May 16, 1939. K. FRITZ 2,158,114

ULTRA-HIGH-FREQUENCY MULTIPLIER

Filed Nov. 16, 1937

Fig. 1

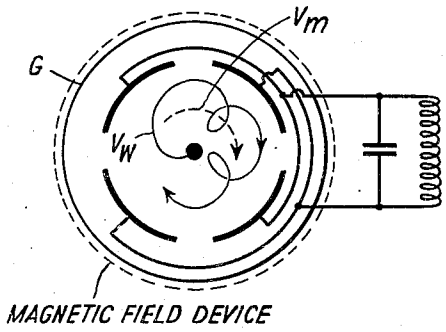


Fig. 2

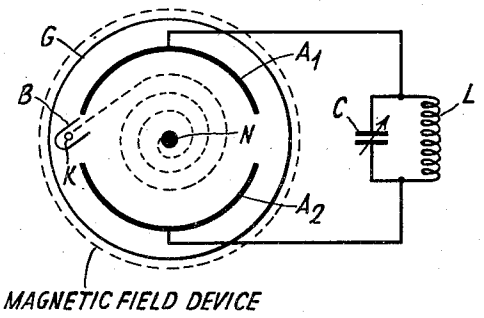


Fig. 3

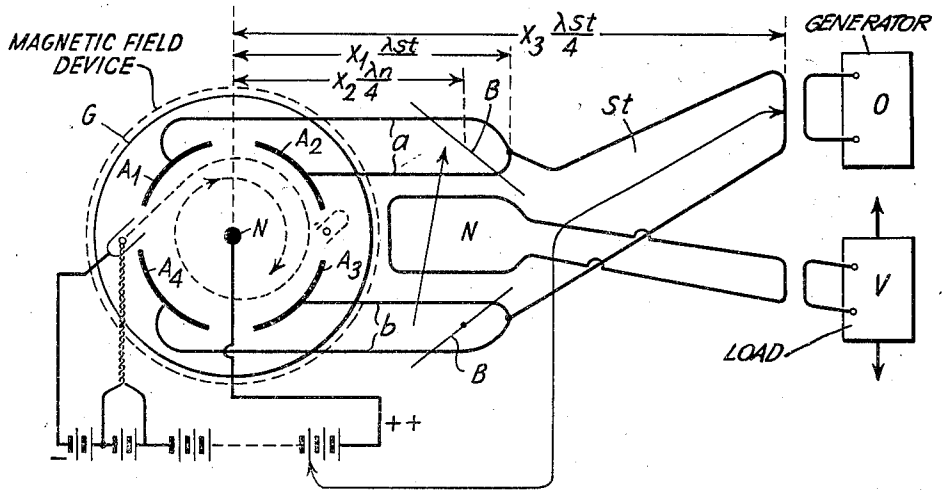
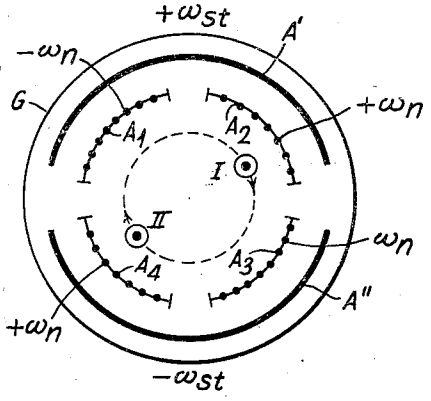


Fig. 4



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ULTRA-HIGH FREQUENCY MULTIPLIER

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Application November 16, 1937, Serial No. 174,773
In Germany November 21, 1936

4 Claims. (Cl. 250—36)

This invention relates to circuit arrangements adapted for the generation of ultra-high frequency oscillations and for frequency multiplication. The invention contemplates the employment of a master oscillator of the magnetron discharge tube type. Some of the fundamental principles involved in carrying out the invention are disclosed in my copending United States application, Serial No. 174,771, filed November 16, 1937, of which this application forms a continuation-in-part.

In the circuit schemes disclosed in the parent application recourse is had to tubes fundamentally known and suggested in the earlier art. The peculiarity and special features of the new circuit organizations makes it possible to practice master excitation and frequency multiplication without distinct control electrodes. In fact, magnetron tubes having a multiplicity of segmented anodes are so connected that, in line with the disclosure of the parent patent application, the identical anode parts function as control and as working electrodes. To this end the segments serving for the maintenance of the control field, in electrical respect, are combined in a different manner than for the production of the useful field so-called.

This, in a general way, is accomplished by so interconnecting the segments that, as regards the control field, they operate like a two-split magnetron, and as regards the useful field, like a four-split magnetron. So far as the circuit organization is concerned, there are the following characteristic properties and features:

Pairs of adjacent or opposite segments or segment groups or assemblies are united immediately and in most cases exclusively through an oscillatory circuit, for instance, a parallel-wire system. Connected with the electrical mid-points (points of symmetry) of the two segment circuits is a third parallel-wire system. The manner of association of a master valve or transmitter with a load will presently be set forth in detail in this specification. Two fundamental embodiments at least are feasible; both of which may be in accordance with the teachings of the parent patent application. Repetition of these details would lead too far away from the basic idea of this invention.

My invention will now be described in full detail, reference being made to the accompanying drawing in which:

Figure 1 shows diagrammatically and in cross-section a more or less conventional magnetron discharge tube and circuit therefor;

Fig. 2 shows a feature of improvement of the magnetron discharge tube, said improvement being of the essence of the invention herein disclosed;

Fig. 3 shows diagrammatically a preferred circuit arrangement for use in connection with my improved magnetron discharge tube; and

Fig. 4 presents diagrammatically, and in the rough, an illustration of electronic action the theory of which is fully explained in the ensuing part of the specification.

The parent patent application shows in the exemplified embodiments there described magnetron tubes having a circulo-symmetric arrangement of parts, the cathode being mounted in the axis of symmetry of a discharge tube system built according to the teachings of Habann as shown in Fig. 1. In magnetrons predicated upon circular symmetry the electrons are traveling along cycloidal paths or trajectories about the cathode K. The angular velocity ω is the mean rate of revolution v_m of the cloud of electrons referred to $r=1$. Individual electrons during the revolution of the space-charge cloud experience rolling motions on cycloidal paths. But the instantaneous speed v_w of the individual electrons is generally greater. The direction of rolling and thus the sign of the instantaneous speed varies during the rolling motion on circular paths.

The mean angular velocity in line with earlier considerations (vide K. Gritz, Zeitschrift fuer Hochfrequenztechnick, 1935, vol. 46, p. 17; and Posthumus, Wireless Engineer, March, 1935, p. 129) is here denoted as ω, and has been shown to be inversely proportional to the magnetic field strength H and directly proportional to the anode voltage U_a.

Now, it is possible to get along in practice with considerably weaker magnetic fields, if tubes are employed, in practicing the basic idea of the parent patent application, of the kind disclosed in my copending United States application, Serial No. 112,940, filed November 27, 1936. Such tubes have the following characteristic features:

The electrodes substantially enclose the discharge space on all sides, thus forming a composite hollow prism. The cathode is disposed on the circumference of the prism, say, along the directrix of a circular cylinder or parallel thereto in a manner similar to the nozzle of a turbine. This arrangement is shown in Fig. 2. The oscillation electrodes consist of segments or sectors placed parallel to the axis. In these "turbine"-type tubes contra-distinct from the circulo-symmetric multi-split magnetron tubes, the transit time of

an electron is equal to, or more particularly greater than, the time of oscillation for a full period of the ensuing oscillations. Hence, it is exactly inverse to that of the conventional magnetron principle. The oscillations of higher order distinguish themselves precisely by the fact that in their case the circulation or transit time of the electrons is greater than the period of oscillation. For example, in the case of oscillations of the second order the transit or circulation time is 2τ, where τ=the time of oscillation for full period. Now, this circumstance is of extremely great importance in practice. For, presupposing like tube dimensions and wave length, it is possible to use far feebler magnetic fields. Moreover, there result the following advantages:

When reducing the oscillation potential there are no regions in which the oscillations will discontinue or break off. Hence, the amplitude of the oscillations can be diminished steadily down to relatively small values. Where low alternating potentials are concerned, there is an increase in the number of transits before the electrons "land".

Recourse is had to the physical fact that an electron which inside a constant magnetic field travels along a rotational path, has an angular velocity, measured in radians, which is purely a function of the magnetic field, and has no relation to the potential through which they passed. Thus, if an electron revolves about a point, its angular velocity, and therefore its reaction upon an oscillatory circuit, is constant. As to amplitude, however, this is dependent upon motional energy, in other words, upon the radius of the circular path for a given magnetic field. Mathematically expressed: ω=const.H

In other words, the invention resides in the fact that in circuit organizations of the kind disclosed in the parent patent, so-called "turbine" type tubes are used. Tubes of this kind make it much easier to carry circuit organizations as disclosed in the parent patent application into practice, and they are thus an improvement of the invention as such.

In the light of the preceding considerations, the angular velocity ω of an electron in a turbine magnetron is directly proportional to the magnetic field strength. Impressing, on the one hand, upon the anodes A_1 and A_2 through oscillatory circuit LC an alternating voltage of the frequency.

$$\frac{\omega}{2\kappa}$$

and, on the other hand, choosing the operating conditions of the tube so that the electrons move inside the tube at an angular velocity ω, then an energy exchange will be brought about between the alternating field revolving with frequency

$$\frac{\omega}{2\kappa}$$

and the electrons revolving at an angular velocity ω. Those electrons which follow the positive wave crest of the alternating field will be accelerated thereby; in other words, they absorb energy and expand the radius of their paths or trajectories. The other electrons which lag behind the negative maximum of the alternating field, the wave trough, must give up energy seeing that they are bucking the field, being incidentally decelerated. Nothing will be altered in this situation by a further sub-division of the anode of such a turbine tube. Nor will the situation be altered if the segments or sectors thus resulting are combined to result in several oscillatory circuits of a higher natural frequency.

Referring to Fig. 3, there is shown a circuit organization comprising a magnetron with a four-split anode. Pairs of immediately adjacent segments A_1, A_2, and A_3, A_4 which are each united through a parallel-wire system a and b, respectively, are short-circuited as regards the control or angular frequency ω_{st}. This is easily accomplishable by tuning the parallel-wire line to $\lambda/2$ or a multiple (x_1) thereof as regards the control wave λ_{st}. Each system at the same time constitutes a continuation or extension of a conductor of the third parallel-wire system S_t which is tuned, for instance, to $\lambda/4$ of the control angular wave λ_{st} (control frequency ω_{st}), or a multiple (x_3) thereof, and connected with a master transmitter 0. The two segment systems a and b each form at the same time an oscillation circuit for the multiplied frequency ω_n tuned to $\lambda/4$ or $x_2 \cdot \lambda/4$ of the useful wave. Tuning bridges B are preferably used for this purpose. Both segments a and b are connected through the output circuit N with a consumer or load V consisting, say, of another multiplier stage or an aerial.

Now, by judicious choice of the working data (electrical and magnetic field), it is then possible to accelerate the circulating electrons from the control frequency, and to decelerate or retard them with the useful frequency. All of these phenomena and actions have already been completely confirmed by experimentation. But the underlying theory will be more readily understood if recourse is had to analogous concepts in the field of electro-mechanical engineering.

Referring to Fig. 4, the revolving cloud of electrons may be conceived as being the rotor of a rotary converter with a ring winding. The segments A in this case would play the part of the stator poles. The rotor is driven by energy of fundamental frequency ω_{st}. The segments A_1, A_2, and A_3, A_4, so far as the said fundamental frequency is concerned, are connected in parallel relation. Hence, looking from the driving end, we are dealing with a two-pole machine with a continuous A. C. ring winding. However, from the same rotor energy is also being absorbed. So far as this action is concerned, each segment separately acts as a pole. In the presence of constant speed of rotation it is possible, as well known, to obtain a higher frequency from a four-part machine than from a two-pole one.

However, we find close agreement with mechanical and electrical engineering from the viewpoint of the theories of an alternating current, particularly as regards energetics and efficiency. If from the useful frequency ω_n that energy is abstracted which is supplied with the fundamental frequency ω_{st}, then, from a viewpoint of principle and disregarding building-up and starting actions, no additional energy expenditure is necessary. The tube functions as a frequency changer. Only such electrons as happen to sever their connections with the revolving electron cloud as a result of disturbances and dissymmetries, may be regarded as a loss or energy consumption which must be covered and replaced by the D. C. fields of the frequency-changer. Reverting to the object of comparison and analogy, losses are occasioned also in a rotary converter, and these are due to friction, heat dissipation, and hysteresis. While these losses may be reduced to a minimum they are never completely eliminable.

In the majority of cases, especially where sev-

eral frequency changers are cascaded, the general and basic aim will be to insure amplification in the various stages of the cascade by accelerating the electrons under control of a constant magnetic field. This may be explained by reference to Fig. 4.

Inasmuch as the energy factors and problems basically hold good for magnetrons involving circular symmetry with the cathode mounted in the axis of the system, as well as for turbine tubes with the gathering electrodes mounted axially, only the alternate current-carrying electrodes are shown in order to preclude any attempt to confine the application of the idea underlying the invention to definite types of tube.

For the sake of simplicity the tube of Fig. 4 is shown with separate electrode assemblies or groups, one group being for control and the other for the utilization circuit. Such an embodiment is fundamentally feasible, but will not offer the merits of an organiztion as here disclosed. The four segments A_1, A_2, A_3, A_4, are shown to be reticulated, or of screen mesh formation, and posteriorly thereof are provided two additional segments A' and A'' of larger size. Segments A' and A'' are fed with the fundamental or control frequency, while the oscillations which have been multiplied in frequency and which have optionally been amplified are put out at the segments A_1 to A_4.

Thus, if electrons appear at any places inside the discharge space which originate from a source no matter where located, then an additional amplification of the oscillations is possible upon the application of sufficiently high direct current potentials between the original source of the electrons and the electrodes. The electrons which lag behind or follow the positive crest of the alternating field (wave crest), and which thus would constitute or represent the rotating armature, preserve a constant radius if a relatively long period of time is considered. Temporarily they absorb energy from the control field, and they deliver this energy periodically into the useful field. Their energy content stays constant upon the average. They act like the flywheel mass of an armature.

However, there will also be electrons which, after issuing from their original source, will happen to arrive at some other time between the electrodes setting up the alternating field. Thus, they will buck not only the useful field, but also the control field, and the result is that they will, wholly or partly, yield such energy as they have acquired from the direct current accelerator field to either of the said two alternating current fields. Now, it is these electrons to which the amplifier effect is due. Reverting once more to Fig. 4, it will be noted that the potential of the electrodes A' and A'' changes at the rate or rhythm of the control frequency ω_{st}, and that of the electrodes A_3 and A_4, for instance, at twice the useful frequency $\omega_n=2\omega_{st}$. It should be particularly noted that two electrons I and II are indicated as being disposed at the places indicated inside the discharge space and which, referred to frequency ω, present a phase shift or angular difference of 180 degrees. Both of these electrons convert part of their kinetic energy into oscillation energy which they yield to the useful field, that is to say, the electrodes A_1 and A_3, because at the time when they travel towards these electrodes the latter are negative. They are trying, as it were, to drive the useful field forwards; incidentally, they are retarded and yield energy.

So far as the control field is concerned, conditions are different. While electron I, to be sure, is bucking action of the temporarily negative electrode A'', it has a reinforcing action as regards the control field. Electron II, however, travels towards the temporarily positive electrode A' and thus absorbs energy from the control field, through this energy the electron yields again in the following motional phase.

To summarize: there results the following balance:

Electron I reinforces or regenerates the field ω_{st} and reinforces or regenerates the field ω_n
Electron II abstracts from or damps field ω_{st} and reinforces or regenerates the field ω_n

The indications "positive" and "negative" refer to the signs of the superposed alternating fields. Apart from that the various electrodes should preferably have positive direct current biasing potentials in reference to the cathode. The best possible arrangement for combined application and frequency multiplication is obtained by connecting a plurality of frequency multipliers in series. The amplification ratio can also be increased by the use of auxiliary electrodes which serve to obtain secondary emission.

In a frequency changer devoid of an amplifier action the amounts of energy which are absorbed from the control field, and which later are yielded to or delivered into the useful field, will balance. A check-up on whether amplification is obtained or whether it is not is very simple. A tube will operate as a frequency changer or multiplier pure and simple whenever the alternating power output is substantially greater than the direct current dissipated in the anode circuit.

Multiplication may take place in various forms and the same is not confined to the ways and means hereinbefore described for which the merit may be claimed that it may be carried into practice in a very simple manner, and that satisfactory efficiencies are obtainable. In order to illustrate and explain the various possibilities, the analogy of the rotary converter proves to be quite convenient:

(1) The multiplication factor may be given by the number of the "poles" as above explained. In most instances doubling at a ratio of the frequencies as 1:2 will be practiced.

(2) The revolving cloud of electrons (the rotor) which moves at a mean angular speed

$$\omega_m=\text{const.}H$$

could also be accelerated by an alternating field having a lower speed, say, a speed of only $\frac{1}{3}\omega_m$, $\frac{1}{5}\omega_m$, etc. This also will result in an acceleration of the electrons, though the intervals of action will be greater. In the presence of odd driving or control fields ω_{st} the number of accelerative moments will always surpass the number of retarding, so that, taking the average of a relatively long period of time, there is possible an actual supply or input of energy from the driving or control field to the rotor.

(3) The revolving electron cloud is driven at a frequency ω_{st} which corresponds to the angular speed ω_m of the rotor; but the working circuits which are united with adjacent or opposite segments are tuned to a higher harmonic, say, the third or the fifth, of the control or the driving frequency ω_{st}.

Now, these three cases as just outlined, if re-

quired, could also be combined. For instance, frequency sextupling is obtainable if the pole pitch (segment disposition) 2:4 (doubling 1:2) is chosen, and if the electrons rotating with ω_m are caused to be periodically accelerated by an alternating field whose frequency is $\frac{1}{3}\omega_{st}$. Whence $\frac{1}{2}\times\frac{1}{3}=1:6$.

Of course, other modifications are feasible and are here mentioned briefly merely for the sake of completeness. For instance, when using a tube with four segments the latter, both for the control frequency as well as for the useful frequency, may be so connected that they work like a two-split magnetron for both frequencies. The output circuit is then tuned to a higher frequency for the purpose of insuring quadrupling. So far as circuit organization is concerned, this case differs from the normal case merely in the fact that two segment connections are interchanged. The coupling of two contiguous working segments is so chosen that these are excited in phase. The plane through the slit or gap for the control system would then, for instance, be positioned horizontally, and the slit plane for the working system would be at a right angle thereto, that is, perpendicular.

Frequency multiplications are also practicable by using tubes with three or a multiple of three segments rather than choosing a number of segments divisible by four, and by supplying the segments in such a way that rotary fields result.

The basic idea of the present invention, more particularly the idea of frequency changing without putting additional energy in the multiplication, is by no means confined to turbine tubes, for it could just as readily be applied to magnetrons of conventional construction, for which similar conceptions would hold good if the mean angular speed ω_m of the electron cloud is taken into consideration rather than the "rolling" speed of individual electrons.

All of the above considerations apply similarly to tubes and organizations predicated for their operation upon linear oscillations of the electrons along roughly rectilinear paths and in which a magnetic field is provided at most for the concentration or focusing of the electron stream, that is, in the direction of electron travel.

I claim:

1. An oscillation generator and frequency multiplier comprising an electron discharge tube having a plurality of at least four segmented electrodes symmetrically disposed about an axis of revolution, means including a cathode exterior to the space enclosed by said segmented electrodes for projecting electrons through an opening therebetween to said enclosed space, means including a tuned circuit interconnecting different pairs of segmented electrodes for producing oscillations of a fundamental frequency, means including tuned circuits each interconnecting individual segmented electrodes of a pair for producing oscillations of a multiple frequency, a centrally disposed anode connected through a high direct current potential source to the cathode, and a utilization circuit mutually coupled to the means for producing multiple frequency oscillations.

2. A device in accordance with claim 1 and having means including a magnetic field exciter for causing the electrons in said discharge tube to describe arcs wherein the mean angular velocity is proportional to the applied magnetic field strength and bears an odd multiple ratio to the angular velocity of the driving frequency.

3. A device in accordance with claim 1 and having said utilization circuit tuned to a frequency which is a multiple of the frequency represented by the mean angular velocity.

4. A device in accordance with claim 1 and having means for delivering amplified output energy to said utilization circuit.

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