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FREQUENCY MODULATION

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*Fig-1*

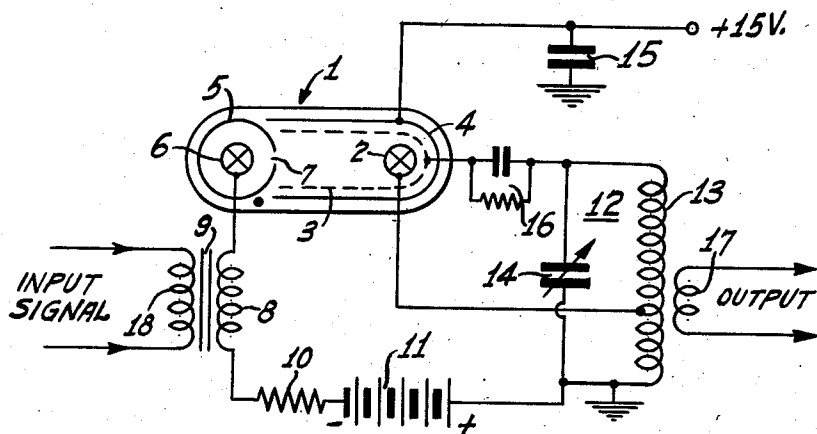
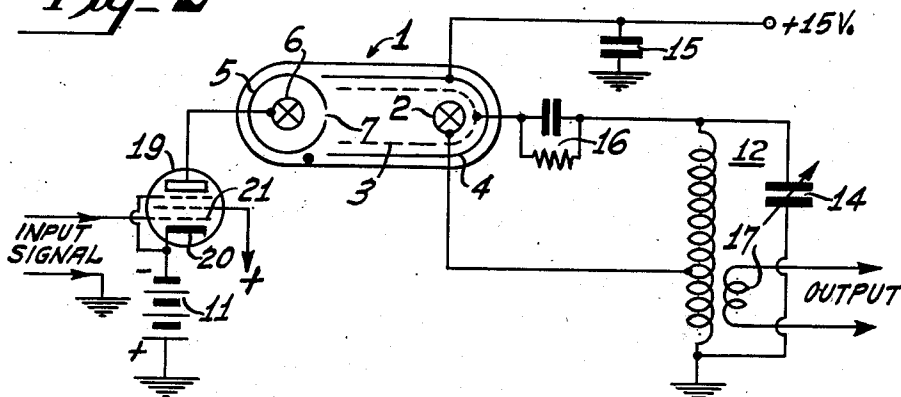


*Fig-2*



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## UNITED STATES PATENT OFFICE

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## FREQUENCY MODULATION

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7 Claims. (Cl. 332-16)

1 This invention relates to frequency modulation, and more particularly to arrangements employing a single gaseous discharge device as an oscillator and as a variable capacitance for the same.

Recently, there have been devised gaseous discharge devices of the type which utilize an auxiliary discharge and in which a grid can be used to control or modulate currents flowing from a cathode to an anode. Devices of this type are known as "plasmatrons" and their operation may be summarized in the following way. In conventional hot cathode gaseous devices the applied anode potential serves a double function, the first being the provision of the ionization needed for space-charge neutralization and the second being the provision of the field needed for drawing the required cathode current. In the "plasmatron," however, these functions are separated. As a result, the potentials needed for drawing given cathode currents are greatly reduced and, in addition, grid control of the anode current becomes possible.

This separation of function is achieved by utilizing what is termed an "auxiliary discharge" to provide the space-charge neutralizing ionization. The ionization from this auxiliary discharge manifests itself by creating a dense cloud of free ions and electrons in the region between the main operating electrodes, viz., the hot cathode, the anode, and the grid. This concentration of free ions and electrons is called a "plasma." Because the ion and electron concentrations are approximately equal, the plasma is electrically neutral and acts as a good conductor for electron currents such as those from a hot cathode. The higher the ion and electron concentration the better will be the conducting properties of the plasma. This property of good conduction is responsible for forcing practically all of an applied cathode-anode voltage to appear across a thin electron sheath at the anode. Then, in effect, the cathode is immediately adjacent to the anode. This gives the "plasmatron" the high perveance associated with a vacuum tube having very closely-spaced electrodes.

If a negative electrode is immersed in the plasma, a thin field-absorbing layer called a "sheath" forms around the electrode. This layer absorbs the electric field so that the plasma remains isolated and can retain its field-free nature. Since the negative field allows only positive ions to enter this region, the sheath is called a positive ion sheath.

The thickness of a sheath such as described

2 increases as the magnitude of the electrode potential increases. Thus, a negatively biased "plasmatron" grid will surround itself with a positive ion sheath that expands and contracts in accordance with an applied grid signal. Then the plasma cross-section, which connects the anode with the cathode through the grid openings, will have its area modulated. This action, in turn, modulates the cathode-anode current by virtue of the fact that the conducting ability of the plasma, like that of other conductors, depends upon its cross-sectional area. This "plasmatron" grid control can be pictured as a control of the area of the effective cathode which appears adjacent to the anode. In some cases, the grid sheath will also simultaneously control the plasma density, and hence its conducting ability, in regions close to the grid openings. This results in an additional control action which might be viewed as a control of the emission capabilities of the effective cathode.

The above action is explained somewhat more fully in the copending Johnson application, Serial No. 185,745, filed September 20, 1950.

Since gaseous discharge devices of the above-described "plasmatron" type have smooth voltage-current characteristics similar to those of vacuum tubes and since a control electrode may be used to continuously control the flow of current through such devices, it becomes possible to utilize such devices in oscillatory circuits similar to those in which vacuum tubes have hitherto normally been employed. The present invention relates to oscillators utilizing such "plasmatrons."

An object of this invention is to devise an arrangement for frequency modulating "plasmatron" oscillators.

Another object is to provide an arrangement whereby "plasmatron" oscillators may be frequency modulated with a high frequency deviation in an effective manner.

A further object is to devise an efficient arrangement for frequency modulating discharge device oscillators having a low plate impedance.

An additional object is to provide an arrangement for frequency modulating an oscillator of the type which is particularly suited for low-voltage, high-current output.

The foregoing and other objects of this invention will be best understood from the following description of some exemplifications thereof, reference being had to the accompanying drawing, wherein:

Fig. 1 is a circuit diagram of one arrangement

whereby this invention may be put into effect; and

Fig. 2 is a similar diagram of modified arrangement.

The objects of this invention are accomplished, briefly, in the following manner: A "plasmatron" gaseous discharge device has its three main electrodes, consisting of the main cathode, grid and anode, connected in a more or less conventional oscillatory circuit of a type which is commonly used for three-electrode vacuum tubes. The potential on the auxiliary cathode is modulated by a modulating input signal to vary the intensity of ionization of the gas. This causes a variation in the thickness of the positive ion sheath around the negative grid, thus varying the capacitance afforded by this sheath. Since this latter capacitance is connected directly across the external tuned circuit, variations of such capacitance produce corresponding variations in the oscillation frequency.

Fig. 1 is a circuit diagram whereby this invention may be carried into effect. Referring to this figure, numeral 1 denotes a gaseous discharge device of the so-called "plasmatron" type, such as described in the aforementioned copending application; it will be seen that the representation of the discharge device 1 is quite similar to that in Fig. 1 of such application. Inside the envelope of device 1 is a main cathode 2 partially surrounded by a U-shaped control grid 3 and a U-shaped anode 4, grid 3 being located between cathode 2 and anode 4. Opposite the open ends of grid 3 and anode 4 is mounted a cylindrical focusing electrode 5. An ionization or auxiliary cathode 6 is mounted coaxially and concentric with respect to cylindrical electrode 5.

As indicated in Fig. 1, electrode 5 is provided with an opening 7 the center of which is in a plane passing through the axes of auxiliary and main cathodes 6 and 2.

For further details of the construction of gaseous discharge device 1, reference may be had to the aforementioned Johnson application.

Device 1 is provided with a gaseous atmosphere prior to sealing off, as indicated in Fig. 1.

In the operation of "plasmatron" 1 as an oscillator according to this invention, focusing electrode 5 is normally left "free" or "floating," although it is to be understood that this electrode may be connected to auxiliary cathode 6 if desired. Auxiliary cathode 6 is connected through the secondary 8 of an input or modulation transformer 9 and through a current limiting resistance 10 to the negative side of a source 11 of unidirectional potential, the positive side of which is grounded. The three main electrodes 2, 3 and 4 are connected as a Hartley oscillator. To effect this result, the lower end of the parallel L. C. oscillatory circuit 12, consisting of inductance 13 and variable condenser 14, is grounded and the anode 4 is also grounded for oscillatory currents by capacitance 15. Cathode 2 is connected to an intermediate point on inductance 13 and operates at D. C. ground potential. Anode 4 is connected to the positive terminal of a unidirectional source, of the magnitude of 15 volts, for example. Grid 3 is connected to the upper end of inductance 13 through a parallel R. C. circuit 16 which functions to establish on said grid, during operation, a bias which is negative with respect to cathode 2 or ground. Alternatively, this biasing arrangement may be omitted and grid 3 left free to seek its own potential during operation, such potential being in-

herently negative with respect to cathode 2 or ground. The output of the oscillator may be taken off by means of a winding 17 inductively coupled to inductance 13. The source 11 has been indicated as a simple battery but it is, of course, to be understood that any suitable source may be utilized.

The potential of source 11, which is the D. C. potential between auxiliary cathode 6 and main cathode 2, is so selected or adjusted that it is sufficient to cause an ionizing discharge to appear between these two cathodes, cathode 2 being positive with respect to cathode 6. For example, this potential may be in the range of approximately 40 to 90 volts. The potential difference between the main cathode 2 and anode 4 is for example 15 volts and is too low to produce ionization; in other words, it is less than the ionization potential.

With direct potentials as described, an intense visible discharge extends outwardly from opening 7 and bathes main cathode 2. Electrode 5 acts to focus the electron stream from auxiliary cathode 6. Furthermore, electrode 5 acts to intensify the ionization. Main cathode 2 acts as the anode for the auxiliary cathode 6. For all practical purposes, the auxiliary current collected by the main anode 4 is of negligible effect on the operation of the device. The plasma extends through the grid openings and in the grid-anode region as well. Thus, there is a highly conductive path from the main cathode 2 through the grid 3 to the main anode 4.

As the grid swings about its bias potential the main current is controlled over a wide range of approximately zero to 200 or more milliamperes, in the manner previously described in the summary of operation of the "plasmatron." Since this grid control of the main anode current does take place, the device 1 may be connected in an oscillatory circuit similar to vacuum tube oscillatory circuits, and such device will function to produce oscillatory energy in a similar manner. In Fig. 1, the device 1 is connected in a Hartley oscillator circuit, such device then functioning to produce oscillatory energy in tank or tuned circuit 12, which energy may be abstracted by coil 17 as output.

According to this invention, the frequency of operation of a "plasmatron" oscillator such as that previously described may be varied or modulated electronically by varying the intensity of the ionization or auxiliary discharge current.

When a negatively charged electrode such as grid 3 is placed in a strongly ionized gas at low pressure it becomes surrounded by a sheath of positive ions. This sheath has a certain capacitance, and by analogy with a condenser of ordinary construction the plates are constituted by the electrode 3 itself and the outer surface of the positive ion sheath. Since electrodes 2, 3 and 4 are connected to tuned circuit 12, it may be seen that this sheath-capacitance is coupled to the oscillator tuned circuit. When this capacitance is increased, the oscillator frequency is decreased, while when this capacitance is decreased, the oscillator frequency is increased; since the sheath-capacitance is essentially connected across tank circuit 12.

The positive ion sheath about grid 3 has a definite thickness, its thickness depending on, among other things, the intensity of ionization of the gas. Thus, about the negatively charged electrode 3 there is an electric field. This field extends out to such a distance that it is exactly

neutralized by the field of the positive ions in the surrounding gas. In other words, we may assume that each line of force projecting from the electrode 3 must terminate in a positive ion in the sheath. Thus, the less the intensity of ionization of the gas the farther the electric field of the electrode extends and the thicker the positive ion sheath, whereas the greater the intensity of ionization of the gas the thinner the positive ion sheath.

The positive ion sheath may be visualized as a nonconductive region compared to the plasma, since electrons cannot enter it and the positive ion current is small. This region extends between two conductive surfaces, one being the electrode 3 carrying a negative electron charge and the other being the surface of the sheath, which is at the potential of the gas within the envelope, that is, with gases at low pressure, at approximately the potential of the cathode 2. This gas is conductive since negative electrons are moving freely about in it. As such, this sheath is in reality a condenser. Since the distance between the plates of the condenser, that is, the thickness of the sheath, varies with the intensity of ionization of the gas, as already explained, the capacitance of the condenser varies in accordance with the intensity of ionization of the gas. The capacitance of the condenser, of course, varies in an inverse direction with the distance between the condenser plates (the thickness of the sheath).

An input modulating signal is applied to the primary 18 of transformer 9. Such a signal, appearing in secondary 8, which is in circuit between auxiliary cathode 6 and main cathode 2, changes the current flowing between these two cathodes. This change of current varies the intensity of ionization of the gas in device 1, it being remembered that main cathode 2 acts as the anode for auxiliary cathode 6. This variation in intensity of ionization causes a variation in the thickness of the positive ion sheath around grid 3, as previously explained, and a variation in the capacitance afforded or provided by this sheath. This capacitance variation produces a corresponding variation in the frequency of the oscillator. Thus, input signals applied to 18 result in frequency modulation of the "plasmatron" oscillator disclosed.

To particularize, an input signal of such polarity as to increase the current flowing between cathodes 6 and 2 increases the ionization intensity in device 1, decreasing the thickness of the ion sheath around grid 3 and thereby increasing the capacitance provided thereby; this decreases the oscillator frequency. Conversely, an input signal of the opposite polarity decreases the ionization intensity, resulting in an increase of oscillator frequency.

In a circuit according to the present invention which was actually built and tested, it was found that the "plasmatron" oscillator was easily frequency modulated; in other words, the frequency deviation was high. This may be seen from the following two examples. At 17 megacycles, increasing the discharge or ionization current from one to two milliamperes caused a frequency decrease of 500 kilocycles, with no change in amplitude. At 70 kilocycles, increasing the discharge current from one to six milliamperes caused a frequency decrease of 50 kilocycles.

It is desirable to point out that the oscillator of this invention is particularly adapted for modulation at audio frequency rates, up to about 10 kilocycles. The upper frequency limit of the

"plasmatron" as an oscillator has not as yet been determined.

Fig. 2 discloses a modified arrangement. In this figure, elements the same as those of Fig. 1 are denoted by the same reference numerals. In Fig. 2, instead of feeding the input modulating signal to auxiliary cathode 6 by way of a transformer as in Fig. 1, the input signal is fed to such cathode by way of a vacuum tube 19 which acts in effect as a series variable impedance between source 11 and auxiliary cathode 6. The negative side of source 11 is connected to the cathode 20 of tube 19 and the positive side of this source is grounded. The input modulating signal is applied between the control grid 21 of tube 19 and ground, while the anode of tube 19 is connected to auxiliary cathode 6. Thus, tube 19 provides a series variable impedance between source 11 and cathode 6, and by the application of a signal to control grid 21 this impedance is varied to thereby vary the voltage between cathodes 6 and 2 to vary the intensity of ionization of the gas. This results in a variation of the oscillator frequency, as previously described in connection with Fig. 1.

What I claim to be my invention is:

1. A frequency modulation arrangement, comprising a gaseous discharge device, means for ionizing the gas in said device, said device having a plurality of electrodes including anode and cathode electrodes and also a control electrode operating at a potential negative with respect to the potential of said gas, thereby forming a positive ion sheath about said control electrode, means for supplying said electrodes with operating potentials, a tuned circuit, means coupling said anode, cathode and control electrodes to spaced points on said circuit, thereby to develop oscillations in said device and said circuit, and means for controlling said ionizing means by a modulating signal to modulate the intensity of ionization of said gas and thereby also the thickness of said sheath and the effective capacitance provided thereby.
2. A frequency modulation arrangement, comprising a gaseous discharge device having a plurality of electrodes including anode, cathode and control electrodes, means for ionizing the gas in said device, connections for supplying said electrodes with operating potentials, a tuned circuit, means coupling said anode, cathode and control electrodes to spaced points on said circuit, thereby to develop oscillations in said device and said circuit, and means effective on said first-named means for varying the intensity of ionization of the gas in said device, to thereby vary the effective capacitance provided by said control electrode.
3. A frequency modulation arrangement, comprising a gaseous discharge device having a plurality of electrodes including anode and cathode electrodes and also a control electrode operating at a potential negative with respect to the potential of the gas in said device, thereby forming a positive ion sheath about said control electrode, connections for supplying said electrodes with operating potentials, a tuned circuit, means coupling said anode, cathode and control electrodes to spaced points on said circuit, thereby to develop oscillations in said device and said circuit, and means for varying the intensity of ionization of said gas when ionized, to thereby vary the thickness of said sheath and the effective capacitance provided thereby.
4. A frequency modulation arrangement, com-

prising a gaseous discharge device having a plurality of electrodes including anode, cathode and control electrodes, means for ionizing the gas in said device, connections for supplying said electrodes with operating potentials, a tuned circuit, means coupling said anode, cathode and control electrodes to spaced points on said circuit, thereby to develop oscillations in said device and said circuit, and means for controlling said ionizing means by a modulating signal to modulate the intensity of ionization of said gas and thereby also the effective capacitance provided by said control electrode.

5. A frequency modulation arrangement comprising: a gaseous discharge device; means for establishing an ionizing discharge in the gas in said device, said means including an electron-emitting cathode, another cathode, and means for establishing an ionizing current between said cathodes; a plurality of electrodes, including said other cathode and also including an anode electrode and a control electrode, in said device; means for supplying said electrodes with operating potentials, a tuned circuit, means coupling said anode, other cathode and control electrodes to spaced points on said circuit, thereby to develop oscillations in said device and said circuit; and means for varying said ionizing current to vary the intensity of ionization of said gas.

6. A frequency modulation arrangement comprising: a gaseous discharge device; means for establishing an ionizing discharge in the gas in said device, said means including an electron-emitting cathode, another cathode, and means for establishing an ionizing current between said cathodes; a plurality of electrodes in said device, said plurality including said other cathode, an anode electrode, and also including a control electrode operating at a potential negative with respect to the potential of said gas, thereby forming a positive ion sheath about said control electrode; means for supplying said electrodes with operating potentials, a tuned circuit, means coupling said anode, other cathode and control electrodes to spaced points on said circuit, thereby

to couple said ion sheath to said circuit and to develop oscillations in said device and said circuit; and means for varying said ionizing current to vary the intensity of ionization of said gas and thereby also the thickness of said sheath and the effective capacitance provided thereby.

7. A frequency modulation arrangement comprising: a gaseous discharge device; means for establishing an ionizing discharge in the gas in said device, said means including an electron-emitting cathode, another cathode, and means for establishing an ionizing current between said said cathodes; a plurality of electrodes in said device, said plurality including said other cathode, an anode electrode, and also including a control electrode operating at a potential negative with respect to the potential of said gas, thereby forming a positive ion sheath about said control electrode; means for supplying said electrodes with operating potentials, a tuned circuit, means coupling said anode, other cathode and control electrodes to spaced points on said circuit, thereby to couple said ion sheath to said circuit and to develop oscillations in said device and said circuit; and means for controlling said ionizing current by a modulating signal to modulate the intensity of ionization of said gas and thereby also the thickness of said sheath and the effective capacitance provided thereby.

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