability of introducing the barriers increases as the number of folds or poles in the conductor 21 is increased. While the barriers might be omitted in the case of six poles as illustrated in Fig. 2, an increase to eight or twelve poles, for example, without increasing the diameter of the ring would be likely to necessitate the use of the barriers.

Instead of folding the ring 10 into radial folds as illustrated in Fig. 2, the folding may be done by laying the folds axially on the surface of an imaginary cylinder. The anode in this case may take the physical form shown in Fig. 3 in which a hollow cylindrical conductor 30 is provided with a plurality of axial slots 31 entering alternately from opposite ends. A cathode 32 may be provided, extending preferably opposite about the middle third of the axial length of the anode where maximum amplitude of the alternating electric field intensity will normally appear. The maximum alternating magnetic field in an anode of this shape is found at the closed ends 33 of the slots. Fig. 4 shows the developed plan of the anode 30 and Fig. 5 shows the developed plan of an alternate construction for the anode 30 comprising a folded wire or rod 34. In Fig. 5 the approximate positions of the electric poles are indicated by plus and minus signs. As in the case of the arrangement of Fig. 3 the cathode may be placed opposite the portion approximately indicated between the broken lines 35.

What is claimed is:

1. An electromagnetic resonator comprising a continuous band of conductive material having a plurality of reentrant portions alternating between open-ended salient portions, whereby oscillating currents in said salient portions give rise to relatively concentrated magnetic fluxes in the space enclosed by the respective salient portions, each said reentrant portion forming an open space between two salient portions, and shielding means in said open spaces to substantially prevent the flux in one of said adjacent salient

portions from taking a return path passing through another of said salient portions, whereby magnetic coupling between oscillating currents in the respective salient portions is materially reduced.

2. An electromagnetic resonator comprising a continuous band of conductive material having a plurality of symmetrically disposed reentrant portions alternating between open-ended salient portions whereby oscillating currents in said salient portions give rise to oppositely directed magnetic fluxes in the interior of adjacent salient portions, the space within each reentrant portion being open for the passage of alternating magnetic flux, and shielding means external to said band of conductive material and disposed between adjacent salient portions to confine said oppositely directed magnetic fluxes to substantially independent return paths, whereby magnetic coupling between oscillating currents in the respective salient portions is materially reduced.

3. A multiple resonator electromagnetic system comprising a conductive structure having a plurality of open-ended inductive loop portions alternating with relatively non-inductive portions, said structure having open spaces between adjacent loop portions, said spaces communicating with the spaces enclosed by the adjacent loop portions and providing a return path for alter-

nating magnetic flux in one loop portion without interlinkage with any other loop portion.

4. An electromagnetic resonator comprising a continuous band of conductive material having a plurality of symmetrically disposed nearly closed inductive loop portions, which loop portions are open in the direction perpendicular to the plane of the loop, said resonator having open spaces between adjacent loop portions, and shielding means disposed in said spaces on either side of each loop portion to substantially confine the alternating magnetic flux in said loop portion to a return path free from magnetic linkage with any other of said loop portions.

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