

May 19, 1942.

R. S. OHL

2,283,568

ULTRA-HIGH FREQUENCY SYSTEM

Filed June 18, 1940

2 Sheets-Sheet 1

FIG. 1

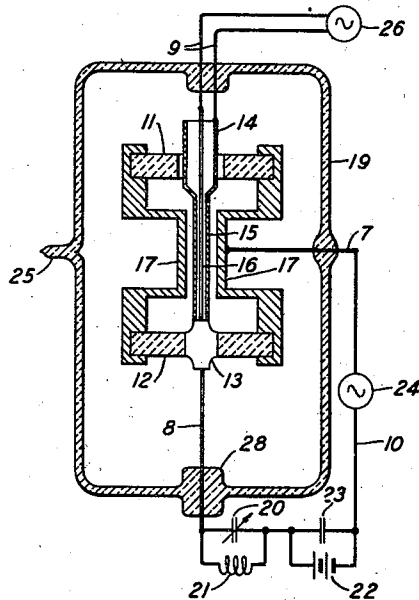
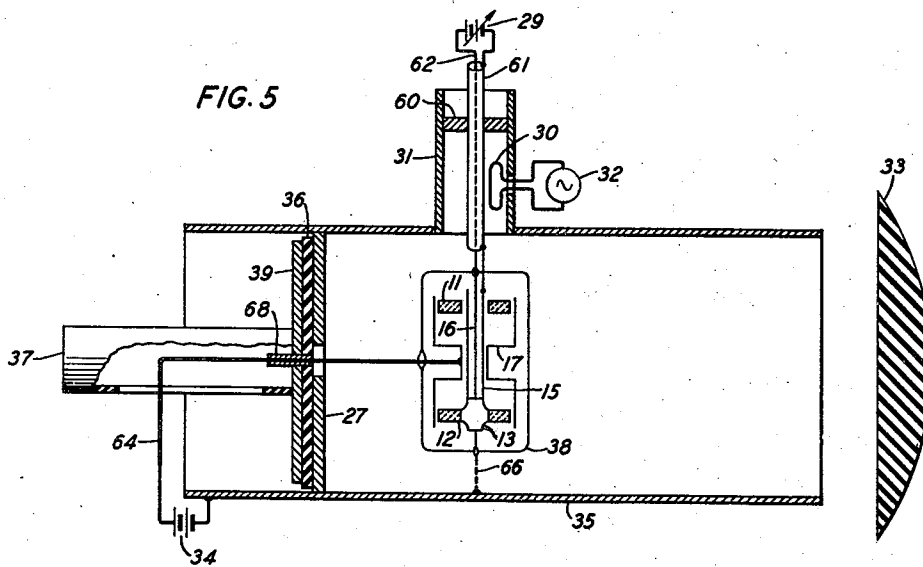


FIG. 5



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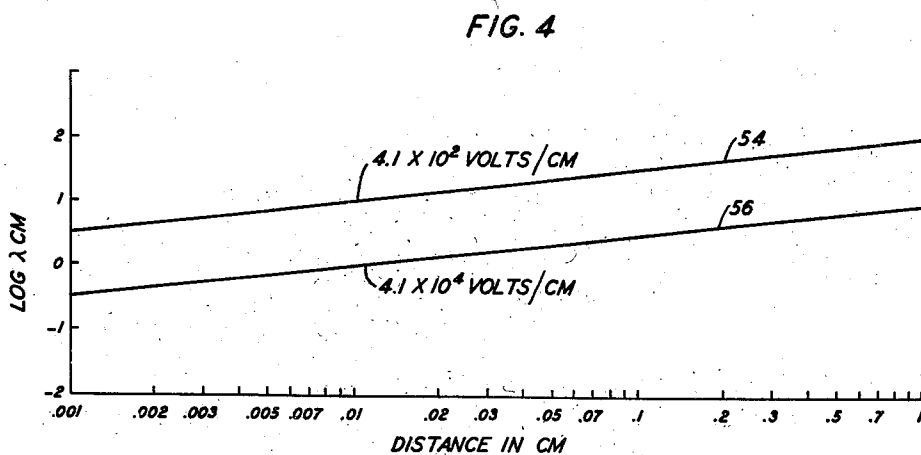
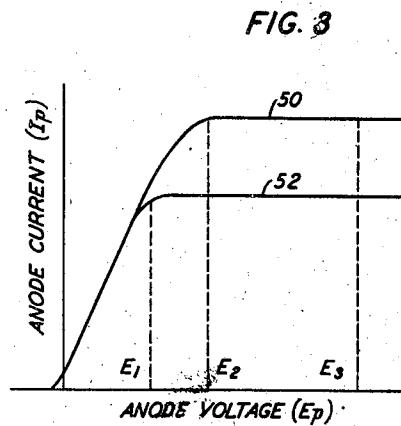
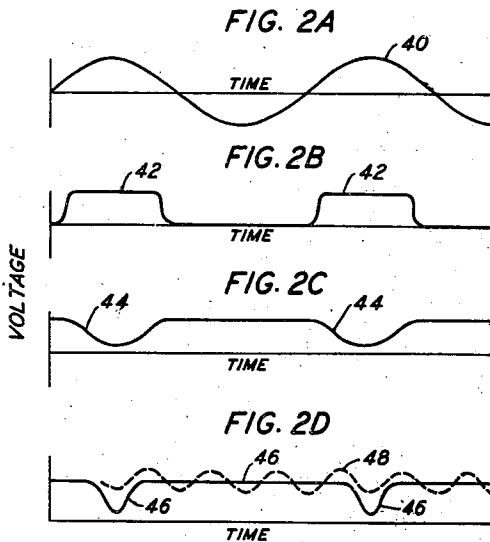
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ULTRA HIGH FREQUENCY SYSTEM

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2 Claims. (Cl. 172-281)

This invention relates to harmonic generators for ultra-high frequencies. More particularly, it relates to electronic harmonic generators operating above the upper knee of the saturation curve of the electronic device.

It is an object of the invention to provide a source of ultra-high frequency, the frequency of which may be conveniently controlled.

A further object is to obtain more favorable physical spacing between the elements of electronic harmonic generators for ultra-high frequencies.

Another object of the invention is to provide electronic harmonic generators for ultra-high frequencies having increased service life.

Other and further objects will become apparent during the course of the following description and from the appended claims.

The invention teaches the generation of harmonics by a multielement electronic tube biased beyond the upper knee of its saturation curve. At lower frequencies it has been the practice to operate electronic harmonic generators on the lower knee of the saturation curve to avoid the use of the higher voltage which would be required to operate on the upper knee of the curve and also to avoid the difficulty of dissipating more power. Under the altered conditions encountered at ultra-high frequencies it has been found advantageous to employ higher voltage and to operate the anode at higher temperature.

Since the transit time of the electron current and the behavior of the cathode normally become dominant factors as the frequency increases, this invention extends the normal operating limits with respect to these factors by increasing the bias of the anode substantially above the value required for saturation and by operating the anode at a higher temperature. The transit time of the electron current is thereby substantially reduced, greater physical spacing between the elements of the electronic device may thereby be employed, the device may be operated as a voltage saturated device and cathode heating means of extremely long operating life may be realized. To reduce the operating demands upon the heating element, this invention teaches, as a particular feature, the operation of the anode at the highest, rather than the lowest, practicable temperature and consequently the invention teaches the prevention of heat radiation from the anode as contrasted with the addition of heat radiating fins, efficient heat radiating surfaces and other similar features of prior art electronic tube anodes

and control elements. From one aspect, therefore, the invention teaches that by reversing a number of concepts of electronic tube design and operation, to which those skilled in the art have rigidly and universally adhered in lower frequency systems, distinct advantages may be realized at ultra-high frequencies.

The invention will be more readily understood in connection with the following analysis and the description of illustrative embodiments of the invention, given hereinafter, together with the accompanying drawings in which:

Fig. 1 illustrates diagrammatically a diode vacuum tube and associated electrical circuits suitable for practicing the invention;

Figs. 2A to 2D, inclusive, show wave form curves which will be employed in explaining the operation of systems of the invention;

Fig. 3 shows saturation curves for two cathode temperatures of an electronic tube;

Fig. 4 shows the relation between potential difference, electrode spacing and frequency for limiting conditions of operation; and

Fig. 5 illustrates diagrammatically the combination of a diode vacuum tube of the invention, a tubular emitter and a lens, capable of employing the principles of the invention to advantage.

When diodes are to be used as detectors or harmonic generators, the transit time of the electron current and the behavior of the cathode become the dominant factors as the frequency is increased. The transit time in a diode which has close cathode-anode spacing is expressible by

$$t = 3.36 \times 10^{-8} \frac{d}{\sqrt{E}} \text{ seconds} \quad (1)$$

where t is the transit time in seconds, E the voltage in common units and d is the electrode separation in centimeters.

When an alternating potential is impressed across a diode, current flows only for one-half a period and it is known from experience with magnetrons and various forms of diodes that if the transit time is about one-tenth as long as the half period of the impressed wave, the diode performs very nearly as though the transit time had no influence upon its operation. Using this as an approximation of the usual operating condition to be desired, Equation 1 can be rewritten so that values of E , and d may readily be calculated for which satisfactory operation can be obtained for any transit time, however short.

$$t_0 = 3.36 \times 10^{-8} \frac{d}{\sqrt{E}} \quad (2)$$

Sometimes it is convenient to express this relation in terms of voltage gradient (abbreviated v. gd.) instead of absolute volts as

$$t_0 = 3.36 \times 10^{-9} \sqrt{\frac{d}{\text{v. gd.}}} \quad (3)$$

The reason for expressing Equation 3 in terms of the voltage gradient arises from the fact that as the frequency becomes very high the distance becomes very small, with the result that the voltage gradient can reach values of nearly 10^6 volts per centimeter, whereupon cold discharges will occur and may damage certain types of cathodes.

The original expression for t can be rearranged so that if t is comparable to a half period, $2t$ is comparable to a full period and this in turn is expressible in terms of wave-length by multiplying by the velocity of light.

$$2t = T = 6.72 \times 10^{-9} \sqrt{\frac{d}{\text{v. gd.}}} \quad (4)$$

$$\lambda = 2.02 \times 10^3 \sqrt{\frac{d}{\text{v. gd.}}} \quad (4)$$

The value of λ in Equation 4 expresses a condition under which the diode will just be inoperable. If we multiply the wave-length by 10 as suggested above in connection with Equation 1, we then obtain a value which represents a usual operating condition to be desired and can be expressed as

$$\lambda_0 = 2.02 \times 10^4 \sqrt{\frac{d}{\text{v. gd.}}} \text{ cm.} \quad (5)$$

By way of illustration, Fig. 4 of the drawings shows a plot of Equation 5 for two voltage gradients, one of 410 volts per centimeter and the other of 41,000 volts per centimeter. These indicate the values of the voltages with which practical systems are concerned and the dimensions of the inter-element spacings when a diode is to be used at a particular desired short wave-length. By way of example, suppose a diode for operation at 10 centimeters is desired. One can be chosen having a spacing of 10^{-4} centimeters and a voltage gradient of about 410 volts per centimeter may be employed or one having a spacing of 10^{-2} centimeters may be chosen and a voltage gradient of 41,000 volts per centimeter may be employed. If the first choice is taken, the actual voltage to be used will be about 4.1×10^{-2} volts while with the second choice the voltage will be 4.1×10^{-2} . Obviously, for radio receiver purposes, neither of these combinations yields reasonable values.

It is, however, practically possible to construct a diode having a cathode-anode spacing of 5×10^{-3} centimeters (.002 inch) and this would require a potential of 100 volts yielding a potential gradient of 20,000 volts per centimeter. This potential gradient will not produce a cold discharge and from experience it is known that with a voltage gradient of 2×10^4 volts per centimeter and a spacing of 5×10^{-3} centimeters the electron current will not be limited by space charge but by electron emission saturation. An estimate of the current density which would be required for space charge current limitation can be readily calculated from

$$i = 2.34 \times 10^{-8} \frac{V^{3/2}}{X^2} \quad (6)$$

for large flat surfaces where X is the distance between plates in centimeters and the current is given in amperes per square centimeter. For a

distance of 5×10^{-3} centimeters and a potential of 100 volts, the current density would have to be about 94 amperes per square centimeter for space charge saturation. There are no known thermionic emitters which will provide such current densities, therefore, such a tube must be operated as a voltage saturated device. Consequently, by judicious design, relatively low values of heater current may be employed and the operating life of the heating element may be greatly increased. An emitter of the pure metal type, such as tungsten, tantalum, or columbium, is necessary. The use of oxide coated emitters is not practicable because the cathode-anode spacing is so small that coatings of sufficient uniformity are extremely hard to manufacture. Furthermore, the coated emitters have very short life when operated out of space charge and in addition they do not have a good voltage cut-off, which, obviously, is needed in this type of device.

In more detail in Fig. 1 of the drawings is shown one type of structure suitable for a closely spaced diode, operating out of space charge. A thimble of tantalum or columbium 15 is used as a cathode. It is heated by an incandescent tungsten wire 16 enclosed within it. The anode 17 is so designed that it becomes hot from the cathode. Its exterior surfaces should be highly polished to reduce radiation of heat to a minimum. In extreme cases a jacket of material which is a non-conductor of heat can be placed around the outer surfaces of the anode. The object is to reduce the heat radiation required from the cathode. This is very desirable, since the temperature of a tantalum or columbium cathode must be very high to provide sufficient thermionic current. The close spacing is maintained by means of accurately ground quartz insulators 11 and 12 which are spun into the ends of anode 17. Expansion of the cathode is allowed by a sliding action of the cathode extension sleeve in the insulator 11. A cathode lead 8 is taken through seal 28 of the opposite end of glass envelope 19 from the heater leads 9. An anode lead 7 is brought through a seal in the side of envelope 19. Projection 25 indicates the seal formed in closing the envelope when the evacuation process had been completed. Anyone skilled in the art of vacuum tube design can readily vary the details of this specific design without departing from the principles involved. The important features are that satisfactory means be provided to accurately obtain and maintain the necessary close spacing between the anode and cathode with extremely low loss insulators so that the impedance at ultra-high frequencies will remain large and that heat radiation from the anode be reduced to a minimum as above mentioned.

Fig. 1 also shows a schematic circuit arrangement for the use of the diode in the detection, frequency conversion, or harmonic production of ultra-high frequency signals. Generator 26 furnishes power through conductors 9 for the heater element 18. Generator 24 is an ultra-high frequency source and may be a source of signals to be detected or a crystal controlled oscillator from which still higher frequency harmonics are to be generated, etc.

An anti-resonant circuit, comprising inductance 21 and adjustable capacity 20, is employed to tune the anode-cathode circuit to a particular frequency, for example, a harmonic of generator 24. Battery 22 provides a suitable bias for the particular function to be performed and ca-

capacity 23 by-passes ultra-high frequency around battery 22.

If a sinusoidal potential such as is illustrated by curve 40 in Fig. 2A be impressed on the diode by the generator 24 and it is assumed that the battery 22 has, for the moment, a zero potential, then at the beginning of each cycle a low voltage will be applied to the cathode and current will increase gradually for a short time and then it will suddenly increase to a maximum limited only by the temperature of saturation of the emitter. Thus a substantially square-topped wave, as illustrated by curves 42 in Fig. 2B, will tend to be produced. This wave form would be inefficient for use in a harmonic producer or in a frequency converter, but it would be useful as a rectifier-detector except for the fact that each unit would need to be individually calibrated since the output would not be exponentially proportional to the signal voltage.

In order to overcome these objections the battery 22 is placed in the circuit and its voltage is made sufficient to bias the tube to temperature saturation of the cathode. The rectifier current then takes the form shown by curve 44 in Fig. 2C. This is similar to the envelope of a rectifier current which could be obtained if a low frequency were used without a biasing potential, excepting that it is inverted. This type of curve is satisfactory for rectification and frequency conversion purposes, the potential 22 being adjusted to provide pulses substantially one-half wavelength long, as indicated by the solid line curve 46 in Fig. 2D where the dotted line curve 48 represents the desired harmonic frequency.

In Fig. 3 are shown the static characteristics 50 and 52 obtained from a typical diode for two different cathode temperatures. When it is desired to use such a tube as a frequency converter, in accordance with this invention it is biased at least to the upper knee of the curve as indicated by E_1 for curve 52, and E_2 for curve 50. Should it be desired to produce a particular harmonic then the bias potential is increased to some value E_3 such that the peak width of the depressed direct current (as shown by curves 46 and 48 in Fig. 2D) is substantially the same width as a half period of the harmonic wanted. Alternatively, it is obvious from the curves of Fig. 3 that adjustment of the peak width can also be effected by changing the filament temperature. In general the latter mode of adjustment will usually be employed only to supplement that effected by changing the bias voltage. The bias voltage will normally be of such value that a relatively low cathode temperature will be required and the life of the heater element will thereby be substantially increased. Increasing the bias not only permits the selection of the particular harmonic desired but also has the highly desirable effect of decreasing the electron transit time, as mentioned above. This makes possible an increase in the cathode-anode spacing and at ultra-high frequencies makes it possible to construct tubes of physically practicable dimensions. Stated in other words, if the tube were to be operated with the relatively low bias required to bias it to the lower knee of the saturation curve, as taught in the prior art, an impracticably small cathode-anode spacing would be necessary at ultra-high frequencies to keep the electron transit time sufficiently short for satisfactory operation.

In Fig. 5 an arrangement of apparatus illustrative of one mode of employing a device of the

invention is shown, which can be used for generating, for example, 10-centimeter waves from a 30-centimeter source, and emitting a highly directive beam of energy of 10-centimeter wavelength. The battery 29 furnishes heater power through concentric conductor pairs 61 and 62, the battery 34 anode potential, the generator 32 a 30-centimeter signal to coupling loop 30 and the plunger 27 is adjusted to resonate the chamber of tube 35 at the third harmonic, or 10 centimeters. Handle 37 is preferably of insulating material and metallic disc 39, rigidly affixed to the right end of handle 37, is insulated preferably by a mica washer 36, from plunger 27, and connected by a sliding metallic connecting sleeve 68 to lead 64, the capacity between disc 39 and plunger 27 furnishing a by-pass path for radio frequency currents around the battery 34. Appropriate channels and slots are provided in handle 37 for the passage of the anode lead 64 to battery 34. The anode-cathode circuit may be completed by a cathode lead 66, shown dotted, connecting to tube 35 or, in the present instance, it may be completed by member 60, which serves an additional function as described below. The lens 33 produces a beam directive from the open end of tube 35, in only one direction, i. e., to the right along the axis of the tube 35. Lens 33 may be made of any of the materials well known to the art, such, for example, as beeswax, suitable for focussing electromagnetic waves. Concentric conductor 61 and projection 31 of tube 35 are short-circuited by member 60 at a distance from tube 35 such that a high impedance is presented to the energy generated within tube 35.

The general arrangements of the invention obviously form advantageous bases for generating crystal controlled signals of appreciable power, of the order of watts, in the centimeter region. They are also the necessary key to the production of efficient double detection receivers in this wave-length region. A particular advantage is that the fundamental frequency can be made relatively low in frequency so that it can conveniently be subjected to precise frequency control by a quartz crystal or by tank circuits of the type, for example, shown in U. S. Patent 2,030,178 issued February 11, 1936, to R. K. Potter, and the harmonics derived therefrom will then be endowed with a like precision of frequency control. Furthermore, the higher the order of the harmonic employed, the higher the voltage bias, the shorter the electron transit time and the greater the permissible cathode-anode spacing which may be employed for a given ultra-high frequency. The general limitations which should be observed have been discussed above.

Numerous applications of the principles of the invention will occur to those skilled in the art. For example, triodes and other more complex electronic vacuum tube devices may obviously employ the principles of the invention to advantage at ultra-high frequencies, the diode being hereinabove employed as an illustrative embodiment principally to avoid complexity and possible confusion. No attempt has here been made to exhaustively cover such applications. The scope of the invention is defined in the following claims.

What is claimed is:

1. In an ultra-high frequency system a precision controlled high frequency generator and means for deriving therefrom a frequency higher than any which may be produced by such a gen-

erator, said means including an electronic harmonic generator having a cathode and an anode, a resonant circuit tuned to the higher frequency and a source of direct current bias, said resonant circuit and said source of bias being connected electrically in series with the first stated high frequency generator, the said series combination of resonant circuit, source of bias and high frequency generator being connected electrically in the cathode-anode circuit of said electronic harmonic generator, the said source of bias being poled and proportioned to bias said electronic generator beyond the upper knee of its saturation curve to an extent such that each negative cycle of said first stated generator produces a pulse of current in said cathode-anode circuit of the duration required for a half cycle of said higher frequency.

2. In an ultra-high frequency electrical sys-

tem, a source of high frequency oscillations, an electronic vacuum tube, having a cathode and an anode, a source of direct current voltage, said source of high frequency oscillations and said source of direct current voltage being connected electrically in series in the cathode-anode circuit of said electronic vacuum tube, the said source of voltage being poled and proportioned, with respect to the amplitude of the oscillations of said high frequency source, to bias said vacuum tube beyond the upper knee of its saturation curve to an extent such that each negative half cycle of said source of oscillations produces a pulsation of the current in said cathode-anode circuit of only the duration required for a half cycle of a particular predetermined ultra-high frequency.

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