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May 11, 1954

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Washington, D. C.

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The Feasibility Report On Ionic Oscillators, as covered by the agreement on Task 2, has been completed and two copies are enclosed herewith.

If additional copies are needed, we will be happy to supply them.

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FEASIBILITY REPORT
ON
IONIC OSCILLATORS
IN RADIO APPLICATIONS

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FEASIBILITY REPORT
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IONIC OSCILLATORS

INTRODUCTION

This report has been written, after a rather intensive review of the literature bearing on ionic oscillations, for the purpose of establishing whether or not it would be feasible to attempt to adapt this phenomena to the practical solution of certain technical problems now existent and known to the sponsor.

Mathematical formulae necessary to understand the mechanics of the phenomena have been omitted from the main part of the report, but are appended to it along with pertinent abstracts and bibliographical data. Furthermore, illustrative sketches and diagrams have been included so that a definite concept of this phenomena may be gained more readily. Certain liberties have been taken in straying from the strict scientific use of terms and definitions in an effort to simplify the material contained herein.

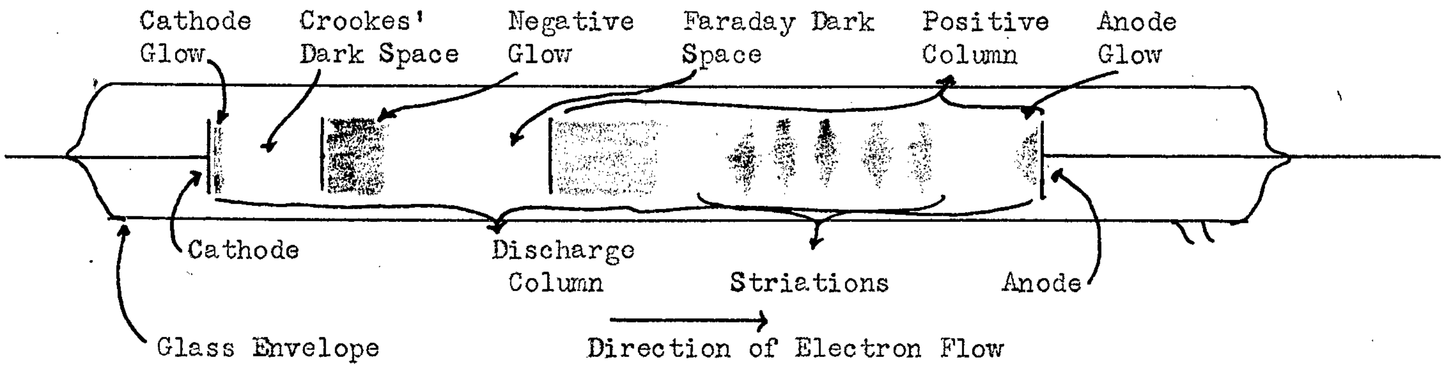
Early studies of gas tubes under discharge conditions did not distinguish between the nature of low frequency and high frequency oscillations. More recently Tonks and Langmuir[86], have demonstrated that there is a transition zone in the neighborhood of 10 mc. The oscillations below this level are definitely ionic in nature while those above are electronic. For the purpose of this review, only material below the 10 mc level has been reported.

Fairbairn[29], described for patent purposes a form of gas tube oscillator which contains no resistive, capacitive or inductive components and needs no external or internal resonant circuits or cavities for operation. He claimed high output at audio and radio frequencies with as little as 2 milliamperes from a plate supply of 22½ v. He used an 884 tube and produced a frequency of about 500 kc as well as others ranging below this level. He modulated ionic oscillations with both AM and FM. The phenomena of ionic oscillations in a gas tube have been described in various ways by others, including those researchers listed in the bibliography.

DESCRIPTION

Ionic oscillations are periodic variations in current flowing through a gas tube caused by vibrating positive ions. The phenomena might best be illustrated by a diagram of a simple laboratory type gas discharge tube.

SCHEMATIC DIAGRAM OF A LABORATORY TYPE GAS DISCHARGE TUBE



When the voltage across a gas discharge tube reaches a certain critical point the atoms of the gas become ionized and an arc condition is produced which permits current to flow. The nature of this arc condition is characterized by several well defined regions.

At the cathode (the negative terminal) there is a sheet of luminosity called the "Cathode Glow." Next to this area is one from which little or no glow is given off; this is called the cathode or "Crookes Dark Space." Just beyond the cathode dark space toward the anode is a region of luminosity called the "Negative Glow." Adjacent to this in the direction of the anode is another dark space called "Faraday's Dark Space." From the Faraday Dark Space to the anode is an area of luminosity called the "Positive Column of Anode Glow."

In an experimental tube, designed so that the anode can be moved toward and away from the cathode, it can be shown that the length of the positive column remains constant as long as the potential drop across the tube and current through the tube are held constant. As the anode is moved toward the cathode the head of the positive column maintains its position in relation to the anode and it and the Faraday Dark Space move across the tube into the negative glow and thence into Crookes Dark Space and into the cathode, filling the tube entirely with a uniform glow.

Striations do not always appear, but when they do, they are always in the positive column and if they are moving, they move toward the anode. The positive column and negative glow are sharp and clearly defined, but fade out as one moves from the cathode to anode.

THE CAUSE

Cousins[18], attributes the cause of ionic oscillations in a gas tube discharge to what is known as the "pinch effect." Charges moving linearly in space create a self-circling magnetic field. The circular magnetic field forces the charges within it toward the center of the magnetic field. This inward radial force is called the Pinch Effect. The region in which moving positive ions and electrons are at equilibrium in a gas tube discharge is called a plasma and is subject to the pinch effect. At the beginning of a discharge, the pinch effect will cause a compression of the plasma. The compression will be of considerable amplitude and, hence, will travel inward as a shock wave in the plasma. It will pass through the center of the tube, travel out to the walls, and be reflected inward again and so on. The discharge oscillates continuously from a wide beam to a narrow beam and back to a wide beam. The frequency of oscillation is determined by the number of pinches per second.

Of particular interest is the fact that the ionic oscillator needs no external components for operation. (2, 8, 10, 20, 21, 31, 42, 51, 69, 79, 83) In some cases multi-element ionic oscillator tubes of special design can be used with external oscillatory circuits added to control the frequency (10, 13, 29).

Many researchers have reported on specific frequencies obtained by varying one or more parameters of ionic oscillators. They are:

1.5 mc[3]
10 kc[8]
15 to 200 kc[31]
1 kc to 10 kc[79]
100 kc[2]
500 kc[18]
300 cps to 150 kc[69]
200 kc[51]
10 kc to 100 kc[30]
2 kc to 10 kc[83]
3 to 100 kc[78]
2 kc to 1 mc[15]
1 cps to 1900 kc[29]
4 kc to 112 kc[10]

Considerable work has been done wherein the oscillation was independent of any external circuit but dependent upon gases used and pressure. These gases, air,[51, 19, 83, 78] argon,[30, 73] cesium vapor,[79] hydrogen H_2(wet),[19] dry hydrogen,[59, 19] mercury,[78, 10] neon,[31, 80] nitrogen,[19, 83, 78] were used with comparable results wherein a difference in frequency response was obtained with different gases.

In an attempt to delineate the parameters of these phenomena, various researchers approached the problem from one or more directions, with the end result that for the most part several parameters are known and agreed upon while some few are still to be more clearly understood.

Only one author[2] of those reviewed to date disagreed with the concensus of findings that frequency increases as the pressure decreases. Again it was accepted that the mass of the positive ion was a parameter effecting the frequency. In 1953 Donahue, etal,[20] stated that in studying deuterium glows under identical conditions as with other gases, no essential differences were noted, and concluded that prominent oscillations in these glows were independent of the mass of the positive ion.

At present there are certain parameters which effect the frequency of oscillation which have been established by several researchers:

Pressure, 12, 19, 20, 30, 31, 51, 59, 69, 79, 82, 83, 94.
Cathode Temperature, 59, 79.
Current Density, 10, 12, 19, 20, 28, 31, 59, 69, 79, 94.
Diameter of Tube, 18, 19.
Gas Used, 8, 19, 20, 21, 39, 31, 42, 51, 59, 73, 78, 79, 80, 83.
Ionizing Potential, 21, 28, 69, 83.
Electrode Spacing, 8, 10, 19, 20, 21, 42.

Important work has been done on ionic oscillations in carbon arc discharges and it has been found[42, 20, 8] that there are two distinct ranges of oscillation. One in the audio range from 100 cps to 400 cps, wherein the frequency is dependent on the electrode materials, size and separation, and also the current. The other range is in the RF up to 90 mc. The frequency of this range is independent of electrode material, arc length or current, but dependent on atmosphere. Both of these ranges of oscillation are independent of external circuits.

A practical consideration of the experimental results obtained by the foregoing referenced researchers leads now to the work of Fairbairn.[29] He used commercially available tubes and found the following frequencies under ionic oscillation:

Tubes	Fundamental	Range	
884	500 kc	Tunable from	400 to 1000 kc
6Q5	1000 kc	Tunable from	500 to 1500 kc
2050	15 kc	Tunable from	1cps to 20 kc
OC3/VR105	1400 kc	Tunable from	900 to 1900 kc
SN7 Strobe	1 kc	Tunable through	Audio Range

Fairbairn reported that some thyratrons used in high current circuits were found to oscillate as low as 8 cycles per minute with current changes up to 1 amp; that other gas tubes (not identified) had outputs up to 9 mc; that no frequency of oscillation was found for neon.

Chetverikova[10] (Moscow) developed ionic oscillators operating them both with and without external control circuits in a similar manner to Fairbairn.

Cobine[14] (Harvard) developed a wide band noise generator using an ionic oscillator in a magnetic field.

Experiments conducted by this laboratory confirmed Fairbairn's results within experimental error. In addition, experiments here demonstrated that type Ne-2 neon tubes can be made to oscillate through the audio spectrum.

SUMMARY

The ionic oscillator is the simplest sinewave oscillator known, requiring no external circuits. It will oscillate when dc voltage is applied between cathode and anode. The dc voltage needs only be equal to the voltage drop across the tube when the gas is ionized. Ionic oscillators can be tuned by changing the voltage in the case of a diode oscillator or by use of a variable resistor between grid and cathode in a triode. When noise is present the oscillation frequency signal can be 100 times the noise level. AM or FM modulation can be used. It can be loaded very heavily; needs no coupling circuit and works almost as well into a low impedance load as to a high impedance load. It is not effected by body capacitance.

It is apparent from a consideration of the foregoing report that there is a wealth of information available on ionic oscillations. However, the work to date has been of a fundamental nature and only three of the ninety-four contributors have applied this knowledge in a practical way. The potentialities inherent in the ionic oscillator for subminiaturization of radio transmitters are far greater than those of the transistor. Therein lies the solution to many existent problems.

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ABSTRACTS

OF

IMPORTANT PUBLICATIONS

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ON IONIC OSCILLATIONS IN THE STRIATED GLOW DISCHARGE

By E. V. Appleton and A. West,

"Philosophical Magazine," Vol. 45, Page 879, 1923

Appleton and West detected oscillations while studying ionized gases. The discharge tube used had a diameter of 3.7 cm and the distance between electrodes was 22 cm. With a hot cathode, the anode potential was normally 80 to 120 volts, but this was increased to 600 to 800 volts in the case of a cold cathode. In both cases the discharge had to be started by an unduction coil. Oscillations seemed to be most easily obtained when the induction coil discharge had continued for some time before the steady anode potential was applied. Their production also seemed to depend on the presence of a small glow at the surface of the anode. When this glow flickered instability of the discharge resulted.

Since the frequency of the oscillations was independent of the external circuit constants, the oscillations are of a new type, being ionic in character. Usually the frequencies were of the order of 100,000 cycles per second. In the particular tube used the conditions most favorable for the production of oscillations were those in which three or four complete striations were present. It was noted that the frequency usually increases with increase of pressure and also with increase of anode potential.

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ELECTRO-MAGNETO-IONIC OPTICS

By V. A. Bailey

"Journal of the Proceedings of the Royal Society," N.S.W.,
Vol. 82, #2, Pages 107 through 113
1948

A theory of emission of electric waves by discharge tubes, by the ionosphere and the solar atmosphere is developed from Maxwell's equations. The electric fields which can exist in a medium consisting of electrons, positive ions and molecules or atoms subject to static, electric and magnetic fields are considered. Solutions of the equations for plane waves are developed which specify possible frequencies and damping co-efficients of waves transversing the material with a given (real) phase velocity and of the waves which can exist in the medium with a given (real) wave length, also, the possible refractive indices and attenuation co-efficients under which waves of a given real frequency are propogated in the medium. If the collision frequency is small, the wave may show negative absorption, i.e., the amplitude grows with time and the gas should be capable of generating oscillations. This gives one explanation of the origin of solar, stellar, and ionospheric noise.

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DECIMETER OSCILLATIONS IN MERCURY PLASMAS - EXPERIMENT AND CONSIDERATIONS

By L. Brennan, J. Saloom, and R. Wellinger, University of Illinois

A three-electrode oscillator as described by G. Wehner has been investigated extensively. It is shown that this structure displays the same behavior as some gas diode oscillators enclosed in glass, thus establishing a close relation between the diode type oscillators and the Wehner structure. A systematic set of data shows the varieties of wave length with each of the parameters involved in the oscillation. These experimental results disagree with the majority of the formulations published to date. The system oscillates in different modes, and as the cathode current is increased continuously the frequency remains constant except for discreet jumps. Further, the transit time of the beam electrons between two electrodes is always an integer plus 1/4 times the period of oscillation. A theory similar to Wehner's based on the model of the double glass klystron oscillator should describe the oscillation satisfactorily; however, this model implies the questionable assumption that within each dark space there exists a layer with marked resonant properties.

REFERENCE: G. Wehner, "Plasma Oscillator," "Journal of Applied Physics," Page 63, January, 1950 (describes very high frequency plasma oscillations).

OSCILLATIONS IN GAS DISCHARGE DEVICES

Moscow, Elektrichestvo,
No. 2, 1951, Pages 16-20

M. M. Chetverikova, Candidate of
Technical Sciences
Scientific Research Institute
of Physics, Moscow State University
Submitted September 9, 1950

(Note: This report was delivered at the Section of Radio Methods of the All-Union Scientific and Technical Society of Radio Engineering and Electric Communications imeni A. S. Popov (VNORIE) on 20 March 1950 and at the Scientific Council of the Scientific Research Institute of Physics and the Physics Faculty of Moscow State University imeni Lomonosov on 14 June 1950.)

ABSTRACT

The article presents basic results of the study of high-frequency oscillation generation by means both of gas-discharge devices specially developed for this purpose and of industrial thyratrons and gas-filled rectifiers (gasotrons). Oscillations were studied with generator circuits in which external oscillatory circuits were present and absent. Oscillograms illustrating the oscillations are given. (All figures and tables are appended.)

Oscillations in gas-discharge tubes with liquid or filament cathodes containing different gases at different pressures with different discharge and heater currents have been studied by many authors. These oscillations range in frequency from several tens of cycles per second to centimeter waves. It has been experimentally established that these oscillations cannot be explained only by the presence of oscillations in plasma. With the aid of gas-discharge tubes it is possible to excite oscillations of different types including, for example, oscillations analogous to those in the retarding field of an anode. Oscillations can be localized in both the anode and cathode regions of a discharge.

A large number of investigations by Soviet scientists has been devoted to "stenotrons," in which the effect of constricting the discharge is used to excite oscillations. Investigations were conducted at the All-Union Electrical Engineering Institute imeni Ul'yanov (Lenin) (VEI) by V. L. Granovskiy jointly with L. N. Bykhovskaya and G. L. Suyetin (1). The majority of researches on oscillations in gas discharges have been conducted with the aid of special experimental tubes having little in common with gas-discharge devices of industrial types (gas-filled rectifiers, ignitrons, thyratrons, powerful mercury-arc rectifiers). The problem of oscillations in gas-discharge devices has received insufficient attention in the literature.

OSCILLATIONS IN THYRATRONS AND GAS-FILLED RECTIFIERS

Oscillations in thyratrons and gas-filled rectifiers were studied in the absence of an external oscillatory circuit on the apparatus whose schematic diagram appears in Figure 1. For filament heating dc was used, since ac heating causes strong modulation of the oscillations being studied. A 114-volt storage battery was used for plate power supply. In the investigation of oscillations in thyratrons the grid was grounded through resistance $R_g = 10^4$ ohm, which was necessary for firing of the thyratron. After firing the grid could be disconnected. The voltage drops on thyratrons and gas-filled rectifiers were measured with a high-resistance voltmeter, while frequencies and amplitudes of the oscillations were measured with a cathode-ray oscillograph EO-5 which was calibrated for different values of amplification and synchronization. The frequency F of the oscillations and the amplitude U_k of the ac voltage component were measured at the plate in dependence on the dc component of the plate current I_a with heater current I_h = const or in dependence on I_h at I_a= const. The results of measurements of frequency F and amplitude of oscillations U_k from the filament current I_h are not cited here.

The article presents some results of the study of oscillations in thyratrons TG-8/3000 and KU-635 and in the VG-237 gas-filled rectifier. Evidently these oscillations originate mainly in the plate region. Oscillations at the grid of a thyratron are insignificant in amplitude and chaotic in form.

OBSERVATION OF OSCILLATIONS IN THYRATRONS AND GAS-FILLED RECTIFIERS

Circuits without external oscillatory circuits. Oscillations are observed in the TG-8/3000 thyratron for nearly all values of discharge current which are allowable for it; from several milliamperes to 2 a (Figure 2). Starting with I_a = 1.7 a, the oscillations take on a disorderly character. Quantitative measurements at $I_a > 1.7$ a were not taken.

Figure 3 shows the form of oscillations for I_a = 250 ma, F = 102 kc, (Figure 3, a) and for I_a = 1.2 a, F = 75 kc (Figure 3, b). These and other photographs reproduced were taken at different amplifications and oscillograph sweep rates.

In the KU-635 thyratron, however, oscillations arise intermittently at I_a = 0.3 a (Figure 4). The oscillation frequency changes from 24 to 50 kc when the discharge current is varied from 0.3 to 2.5 a. The amplitude of oscillations U_k is considerably higher than with the thyratron TG-8/3000. The characteristics shown by the solid and dotted lines are for two different specimens of the KU-635 thyratron. The small difference in frequency of oscillations is explained by the fact that the internal parameters of the thyratrons (electrode configurations and pressure) were not completely identical.

The oscillations are of a stable character and their form, close to sinusoidal at the beginning (Figure 5, a), becomes distorted as the discharge current increases (Figure 5, b).

In the VG-237 gas-filled rectifier oscillations were observed only for a very small range of variation of the discharge current (from 2 to 450 ma). Beginning with 14 ma, the oscillations become chaotic, and their amplitude rapidly decreases. (Figure 6) At I_a = 450 ma oscillations disappear. Clearly observable oscillations occur in the range from 2 to 13 ma. Oscillation frequency has a sharp minimum at I_a = 5 ma, while the amplitude has a sharp maximum at I_a = 6 - 7 ma. The form of the oscillations depends to a considerable extent on the value of the discharge current.

ISOLATION OF OSCILLATIONS IN AN EXTERNAL OSCILLATORY CIRCUIT

In order to isolate the high-frequency component, the oscillation generator was set up connected in parallel with an external oscillatory circuit (Figure 7). Operation of the generator was studied on two specimens of thyratron KU-635 at I_a = 2 a. The resonance frequency for one specimen was f = 47 kc, for the other f = 39 kc. The greatest amplitude of voltage on the oscillatory circuit was 60 v. Tuning to resonance was accomplished by varying one of three values, I_a, I_h , or $C = C_1 + C_2$, with the other two held constant. Rough tuning was accomplished by varying C_2 and I_a, fine tuning by varying C_1 and I_h (within the allowable limits). The power isolated in the oscillatory circuit was of the order of 1 watt.

Connecting the oscillatory circuit as a load for the high-frequency component of the thyratron anode current distorts the form of anode oscillations.

In view of the small internal resistance of a thyratron, series connection of the oscillatory circuit to the main circuit seemed most rational. The internal resistance of the thyratron in this case goes into the oscillatory circuit. When R = 20 ohm (including the resistance of a thermal miliammeter) the current in the oscillatory circuit reached 330 ma, the power 2 watts. For excitation of high-power oscillations with gas-discharge devices of the usual type (thyratrons, mercury-arc rectifiers, ignitrons, etc.), development of special generator circuits is necessary.

GENERATION OF HIGH*FREQUENCY OSCILLATIONS BY MEANS OF GAS-DISCHARGE DEVICES WITH MERCURY CATHODES

In working out the design of a gas-discharge device intended for the generation of high-power, high-frequency oscillations, the liquid cathode with a non-fixed cathode spot, which does not limit the current to be converted, is of basic interest. The gas-discharge device with a mercury cathode selected for experimental purposes was a type RMNV-500 uncontrolled metal demountable mercury-arc rectifier.

The results cited below were obtained by use in studying the RMNV-500 plate assembly. The deionization grid was removed from the anode sleeve and two electrodes g_1, g_2 (Figure 8) were placed at a given distance from the anode. The electrodes were connected to vacuum bushings built in to the flange of the anode assembly.

The oscillations were investigated with the excitation switched on. They were observed on a cathode-ray oscilloscope type EO-5 calibrated for different values of amplification and synchronization. In taking the load characteristic $U_{g2} = f(I_{g2})$ we measured the frequency F and the oscillation amplitude U_k as a function of the load current I_{g2}. Using the circuit in Figure 8, oscillations were obtained in the range from 4 to 112 kc. The amplitude of oscillations U_k was measured in the range from 6.35 to 58 v. Oscillations with frequency F = 4 kc and amplitude U_h = 17.4 v were obtained at C_2 = 25 ufd, C_4 = 1.5 ufd, C_5 = 0, and C_1 = 0.5 ufd. The dc component of the discharge current I_{g2} = 0.2 a.

Oscillations with a frequency F = 112 kc were obtained at C_1 = 1 ufd, C_2 = 22 ufd, C_4 = 1.5 ufd, and C_5 = 11,600 uufd; the dc component of the discharge current I_{g2} = 4.5 a. Oscillations of the amplitude U_h = 58 v were obtained under the following conditions: C_1 = 0.5 ufd, C_2 = 25 ufd, C_4 = 1.5 ufd, C_5 = 0; the dc component of the discharge current I_{g2} = 10 a. The form of the oscillations F = 14.8 kc as recorded by the EO-5 cathode-ray oscilloscope are shown in Figure 9. The dc component of the discharge current I_{g2} = 2 a, U_{g2} = 36 v.

In Figure 10 the curves 1 and 2 show the dependence of oscillation frequency and amplitude on capacitor C_2, while curves 3 and 4, 5 and 6 show the dependence of the same parameters on the discharge current I_{g2}.

Neither varying C from 0.25 ufd to 2 ufd nor disconnecting C_1 and g_1 from the circuit has any effect on the frequency or amplitude of the oscillations. In the circuit shown in Figure 8 the frequency and amplitude of the oscillations are determined by the external parameters of the circuit and the value of the discharge current. We studied oscillation phenomena in eleven different circuits. The form of oscillations with frequency F = 21.8 kc, U_k = 33 v for one of the variants of these circuits (Figure 11; I_{g2} = 2.5 a, C = 3 ufd) is shown in Figure 12.

The frequency and amplitude of oscillations for different capacitances C and discharge currents I_{g2} or I_{g1} for the circuit in Figure 11 are cited in the table. It is not difficult to see that in this circuit the discharge currents I_{g2} and I_{g1} have no effect on the frequency of oscillations. The amplitude of oscillations U_k, however, grows with an increase in I_{g2} or I_{g1}. It was also established that in the circuit of Figure 11 connection of capacitance and inductance in series between electrode g_1 and the cathode does not effect either the frequency or amplitude of the oscillations.

CONCLUSION

Further study as to the possibility of increasing the frequency and power of oscillations generated in gas-discharge devices is needed. It is also necessary to study oscillations in gas discharge devices as causes of breakdowns and sources of interference. The relation between back firings and oscillations in gas-discharge devices should be cleared up. Superimposing the characteristics $F = f(I_a)$ and $U_k = f(I_a)$ of thyratrons TG-8/3000 and KU-635 with the values of their maximum allowable back voltages shows that to an increase in oscillation amplitude for thyratron (KU-635) there corresponds a decrease in the allowable value of back voltage. This proposition should be checked with other types of gas-discharge devices.

Participating in the investigation of oscillations in gas-discharge devices were student V. I. Shelyubskiy (thyratrons and gas-filled rectifiers) and scientific associates P. P. Klimentov and T. M. Sviridov (mercury-cathode devices).

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V. L. Granovskiy and G. L. Suyetin, DAN SSSR, Vol. KLIX, No. 6, (1945), Page 420.

G. L. Suyetin, Zhur Tekh Fiz, Vol. XVII, No. 7, (1947), Page 809.

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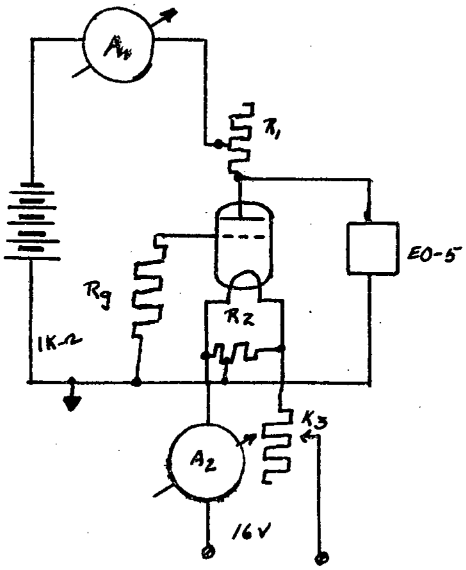
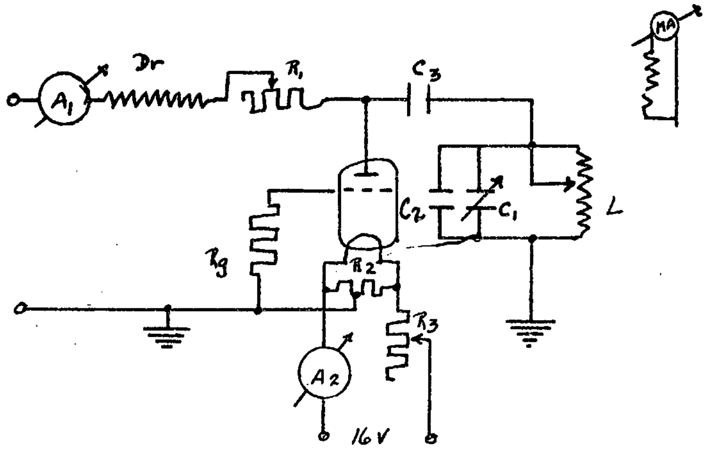


Figure #1.



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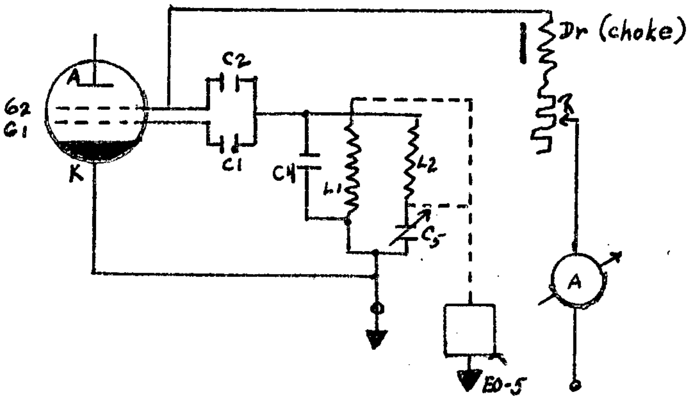

Figure #8.

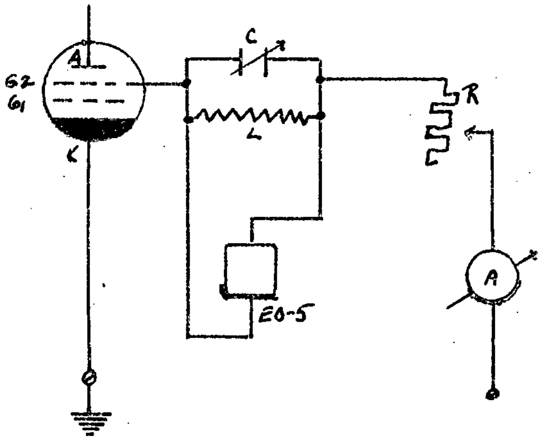

Figure #11.

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OSCILLATIONS AND TRAVELING STRIATIONS IN AN ARGON DISCHARGE TUBE
By T. C. Chow, Palmer Physical Laboratory, Princeton University
"Physical Review," Vol. 37, Page 574, 1931

The author conducted experiments on the properties of moving striations in an Argon discharge tube. The author took Langmuir probe measurements to determine the voltage fluctuations in an oscillating tube. He found that moving striations do not appear distinctly until the gas pressure is below 1mm mercury. He concludes from this that the disturbance is small in the cathode region compared to that in the anode region, which agrees with the fact that the traveling striations are present in the positive column. He found no voltage fluctuation in the Faraday dark space. He tabulates the range of striation velocity and frequency with respect to anode current and finds that they are approximately constant. He found that the frequency of motion of the striations varied with the external non-inductive resistance. When the battery voltage is high, the Faraday dark space is present, and when it is low, the Faraday dark space disappears. He also found that inductance increased the frequency while capacitance decreased it. He found further that an increase in filament currents decreases the frequency. The author tried to relate the flash frequency of the striations, i.e., the frequency of motion of the striations, to the theory of plasma ion oscillation derived by Tonks and Langmuir, but does not find a significant relationship other than the fact that the wave length coupled with the flash frequency is always an integral or half integral multiple of the length of the tube. The author offers no explanation of the observed phenomena.

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NOISE AND OSCILLATION IN HOT CATHODE ARCS

By J.D. Cobine and C. J. Gallagher
Radio Research Laboratory, Harvard University

"Franklin Institute Journal," Vol. 243, #1,
Pages 41-54, January, 1947

Cobine and Gallagher indicate that when both oscillation and noise are present in gas tubes operating without external magnetic field the oscillation amplitude may be 100 times greater than the noise level. Another type of oscillation observed by Ballantine is discussed. "This oscillation was detected for currents as low as 0.38 ma, which is in the Townsend discharge region." Hence, this cannot be a plasma oscillation since a plasma or arc column does not exist for this type of discharge. It is interpreted as the oscillation of positive ions in the potential minimum at the cathode.

Effects of grid bias on the amplitude and frequency of oscillations are shown in graphs. Oscillation frequency increases continuously as the current is made more negative. The amplitude of oscillation varies irregularly with a general trend toward slower values as the bias becomes more negative.

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H. Kniepkamp, "Zeits f. Tech, Phys," Vol. 17, Page 397, 1936 (Low Frequency Oscillations Caused by Path Change).
K. H. Kingdon, "Physics Review," Vol. 33, Page 1075, 1929 (Oscillations between 650 and 700 kc caused by vibrating Positive ions in the potential minimum at the cathode).

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PINCH EFFECT OSCILLATIONS IN A HIGH CURRENT TOROIDAL RING DISCHARGE

By S. W. Cousins, and A. A. Ware
Department of Physics, Imperial College, London

"Physical Society of London Proceedings," Vol. 64B, Pages 159-166,
1951

I. THEORY

Charges moving linearly in space create a self-circling magnetic field. This circular magnetic field causes charges within it to go toward the center of the magnetic field. This inward radial force is called the "pinch effect." A discharge tube in the shape of a torus was filled with gas at low pressure and subjected to a high current (100-10,000 amperes), discharge consisting of a cylindrical beam or plasma inside the toroidal ring. This plasma, since it consists of moving positive ions, is subject to pinch effect forces. At the beginning of the discharge, the pinch forces will cause a compression of the plasma. The compression will be of considerable amplitude and, hence, it will travel inward as a "shock wave" in the plasma. It will pass through the center of the tube, travel out to the walls, and be reflected inward again, and so on.

The discharge oscillates continuously from a wide beam to a narrow filament and back to a wide beam many times per second (on the order of 1/2 million per second) depending upon the gas used and the pressure. A rotating mirror is used to photograph the oscillating plasma. When a pinch occurs there is a temporary decrease in gas current; the actual gas current minimum occurs slightly after the instant when the discharge is narrowest. These decreases in gas current constitute

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high frequency oscillations (on the order of .5 mc). The ionic oscillation frequency depends upon the diameter of the tube and is given approximately by:

$$f = \frac{1}{d}\left[\frac{k(T_e + T_p)}{M}\right]^{1/2}$$

where d = Diameter of discharge tube
Te = Temperature of electrons
Tp = Temperature of positive ions
k = Boltzmann's constant
M = Mass of a positive ion

II. QUALITATIVE EXPERIMENTAL RESULTS

1...Period of pinch oscillations increases with gas pressure (frequency decreases).

2...Period of pinch oscillations is directly proportional to the square root of the atomic weight.

3...When the gas current is large, pinch periods are shorter (higher currents create stronger magnetic fields whose pinch forces are stronger).

4...Main gas current oscillations (of the order of 55 kc) have lower frequencies than corresponding pinch oscillations and are larger in amplitude (on the order of 100 amperes).

5...During the part of the cycle when the plasma is very narrow (pinched) the self-inductance of the gas circuit increases considerably. Hence, the observed decrease in current when the discharge is contracted can easily be explained by the increase in inductance of the gas.

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MOVEMENTS OF STRIAE IN DISCHARGE TUBES UNDER VARYING PRESSURES

By L. H. Dawson, Naval Research Laboratory, Washington, D.C.
New York Meeting of the American Physical Society, February 26 and 27, 1927
Abstract #18 from "Physical Review," Vol. 29, Page 610
1927

The striae of the positive column of a discharge tube move along the tube when the pressure of the gas in the tube is varied. The curves of this motion have been obtained as a function of the pressure, the distance apart of the electrodes, the diameter of the tube, and the density of current for wet and dry H_2, H, N_2, air, CO, and CO_2. The pressures made by a McLeod gauge ranged from 0.6 to 0.05 mm Hg. With these curves the discharge tube may be used as a synthetic and quickly responding pressure gauge. The motion of the striations increased with the diameter of the tube being roughly 10 times greater in tubes 30 mm in diameter than in tubes 16 mm. in diameter. For tubes in which the distance between the electrodes was less than the maximum distance of motion of the striae as the pressure was diminished the positive column marched into the anode without distortion and vanished.

33

MOVING STRIATIONS IN H_2 AND D_2 GLOW DISCHARGES

By T. M. Donahue, Johns Hopkins University

(This Work Supported Through ONR contract under
the Direction of G.H. Dieke)

A study of glows in hydrogen by means of photo multiplier tubes used in conjunction with an oscillograph has revealed that such DC discharges can exist in both oscillatory and non-oscillatory states. The oscillations found generally have a frequency of a few times 10,000 per second. Two distinct regimes for these discharges will be discussed:

1..Low Pressure, Low Current (below 0.2 millemeters and 1.0 milleamperes)

The positive column appears homogeneous, but there exists in it moving striations. The most prominent of these travel toward the cathode at a speed higher than five times 10^7 centemeters per second. The frequency of oscillation increases linearly with current and decreases with pressure.

2..Higher Pressure and Current

Stationery striations begin to appear in the column. Oscillations do not usually exist, but they may appear. Generally, this occurs when there are a few standing striations at the head of a homogeneous column. In the homogeneous column moving striations are found, all of which Move Toward The Anode. The light in the stationery striations also oscillates. When deuterium glows were studied under conditions identical with these no essential differences were noted. Thus, the prominent oscillation parameters in these glows are independent of the mass of the positive ions.

REFERENCE: T. Donahue and G. H. Dieke, "Oscillatory Phenomena in Direct Current Glow Discharges," "Physical Review," Vol. 81, #2, Pages 248 to 261, January 15, 1951.

8

OSCILLATORY PHENOMENA IN DIRECT CURRENT DISCHARGE

By T. Donahue and G. H. Dieke, Johns Hopkins University,
Baltimore, Maryland
"Physical Review," Vol. 81, #2, Pages 248 to 261
January 15, 1951

This article discusses the results of a series of experiments done under the auspices of the O.N.R. and directed by G. H. Dieke. A more detailed report was published in 1948 as Technical Report #1 of this project. A paper presented to the 1951 Gaseous Electronic Conference by W. D. Parkinson reports on another aspect of this same research.

The experiments recorded dealt with varying intensity of light in a given part of the discharge as the pressure and current were varied. Both oscillations of the light intensity and tube voltage were measured at different currents used. They concluded that the voltage and the light intensity oscillations had the same frequency, but the magnitude of the voltage oscillation was only a few percent of the all-over tube drop (example - 5 volts and 200 volts). A long type tube was used in most of the experiments (30 to 50 cm) and the frequency was about 1 to 5 kc. They noted that the magnitude of the voltage oscillations remain constant even though the external resistance was changed. A shorter tube, a GE-H6 mercury tube with 2.5 cm between electrodes and 0.25 cm in diameter, gave a higher frequency of oscillation (10 kc) and a larger voltage magnitude of oscillation (50 v). They also presented a table that showed a strong trend toward the similarity between the voltage oscillation magnitude and the excitation and ionization potentials.

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	V_e (ev)	V_i (ev)	ΔV (v)	
Hg	4.9	10.4	5.4	
Kr	9.9	14.0	10.1	
A	11.6	15.8	12.4	
Ne	16.6	21.6	14.4	
He	19.8	24.6	16.6	

Table showing similarity between voltage oscillation magnitude (ΔV) and excitation potential and ionization potential.

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The voltage oscillation magnitude almost always appear in between these two values or a little less than the excitation potential. They also presented a very worthwhile, in my opinion, qualitative theory of the mechanics of moving striations in monatomic gases in terms of the electron and ion flow. In concluding, they stated that further work was to be done and they hoped to publish results that would enable them to present a quantitative theory.

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16

THE ABNORMAL LOW VOLTAGE ARC

By Carl Ekart and K.T. Compton
"Physical Review," Series 2, Vol. 24, Page 97, 1924

An article describing experiments made in studying the fact that in hot cathode tubes arcs can be maintained with applied voltages less than the minimum critical potential in helium and in mercury, but not in hydrogen and neon. The theory given is that hydrogen and neon do not have metastable states and, therefore, cannot ionize by accumulation of energy. The authors found that the arcs with abnormal low voltages oscillated if a high resistance was placed in series with the tube. Though the instrumentation was crude, it is definitely established regions of oscillations when a mercury tube had an average drop of 15v and a current of 0.3 and 0.7 amperes. No measurements of the frequency were made.

No bibliography was given.

3

THE CONDUCTION OF ELECTRICITY THROUGH GASES

By K. G. Emeleus

Articles of Interest in Book #22, 25, and 30, 3rd Edition, 1951

The article mentions ionic oscillations as occurring from 10^4 mc down to audio frequency. It derives a formula (10^7-10^9 cps) (Langmuir's formula) for calculating electronic oscillations for the upper part of the range. The formula is:

$F = 8980\ N^{\frac{1}{2}}$

$N =$ Electrons per C.C.

The article further states that these electronic oscillations have no external field and cannot radiate, but suggest a couple of methods by which they might be utilized (such as electrodes). States the positive ion oscillations cover the lower range (up to 1.5 mc for Hg). States that a complex relation results unless a high temperature is assumed to exist. Emeleus then derives the formula for the upper limit of the ionic oscillation frequency to be:

$F = 2.09 \times 10^2\ (N/M)^{\frac{1}{2}}$

$M =$ Molecular weight

$N =$ Positive ions or free electrons per C.C. in plasma

The article further states a complete spectrum exists with peaks.

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PLASMA ELECTRON OSCILLATIONS

By K. G. Emeleus and T. R. Neill

"Proceedings of the Royal Irish Academy," Vol. 53, Page 12, 1950

Probe measurements have been made of the high frequency oscillations generated near a hot straight wire cathode in an electric discharge through mercury vapor at low pressure. Their frequencies are of the order of 1,000 mc. An oscillation pattern exists in the space within about 1 cm from the filament of a character similar to but in some respects simpler than that previously found for a flat cathode. A theory of the maintenance of the plasma oscillations through coupling with transit time oscillations extending to the cathode is discussed and it is also shown that the power delivered to the oscillating sheet of plasma is probably sufficient to compensate for frictional collision loss of energy in the plasma oscillations. This article deals entirely with electron (high frequency) vibration.

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TURBULANCE IN GASEOUS CONDUCTORS

By K. G. Emeleus

"Physical Society Proceedings," Vol. 64, #374B, Page 166 to 169

February 1, 1951

A brief general discussion of both low frequency and high frequency oscillations in the gas. He mentions numerous other works. He states that there probably exists an analogy to ion plasma waves and the low frequency discharge. He states that possible turbulance exists in the plasma and anode spots. He further states that it may be possible to relate this turbulance to similar hydro-dynamic models. He states that a definite correlation needs to be proven between gas flow and electron flow before hydro-dynamics can be applied to the problem. In concluding, the author stated that it is a definite experimental fact that instability of discharge of many forms is often associated with oscillatory disturbance at large amplitude.

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15

THE TRANSMISSION OF WAVES THROUGH AN IONIZED GAS

By R. W. Evans

"Physical Review," Vol. 44, Serial 2, Page 799, 1933

An article discussing experiments using a mercury tube and a hot cathode and approximately one micron of pressure. The tube was a spherical bulb 9 cm in diameter and was kept at a constant ambient temperature. From the diagram of the apparatus it was noticed that the filament and anode were about 1 cm apart. The reason for a much larger tube than the distance between the cathode and anode was that the author was attempting to form a resonator. The frequencies present were 2×10^4 up to 10^6 cycles per second. Many of these higher frequencies were harmonics of the fundamental frequency.

The author noted that:

1...The oscillations did not start until a certain arc current was flowing in the tube. The value of this arc current varied as the anode potential varied. Usually the critical current value increased as the anode voltage increased.

2...The oscillatory state was easily destroyed by a magnetic field.

3...From #2 it was concluded that the shape of the filaments and the heating current they required probably is important in the study of oscillations.

4...With Oxide coated filaments oscillations appeared at lower ionization densities.

5...Straight wire filaments produced oscillations more easily than spiral filaments.

6...The author noted that a high audio frequency and an r.f. frequency of about 10^6 cycles per second appeared at the same time.

7...Noted the oscillation frequency would stay steady over a wide range of current and then suddenly jump to another frequency and again remain constant over another range of current.

8...Concluded the tube resonance situation was similar to a Helmholtz resonator.

In concluding, the author discussed J. J. Thomson's theory of waves traveling through an ionized gas. The formulae for the velocity of the wave limits being:

$$\left(KT_i / M_i\right)^2 \quad \text{LONG WAVES}$$

$$\left(\frac{KT_i + KT_e}{M_i}\right) \quad \text{SHORT WAVES}$$

T_i ≡ ION TEMP
T_e ≡ ELECTRON TEMP
M_i ≡ MASS OF POSITIVE ION

The author noted that he had an electron temperature of about 50,000 to 80,000 degrees cm which would give a wave velocity of 1.5×10^5 cm per second. This would give a bulb resonant frequency of 1.7×10^4 cycles per second. The observed frequencies were slightly higher than the calculated value. A table giving different frequencies at different anode currents is shown below:

ANODE VOLTAGE + 38 VOLTS

ANODE CURRENT (MA)	FREQ OF FUNDAMENTAL
200	2.0×10^4
300	1.96×10^4
400	1.94×10^4
500	1.88×10^4
600	1.90×10^4
700	1.88×10^4
800	1.90×10^4

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"Radio-Electronics" December 1953

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THE IONIC OSCILLATOR

By Thomas E. Fairbairn

A patent (U.S. patent No. 2,607,897) was issued August 19, 1952, on a new form of gastube oscillator which contains no resistive, capacitive, or inductive time-constants, and needs no external or internal resonant circuits or cavities. This new ionic oscillator can deliver high output at audio or radio frequencies and has good stability over long periods of time. This is the simplest electronic oscillator known, and operates on as little as 2 milliamperes from a plate supply of $22\frac{1}{2}$ volts or less. Fig. 1 shows the ionic oscillator's simple circuit.

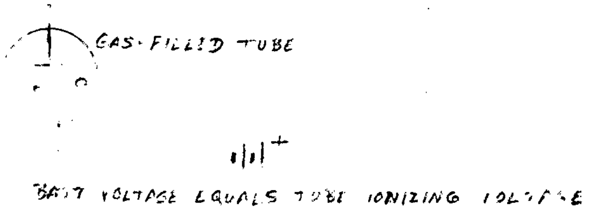

Fig. 1-The utter simplicity of the ionic-oscillator circuit. The battery voltage is made equal to the normal ionization drop across the gas tube.

The U.S. Naval Research Laboratory in Washington found that when a certain critical voltage is applied between the plate and cathode in an inert-gas or vapor-discharge tube, the ionized gas generates oscillations in the audio- or radio-frequency range. This is something like the oscillations in a resonating crystal -- but with the added advantage of much higher output.

A very simple experiment convinced the Navy and patent men that the oscillations were generated in the ionized gas of the tube and not in any external circuits. Fig. 2 shows the basic circuit used in the experiment -- nothing but

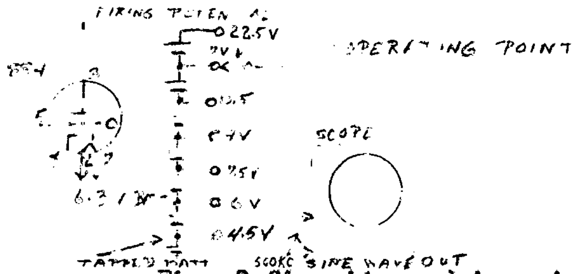

Fig. 2-Circuit used in original ionic-oscillator experiments. The full $22\frac{1}{2}$ volts is applied first to fire the 884; then the voltage is reduced to the optimum value for stable sine-wave oscillations.

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an 884 thyratron, a 6-volt filament battery (a.c. can be used as well), a tapped 22½-volt B battery, and an oscilloscope connected across the plate-cathode circuit to show the output waveform. The physical setup is shown in the photograph. If you check the settings of the scope controls you can see that the frequency of oscillation of the 884 is about 500 kc.

This experiment showed that any gas-filled tube (except certain neon bulbs) will oscillate when you apply a d.c. voltage across its plate and cathode equal to the voltage drop of the tube when ionized, and it will generate an almost perfect sine wave (not a saw-tooth as in other gas-tube oscillators). Many gas tubes besides the 884 were tested in the same circuit and they all oscillated in the same way, except that each tube had its own fundamental frequency of oscillation just as crystals have.

The ionic oscillator in this experiment put out enough r.f. to be picked up on a home receiver at distances of 10 feet or more -- without an antenna.

The ionic oscillator can be tuned over a limited range by changing the plate-cathode voltage in diode types, or by inserting a variable resistor between plate and grid in triodes and adjusting it for the desired output frequency.

Some of the gas tubes tested and their fundamental single-frequency outputs are as follows: 884 -- 500 kc, tunable from 400 to 1,000 kc; 6Q5 -- 1,000 kc tunable from 500 kc to 1,500 kc; 2050 -- 15,000 cycles tunable from about 1 cycle to 20,000 cycles; OC3/VR105 -- 1,400 kc tunable from 900 to 1,900 kc. The Navy SN7 stroboscope tube has an output of about 1,000 cycles tunable over the entire audio range. Neon bulbs have no frequency of oscillation as yet discovered. Fluorescent lights oscillate over a very broad frequency band and can be detected almost anywhere on the dial, but have definite peaks at certain frequencies. Some large thyratrons used in high-current circuits were found to have outputs as low as 8 cycles per minute, with current changes of up to 1 ampere. Many other types of gas tubes were tested and frequencies as high as 9 megacycles were noted.

MODULATION

Either frequency modulation or amplitude modulation may be applied, depending upon whether the modulating voltage is inserted in series with the plate or in parallel with the grid and cathode. A .01-volt a.c. signal applied between the grid and cathode of a triode-type gas tube as shown in Fig. 3 will modulate the output of the ionic oscillator from zero to well over 100 percent. (With over 100 percent modulation you get a pulse-modulated carrier.) A .01-volt input to the grid will produce as much as 1.5 volts change in the output carrier. This represents an a.c. amplification factor of 150, and also shows that grid control is possible with gas oscillators.

When a sound-powered or crystal microphone was connected between grid and cathode of the thyratron (Fig. 3) the voice-modulated output could be heard clearly on a radio receiver tuned to the fundamental frequency of the ionic oscillator.

When two ionic oscillators with different fundamental frequencies were connected in series as shown in Fig. 4 the result was a frequency-modulated carrier with an output of at least 1½ volts r.f. The percentage modulation of this series circuit could be varied with the 50,000-ohm control of the upper triode.

ADVANTAGES

Now let's look at the differences between this ionic oscillator and other more familiar oscillators. First we'll compare the ionic oscillator with the relaxation oscillator which also uses a thyratron (or a gas diode) and may confuse a person who is hot up on his electronics. The relaxation oscillator gives out a sawtooth waveform, whereas the ionic oscillator gives out a sine wave. The relaxation oscillator has a top frequency limit of about 50 kc because of the electron transit time between the plate and cathode elements and the ionization and deionization time of the gas. The ionic oscillator has an upper limit of over 1,500 kc. In the relaxation oscillator an external R-C time-constant network sets the frequency of oscillation; but an ionic oscillator using the same tube type has nothing but a battery in the external circuit.

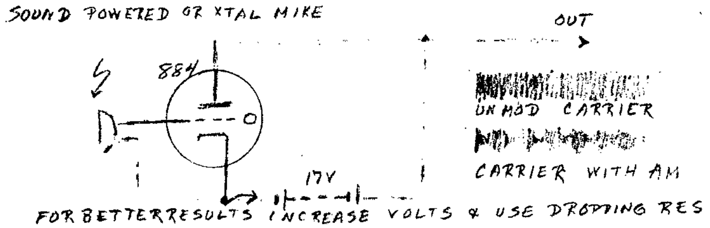
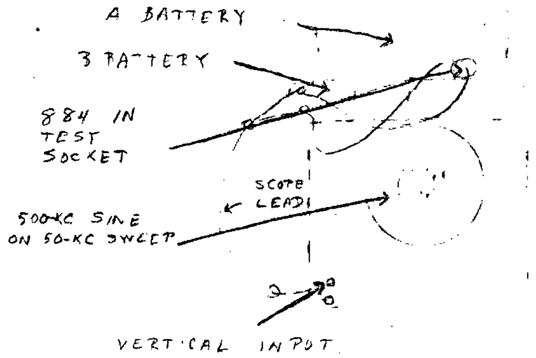


Fig. 3-Circuit of a voice-modulated ionic oscillator. The carrier frequency with an 884 is approximately 500 kc; with a 6Q5, approximately 1 mc.

In the gas-tube relaxation oscillator the grid loses control over the output waveform once the oscillation starts, but in the ionic oscillator the grid maintains control at all times. This is proved by the voice-modulation circuit shown in Fig. 3. In addition, the ionic oscillator works at a voltage equal to the plate-cathode voltage drop of the ionized gas tube used, but the relaxation oscillator must have a much higher B supply due to the voltage drop in the external R-C network.



The physical setup of the circuit shown in Fig. 2. Sweep-control settings show the sine-wave oscillations have a frequency of approximately 500 kc.

In comparing the ionic oscillator with the inductance-capacitance tuned-tank oscillator or the crystal oscillator, the ionic oscillator can be loaded very heavily; it needs no coupling circuit, and will transfer almost as much of its output to a low-impedance load as to a high-impedance load. In the L-C oscillator the resonant-tank circuit determines the frequency of oscillation, whereas in the ionic oscillator the ionized gas itself determines the resonant frequency regardless of the external circuit.

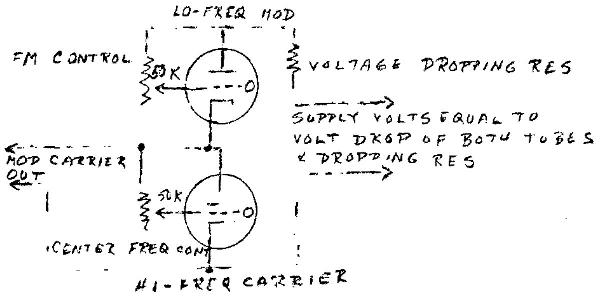


Fig. 4—An ionic-oscillator adapted to direct frequency-modulation.

One further advantage: An L-C oscillator can be detuned or killed by hand capacitance. The ionic oscillator is not affected at all.

In tuning an ionic oscillator the plate-cathode voltage is adjusted so that a small plate current flows. This current is fairly critical over a limited region for single-frequency operation. (With larger plate currents, the ionized gas oscillates erratically at random frequencies.)

A circuit for general experimental work is given in Fig. 5. Either an 884 or 6Q5 thyratron can be used. R1 is a variable voltage-dropping resistor, and R2 is a variable grid resistor for tuning. The battery is 140 volts, and the 6.3-volt filament supply may be either a.c. or d.c. A current of about 10 ma should produce a good sine wave at about 1,000 kc with a 6Q5, and at about 550 kc with an 884. This oscillator can be modulated with a crystal phono pickup or microphone connected between grid and cathode, and the modulation should be heard clearly in a nearby radio.

OTHER APPLICATIONS

What uses can this oscillator be put to? Well, the ionic oscillator will drive an 807 r.f. power amplifier directly. No elaborate modulator circuit is needed for phone operation, as modulation can be applied to the oscillator itself.

The circuit of this transmitter is shown in Fig. 6. Here the ionic oscillator is used as the master oscillator for the 807. (Remember -- this is an experiment only and keep F.C.C. regulations in mind!) At 500 kc the power output of the 807 is enough to light a 40-watt fluorescent tube. The bandwidth is no more than 10 kc on any conventional receiver.

The 807 is set up as a conventional class-A amplifier except for the fact that there is no grid tank circuit. The plate tank circuit was designed only to prove a point and not to stand up on any breakdown test. The tank coil was a four-pie 1-mh r.f. choke and the tank capacitor was a midget 144-uuf variable. A 450- to 500-volt d.c. power source supplied the plate and screen voltages, and a dropping resistor supplied the ionic oscillator plate voltage. The ionic oscillator and the r.f. amplifier were coupled through a .05-uf 200-volt capacitor. (This may be varied for optimum drive to the 807; the cut-and-try method will give the best results.)

The ionic oscillator is adjusted till it oscillates best. Then the amplifier is turned on and the plate tank is tuned till the fluorescent tube lights with maximum brilliance when touched to the plate of the 807. Those who know tank circuit design and are licensed to operate on 160 meters or higher frequencies can operate the 807 as a doubler. Those who do not have a license are advised not to try this experiment, as this simple transmitter will radiate quite a distance.

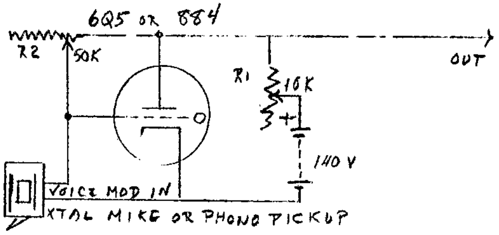


Fig. 5-A circuit for general experimental work with the ionic oscillator.

The ionic oscillator has been used also in audio signal generators, photocell amplifiers, radio receivers, pulse generators, special waveform generators, frequency- and amplitude-modulated oscillators, control circuits, and other special devices.

OTHER CHARACTERISTICS

For those who are more interested in the experimental value of the ionic oscillator the following data were recorded during actual experiments:

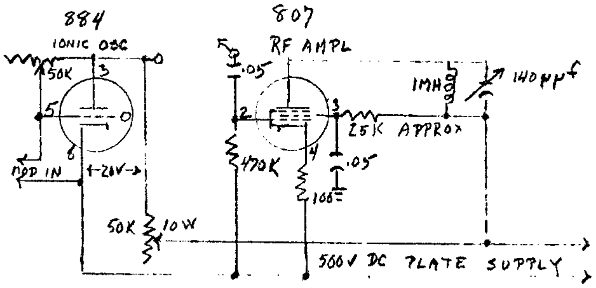


Fig. 6-A 40-watt 500-kc transmitter with an ionic master oscillator. Values are for experimental work only with all precautions taken to prevent radiation in violation of FCC regulations.

It was found that an OC3/VR105 voltage-regulator tube will oscillate at as many as five different modes. These modes can be produced by opening and shutting the plate-current circuit. Each mode will follow the other in sequence as the plate circuit is interrupted. At the same time a spot of blue light can be seen switching up and down the cathode as each mode is reached. These modes or frequencies will always be the same for the same position of the blue cathode spot. This same shifting of frequency can be accomplished by beating one variable-frequency ionic oscillator against another.

It was also noted that if a d.c. or a.c. arc is made on a hard metal surface any ionic oscillator in the vicinity will shift frequency. Arcs on soft metal will not produce this effect. When a Navy type-SN7 stroboscope gas tube is hooked up as an ionic oscillator and placed in the beam of another stroboscopic light source, alternate light and dark bands can be seen moving slowly toward the plate from the cathode. If one pole of a magnet is brought near the column of ionized gas in the SN7 the frequency of this ionic oscillation will decrease as the bands move farther apart.

When an SN7 stroboscope tube is working as an ionic oscillator at about 5,000 cycles, the high-pitched audio note can be heard clearly coming from the tube elements.

If a variable resistor is connected between cathode and grid of a 6Q5 ionic oscillator, the oscillator will continue to work, even after the filament voltage has been removed, when a certain resistance has been reached.

If the grid of a triode-type ionic oscillator is driven very hard by an audio signal generator, the output carrier frequency will increase from about 1,000 kc to 9 mc. There will also be many different waveforms and pulsed radio- or audio-frequency combinations.

A tetrode gas tube such as the 2050 used as an ionic oscillator can have two separate control signals -- one applied to the control grid and the other to the screen grid. These two signals can gate the tube to work only when both are present or when one or the other is present. In some tubes fixed a.c. modulating waveforms may be used for switching the ionic oscillations on and off.

In summary, the ionic oscillator is unique in that it is a high-frequency gaseous tube oscillator. In addition, it is a stable oscillator whose frequency and voltage output is constant for wide variations in load impedance. All this is done with extreme simplicity of construction.

Prior to the ionic oscillator, all oscillators using gaseous discharge tubes had the frequency determined by a tuned tank circuit connected to the output of the tube or by the charging time of an external capacitor as in a relaxation oscillator. The upper limit of most gaseous tube oscillators is generally no more than 50 kc because of the off-on process which has a definite minimum time limit. However, the ionized gas in a discharge tube normally oscillates within the tube at a frequency between 500 and 1,500 kc at low orders of ionization, the frequency being dependent on certain of the external circuit constants.

It should be clear to the reader that this is truly a new and unusual electronic invention that has many possibilities. Data will have to be compiled and checked before practical applications can be made.

OSCILLATIONS IN THE GLOW DISCHARGE IN ARGON

By G. W. Fox, Iowa State
"Physical Review," Vol. 37, Page 815
1931

The author observed radio frequency oscillations in the frequency range of 10 kc to 100 kc in approximate harmonic relationship. This is the second of articles by the author dealing with ionic oscillations in inert gases, the first being on Neon, which he said exhibited somewhat different properties from Argon. The frequency range for Argon was not as large for given pressure difference as he found in Neon. The frequency varied inversely with the pressure down to a certain "value when no further change could be produced, the frequency remaining constant but becoming weaker until on further pressure reduction it broke completely."

The relationship of frequency to two current which appeared in Neon did not appear in Argon. "Having set a particular frequency, this frequency persisted within a few cycles of the same value while the current changed as much as an ampere, when the oscillations would stop suddenly to start again when the current was returned to its former original value."

A horseshoe magnet placed so that its field was at right angles to the discharge and moved from the anode end of the discharge to the cathode caused the frequency of oscillation to vary periodically as the magnet was moved. In the Faraday dark space the oscillations under these conditions became very noisy, to re-appear again coherently when the magnet was removed.

On the basis of this phenomena, the author presents a simple theory to account for the oscillations and some calculations based on the theory that the

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OSCILLATIONS IN GLOW DISCHARGES IN NEON

By Gerald W. Fox
"Physical Review," Vol. 35, Page 1006
May 1, 1930

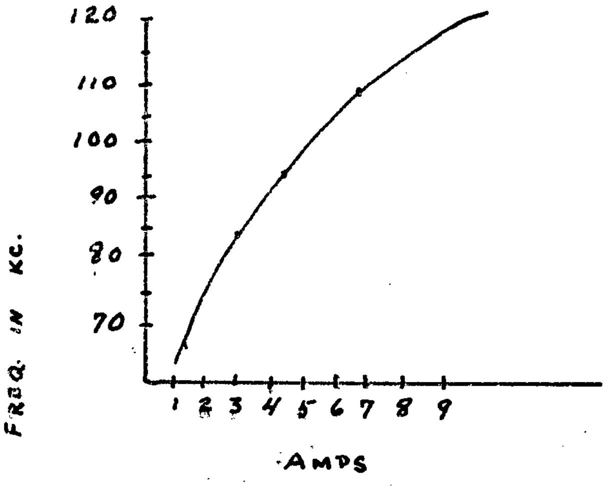
A short article discussing results of experiments on oscillations in neon discharges from 15 to 200 kc. The conclusions were:

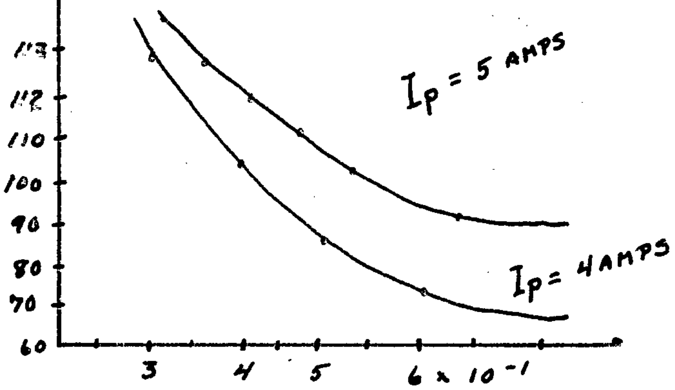
(1)..The frequency was independent of the external resistance in series with the discharge tube.

(2)..The frequency increased with decreasing gas pressure.

(3)..The frequency increases with increasing current flow in the tube.

The tube was a long gas discharge type that carried much higher currents than any of the other experiments I have read about (1 ampere as compared to the usual 1 to a hundred ma). He also claimed that there was a perfectly steady positive column, which is also in disagreement with most of the other reported data. A basic frequency and its harmonics were present in most experiments.





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OSCILLATIONS OF PLASMA AND STRATA

By G. V. Gordeev

"Dokl. Akad. Nauk S.S.S.R.," Vol. 79, Page 771, (In Russian), 1951

The strata are considered as wave group oscillations of potentials, their velocity being identified with group velocity. For stationary strata, the distance between the strata peaks is compared with the length of almost monochromatic waves of the group or, for traveling strata, with the distance between the maximum of wave groups. The theory is supported by experimental graphs and results with H_2, N_2 and Hg used as gases.

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PLASMA OSCILLATIONS AND STRIAE

By G. V. Gordiev

"Zh. Eksper. Teor. Fiz.," Vol. 22, Page 230 (In Russian), 1952

It is postulated that the velocity of striae in the positive column of a gas discharge is the group velocity of plasma oscillations. Using the relation between the frequency and wave length of such oscillations derived by Landau (1946) the group velocity and the distance between successful group maxima, which is identified with the separation of individual striae, are calculated. Comparison with experimental measurements on striae separation in H_2, N_2 and Hg shows very good agreement with the theoretical predictions. Moving striae are obtained when the reflected wave from the cathode is rapidly damped by atomic collisions. This occurs most readily when the group velocity of the incident wave is high, and nearly equal to the electron drift velocity; when the reflected wave is insufficiently damped, interference between incident and reflected waves produces a continuous positive column. This is in accordance with the experimental observation that in many gases, although the velocity of moving striae increases as the pressure is reduced, stationary striae are produced at a very low pressure region in which the positive column is continuous. A sudden transition from moving to stationary striae should theoretically be possible in certain cases (e.g., H_2 and Hg) but in these cases moving striae have not been observed.

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OBSERVATIONS ON THE THEORY OF THE POSITIVE COLUMN IN DIATOMIC GASES

By Ragnar Holm

"Zeits f. Phys.," Vol. 75, Page 171 (In German), 1932

An observation of the gradient of the positive column in diatomic gases is corrected and compared with calculations on Schottky's theory. The theoretical analysis seems to be largely right. Negative ionization is stopped at the sharpening of the positive column striations under special conditions, and their probabilities are calculated. This article does not mention oscillations as such, but as a study of striations in the positive column, and it might be worth while.

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HIGH FREQUENCY DISCHARGE BREAKDOWN MECHANISM AND SIMILARITY RELATIONSHIPS

By F. L. Jones and G. D. Morgan,
"Physical Society Proceedings," Vol. 64B, Page 560, 1951

A study of high frequency breakdown between wires and coaxial cylinders in air and H^2 at less than 20 mm pressure. The frequencies used were from 3 1/2 to 70 mc. The article has some bearing on the subject in that it shows the variance of breakdown potential as a function of pressure and tube size. It generally shows that the smaller the filter the higher the breakdown frequency. It also shows that the lower the pressure the lower the breakdown potential. This article also contains a discussion of the mechanism of breakdown. In general this article should be classed as an interesting supplementary article for possible future study.

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ELECTRICAL PHENOMENA IN THE HISSING ARC

By T. B. Jones and B. H. List, Johns Hopkins University

4th Annual Conference on Gaseous Electronics, October 4, 5, and 6, 1951

Verbatim abstract from "Physical Review," Vol. 84, Page 1072, 1951

"When the carbon arc begins to hiss in air, several phenomena occur simultaneously. (1) There is an abrupt drop in the arc voltage of about 10 volts. (2) The anode spot begins to move in a rapid random manner. (3) Audio and radio frequency oscillations are produced by the arc. (4) There is a darkening of the anode, indicating a lower anode temperature. A study of the hissing arc at atmospheric pressure in air, Nitrogen, Oxygen, Argon, Helium and Carbon Dioxide showed that these characteristic changes occurred only in air, Nitrogen, and Oxygen. The abrupt drop in voltage was shown to be related to the mechanism of supplying positive ions in the vicinity of the anode. The magnitude of the voltage drop is believed to be dependent upon the ionization potential of the chemical products formed in the arc. Both types of oscillations were independent of circuit parameters. The low frequency random oscillations of voltage current and sound were produced by the rapid motion of the anode spot. The radio frequency oscillations occurred in narrow bands at 1, 2, 4, 8, 16, 32, and 64 mc. It was shown that these oscillations might be caused by motions of positive ions in the arc plasma.

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ABSTRACTS 32, 33, 34

PAPERS GIVEN AT THE CONFERENCE OF GASEOUS ELECTRONS,
October, 1950, Sponsored by the American Physical
Society, Division of Electron Physics

The following three abstracts were taken from the conference program:

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LOW FREQUENCY SELF-GENERATED OSCILLATIONS IN THE DIRECT CURRENT CARBON ARCS

By T.B. Jones and B. H. List, Johns Hopkins University
(This work was supported by the Office of Naval Research)
Source: "Electrical Engineering," Vol. 72, Pages 612-616, July, 1953

Two types of oscillations have been discovered in direct current carbon arcs in air. One type, consisting of low audio frequency oscillations of 100 to 400 cycles per second, occur in a narrow current range just below the hissing point. Simultaneous oscillations of voltage, current, light and sound have been observed. High speed motion pictures show that these so-called "quiet" oscillations are the result of the modification of the anode spot around the anode crater circumference. The voltage oscillations are the result of the varying arc length as the spot rotates. Their frequency was found to be dependent on the medium ? size and separation of the electrodes and the arc current.

The second type of oscillations begins as soon as the arc enters the hissing stage. They occur in the radio frequency spectrum in definite bands up to at least 90 mc. The frequency in this case appears to be independent of electrode material, arc length or current, but dependent upon the atmosphere. Both types of oscillation are independent of any external inductance or capacitance in the arc circuit. Oscillations are present in materials other than carbon, e.g., tungston, aluminum and copper. However, "quiet" oscillations in these materials are very unstable due to melting of electrodes.

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THE EFFECT OF HEAT ON A FREQUENCY OF THE RADIO FREQUENCY OSCILLATIONS IN ALTERNATING CURRENT SILENT DISCHARGES

By S. R. Khastgir and C. M. Srivastava

A letter in "Current Science," Vol. 21, Page 307, 1952

It was found that the frequency of certain radio frequency oscillations (approximately 4 mc) in ionized discharges through H_2, Cl_2 and I_2 decreased with increase of discharge tube temperature. The latter was approximately 30 to 50 degrees centigrade.

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ARGON LOW VOLTAGE ARC CHARACTERISTICS

By H. Kniepkamp
"Phys. Zeits.," Vol. 37, Page 824, (In German), 1936

The low voltage arc in Argon is investigated for hot cathodes, particularly Oxide cathodes, with respect to the form of the current-potential characteristic. The characteristics of the non-oscillating low voltage arc in Argon has one part below the lowest excitation potential of Argon exhibiting to a slight extent dependence of the arc potential on the current; and a steep part in the region ranging from smaller currents to a little above the ionization potential. With further decrease of the current the arc potential rises into the region of the oscillating arc. The characteristic of the non-oscillating arc is practically independent of the magnitude of the gas pressure in the discharge tube and of the distance between the anode and the cathode in the region of technical interest. A variation of cathode temperature effects a definite displacement of the characteristic. The oscillations in the oscillating arc consist of time fluctuations of the space charge structure. The potential oscillations are limited in amplitude by the ionization potential and the low voltage arc potential. The frequency is dependent in a characteristic manner on the mean direct current through the discharge tube.

5

DETERMINATION OF ELECTRON TEMPERATURE IN GAS DISCHARGES BY NOISE MEASUREMENT

By K. S. Knol
"Phillips Research Reports," Vol. 26, #4, Pages 288 and 302
August, 1951

The article consists of a discussion of noise production in the micro-wave region by gas discharges in Xenon, Argon, Neon and Helium. The temperature of the above gases was measured as a function of gas pressure and tube current. They concluded that noise power is a function of temperature, the formula being:

$$(\lambda_{RES})T_{E} \equiv 0.253$$

The above formula they derived for the relationship between the longest resonant wave-length of a gas and the electron temperature. They suggested using this formula as a method for measuring electron temperature. The article also contained bibliography which I did not copy, since it deals mainly with micro-wave oscillations.

A STUDY OF IRREGULAR ELECTRON OSCILLATIONS IN AN ELECTRODELESS HIGH FREQUENCY DISCHARGE UNDER THE INFLUENCE OF A CONSTANT MAGNETIC FIELD

By B. Koch and H. Neuert

"Ann. Phys., Lpz.," Vol. 7, #1 & 2, Pages 97 through 102, (In German)
1950

Describes the generation and detection of electron oscillations for pressures of the order of 10^{-3} mm as a function of the magnetic field and of the electrical parameters of the discharges. Frequencies studied were of the order of 20 mc. A brief discussion of the relations between these oscillations and plasma oscillations produced in the absence of magnetic fields is given.

ELECTRIC OSCILLATIONS IN IONIZED GASES - SOME REMARKS ON THEIR PRESENT THEORIES

By J. Kunz, University of Illinois
This paper presented to American Physical Society at Chicago
Meeting November 27 through 28, 1931
Abstract from "Physics Review," Vol. 39, Page 183, 1932

"The theory of Sir J. J. Thomson, I. Langmuir and L. Tonks can be applied also to a gas containing mostly positive ions and finally to a gas containing positive and negative ions. Let E be the electric force acting in the gas, $E = E_0 \cos wt$, i be the current, $i = Neu$, where u is the velocity of the electrons,

$u = [Ee/\omega m] \sin wt$, THEN

$i = N \left(\frac{E_0 e^2}{\omega m}\right) \sin wt = I \sin wt$

where amplitude of alternating current is $I = \frac{N E_0 e^2}{\omega m}$ THEN $\omega = \frac{4 \pi I}{E_0}$.

For a constant electric force E we see that frequency is proportional to alternating current, I. In this paper I hope to offer further considerations regarding the coupling of these oscillations with external circuits.

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OBSERVATIONS ON RADIO FREQUENCY OSCILLATIONS IN LOW PRESSURE ELECTRIC DISCHARGES

By N. R. Labrum and E. K. Bigg

Physical Society of London Proceedings, Vol. A65, Page 356, 1952

The authors previously reviewed the recent work in the field citing work showing the possibility of an initial small disturbance growing by the conversion of some of the kinetic energy of the ions into high frequency energy. In conditions favorable to the processes of this kind, sustained plasma oscillations are evidently possible. The authors describe two types of oscillations detected. One in the form of noise centered about a band at 200 mc. The other, coherent oscillations at frequencies below 1 mc. They discuss and show diagrams of several types of gas discharge tubes with built in probes used for their work. They made some measurements of the radiations by these tubes and the associated circuit and showed that the energy of radiation was too large to be accounted for by the known electron temperature. The tubes were air-filled. All oscillation frequencies were found to vary inversely with the pressure. They found a coherent oscillation at a frequency around 200 kc occurring over a wide range of discharge currents with pressure less than 150 microns, in either hot or cold cathode tubes. It was distinct from random noise, often also present in the same band. He found the oscillations independent of the external circuit. The amplitude was very variable. There were several indications of a connection between these low frequency oscillations and striations of the positive column. The two phenomena were usually present at the same time. The amplitude of the oscillations developed between the anode and the cathode was correlated with the presence of striation nearest the anode and the radio frequency voltage produced on a probe was greatest when it was situated in the luminous part of a striation. A signal with frequency variable between 200 kc and 800 kc was applied to a probe near the cathode end of the tube. It was found that the spacing of the striation varied considerably with the frequency of this signal, decreasing as the frequency increased. The authors try to explain the origins of the high intensity noise present at the lower frequencies. They suggest it is possibly due to a contraction of the discharge column accompanied by a reversal of the potential gradiant, but they say this hypothesis is open to serious objection. The suggestion is made that the relationship between the striations and the coherent oscillations may mean that the striations are the visible effect of a standing wave set up by the oscillations. They show calculations on the wave velocities in relation to the electron temperature as given by Langmuir (1928). They found that the distance between the striations is approximately equal to 1/4 the wave velocities of the oscillations.

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STUDIES OF ELECTRICAL DISCHARGES IN GASES AT LOW PRESSURE
By Dr. I. Langmuir and H. Mott-Smith
"General Electric Review," 1924

A series of five articles appeared in the "General Electric Review" in 1924 and they were continued into the 1925 issues. Article one discusses probes and connectors. No mention of oscillations. Article two discusses sheaths and other general phenomena in gas discharges as discovered by probes. No mention of oscillation. Article three presents the theories, data and graphs for use with probes that they had designed. Article four summarizes the first three articles and discusses random and draft currents (no mention of oscillations), theories, formulae and data. Article five discusses spherical probes and effects of magnetic fields on discharges.

Nothing in the series of articles mentioned oscillations. It generally reported work that was done and theories developed in the General Electric Research Laboratory. There was no bibliography.

OSCILLATIONS AND IONIZED GASES
By Irving Langmuir
Proceedings of the National Academy of Sciences,
Vol. 14, Page 627, 1928.

This is generally a discussion of high frequency oscillations which Dr. Langmuir attributes to electrons, but he cites work by Pardue, Webb and Tonks in detecting oscillations in the plasma region under low pressures of air with frequencies from 1 to 240 kc. He suggests that these oscillations would vibrate with the frequency: $\nu = \sqrt{\frac{ec}{m\pi}} = 8980\, n^{1/2}$

He cites work of Tonks that shows that when the wave length of the ionic oscillations becomes small compared to $2\pi\lambda_D$ (λ_D is a constant given by $6.92 \times \sqrt{(T/N)}$cm where T is the electron temperature), the frequency approaches a limiting maximum value given by $8980 \times \sqrt{N}$. On the other hand, when wavelength becomes large compared to $2\pi\lambda_D$ the wave velocity approaches a limiting maximum given by $3.9 \times 10^5 \times \sqrt{\frac{(T_e \times M_e)}{N_p}}$ where M_e is the mass of the electron and M_p is the mass of the ions and T_e is the electron temperature.

ON THE THEORY OF THE DOUBLE REFRACTION OF CENTIMETER WAVES IN AN IONIZED GAS UNDER THE INFLUENCE OF A CONSTANT MAGNETIC FIELD (IONOSPHERE)

By H. Lassen

"Ann. d. Phys.," Vol. 1, Page 415, (In German), 1947

Relations are given between formulae established by different authors. The form of the oscillations of the electric and magnetic fields and of the electronic orbits is also investigated.

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THE EXCITATION OF PLASMA OSCILLATIONS

By Duncan H. Looney and Sanborn C. Brown, M.I.T.
Printed in "Physical Review," Vol. 93, #5, Page 965
March 1, 1954

(This work has been supported in part by the U. S. Army Signal Corps, the Air and Material Command, and the U. S. Office of Naval Research).

A beam of high energy electrons injected into the plasma of a DC discharge from an auxiliary electron gun excited oscillations in the plasma at the plasma electron oscillation frequency $Wp^2 = ne^2/me_o$ on the order of 800 mc. A movable probe showed the existence of standing wave patterns of the oscillatory energy in the region of the plasma in and around the electron beam. Nodes of the patterns coinsided with the electrodes which limited the region of the plasma traversed by the beam. The standing wave patterns were independent of the frequency of the oscillation. At any particular frequency the standing wave pattern was determined by the thickness of the ion sheaths on the bounding electrodes. The mechanism of the energy transfer from the electron beam to the oscillation of the plasma electrons was established as a velocity modulation process by the detailed behavior of the frequency of oscillation and the transitions in the standing wave patterns as the sheath thickness was varied. Experimental attempts to produce plasma oscillations as predicted by Bohm and Gross proved to be fruitless.

TERMS: Wp = Radian frequency plasma electron oscillation.
n = Electron density.
m = Mass of an electron.
E_o = Permativity of free space.

REFERENCES:

G. Wehner, "Journal of Applied Physics," Vol. 22, Page 761, 1951.

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THEORY OF GASEOUS CONDUCTION AND ELECTRONS
By T. A. Maxfield and R. Ralph Benedict

In Chapter 10 the book deals with glow discharges in sections 4 through 7. It discusses a positive glow column which becomes striated, and states that they are probably closely connected with the plasma oscillations. Striations depend on pressure, temperature, current density, diameter of tube, and nature of gas. With the exception of Hydrogen, pure gases do not striate. Experiments have never removed the striation from Hydrogen regardless of how pure the gas was.

It also discusses the only workable method of measuring the potential density as developed by Langmuir and Mott-Smith in 1923.

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"Physical Review," Vol. 28, Page 727, 1928.

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Merrill and Webb
"Physical Review," Vol. 55, Page 1191, 1939

Discusses stable discharges that appear periodically in narrow bands and their relationship to electron scattering. Their results agree with Langmuir's formula, but all oscillations were of a high frequency (10^9 cps). The one point of interest might be that they graphed the positions of these bands in relationship to the cathode (usually 4 to 8 mm), and also presented a chart of the data relating pressure (3 to 7 microns) arc drop, space potential (measured from anode) primary beam energy, electron velocity, electron concentration, and oscillating frequency calculated and measured. Also states in last paragraph of article that at a high pressure and current it is suggested that a very violent oscillatory disturbance exists in a narrow layer near cathode.

No bibliography.

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ORIGIN OF STRIATIONS IN DISCHARGE

A letter by G. D. Morgan, Department of Physics,
University Corporation of North Whales, Bangar
to "Nature" (London), Vol. 172, Page 542
September 19, 1953

If an electrical wave of sufficiently short length is propogated through the plasma and a standing wave set up, then striations may be accounted for by the positions of the nodes and the antinodes. If the electron density changes, the striations will move. Thus, the striations have their origin in the plasma itself. This supports the view that they may be due to a standing wave system associated with oscillations of the charges constituting the plasma.

REFERENCE:

G. O. Gale, "American Journal of Physics," Vol. 21, #389, 1953.

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ON THE PLASMA-LIKE OSCILLATION

By T. Nishimaya
Osaka University
A letter in Progress of Theoretical Physics, Vol. 6, Page 1025, 1951

A brief note on the theoretical studies of plasma oscillation frequencies, and related to earlier work by the author and by Pines and Bohm.

REFERENCES:

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T. Nishimaya, "Progress of Theoretical Physics," Vol. 6, Page 366, (1951).

S. Tomumaga, "Progress of Theoretical Physics," Vol. 5, Page 544, (1950).

IONIC OSCILLATIONS IN THE GLOW DISCHARGE
By L. A. Pardue and J. S. Webb
"Physical Review", Vol. 32, Page 946, 1928.

Pardue and Webb conducted experiments trying to correlate the phenomena of moving straie and ionic oscillations in a striated discharge. They studied the dependence of the oscillations upon pressure voltage and violent current vibrations. The discharge tube was the hot cathode type, three centemeters in diameter and 26 cm long. They ascribe the oscillations to "a changing potential gradient within the tube caused by a shifting space charge concentration." They observed frequencies from a few hundred cycles per second to 150 kc. They say that the circuit parameters do not effect the oscillations. They cite works by Tonks, Langmuir and Mott-Smith which states that the electron oscillations are due to the concentration of electrons being altered in some way. In trying to return to its original value, a concentration may cause compression waves whose frequency is independent of wave length to occur. ? They say that the ionic oscillations apparently follow Langmuir's law with the discrepancy due to the much higher temperature of the electrons. When electron temperature becomes insufficient, they say the law holds exactly for ionic oscillations. Their observations indicate that oscillations begin at the instant diffusion between adjacent straie begins and continue until all forms of striation disappear and the tube is filled with a uniform glow. At this point oscillations become unstable and subside with further increase in pressure. They show graphs which indicate that frequency is proportional to $\sqrt{N}$ and the frequency is equal to a maximum pressure when P is equal to $\frac{X}{CV}$ where X is equal to the field strength and

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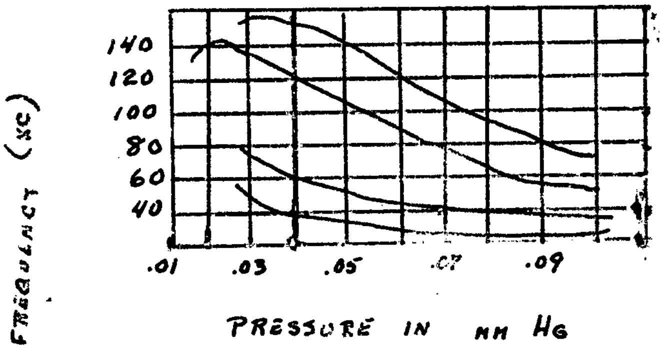
C is equal to the reciprocal of the electron mean free path and V is equal to the ionization potential. They found at least four frequencies at any given pressure. The value of the frequencies suggests the existence of two independent fundamental frequencies and their harmonics since they are in the ratio 3 to 4 to 6 to 8, but they may be harmonics of an unobserved fundamental frequency. They show graphs to indicate the relationships between anode potential and frequency; and filament current and frequency. "The principal of electronic emission from hot bodies as expressed by Richardson's equations governs the number of ionizing electrons which in turn governs the frequency equation."

"If plates are attached to the tube, one finds a slightly different condition. At the lower filament temperatures when the discharge fills the tube the oscillations are audible and can be heard as mechanical vibrations of the tube at certain conditions. At the higher temperatures the oscillations become inaudible but can be detected as beats. These occur even when straie are present. It is possible that the plates affect the potential gradient within the tube."



RELATION BETWEEN FREQUENCY AND PRESSURE.

ANODE POTENTIAL = 640 v
FILAMENT CURRENT = 6.3 AMP

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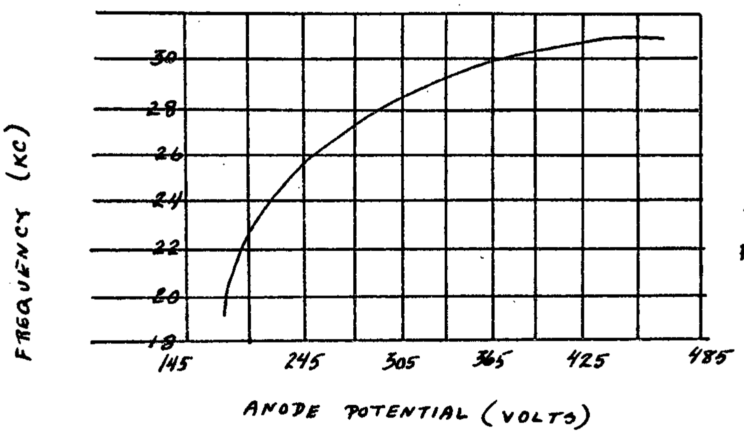
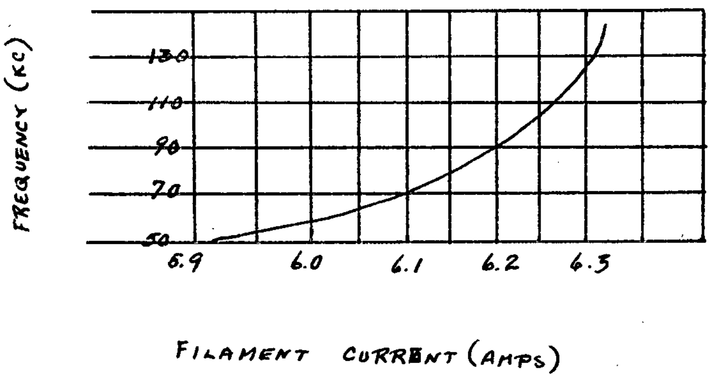


RELATION BETWEEN FREQUENCY
AND ANODE POTENTIAL

PRESSURE = .01 MM HG
FILAMENT CURRENT = 1.4 AMP



RELATION BETWEEN FREQUENCY
AND FILAMENT CURRENT

PRESSURE = 0.01 MM HG
ANODE POTENTIAL = 640v

72

ON THE STRIATIONS OF THE POSITIVE COLUMN IN THE GLOW DISCHARGE OF HYDROGEN

By H.H. Paul

"Zeits f. Phys.," Vol. 97, Page 330, (In German), 1935

With the discharge tube containing two probes, one of which is movable along the axis, current-potential characteristics are taken at various positions in the striations of a Hydrogen discharge. In the middle of the striations, "S" characteristics are found corresponding to two groups of electrons at different speeds.

Experiments with a wall probe and on the appearance of paired striations are described. On the basis of the probe measurements a theory of the striation mechanism in the axial region of the discharge is developed whose essential feature is the assumption of a kind of electrical double layer at the head of a striation originating from the presence of negative ions. The theory is extended to the wall region and the formation of space charges is discussed. It is shown that the various forms of striations can be explained by a varying "ion-mantle" effect. It is also shown that the assumed simple connection between striation form and tranverse gradient does not exist.

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K. G. Emeleus and R. H. Sloan, "Philosophical Magazine," Vol. 14, Page 355, (1932).

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65

A NOTE ON PLASMA OSCILLATIONS

By J. R. Pierce, Bell Telephone Laboratories

"Physical Review," Vol. 76, Page 565, 1949

A letter to the editor in which the author notes that phenomena similar to the plasma oscillations in gas discharge tubes have been discovered in vacuum tubes and were explained by a similar analysis. "A case of a finite beam filling a tube and confined by a magnetic field was also analyzed. In such a case the electron beam can excite not only plasma oscillations of the ions, but oscillations of the ions in the magnetic field as well. These oscillations usually have a lower frequency than plasma oscillations, and they were suggested as an explanation for lower frequency fluctuation which had been observed.

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D. Bohm and E. P. Gross, "Physical Review," Vol. 75, Pages 1851 and 1864 (1949).

J. R. Pierce, "Journal of Applied Physics," Vol. 19, Page 231, 1948.

potential distribution in the Faraday dark space is parabolic.

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Tonks and Langmuir, "Physical Review," Vol. 33, Page 195, 1929.

THE ROLE OF PLASMA OSCILLATIONS IN THE DISTRIBUTION OF ELECTRON INTER-ACTIONS

By David Pines and David Bohm, Princeton University
"Physical Review," Vol. 79, Page 232, 1950
Verbatim abstract of a paper presented to the 299th meeting
of the American Physical Society, April 27-29, 1950

"Because of the long range of the coulomb force the usual 1 particle formulations are for many purposes a poor description of the inter-actions in a collection of electrons. As a first step in the development of a new description, we investigate classically the electron inter-actions in the plasma and show that a transition from a single particle to a collective description of the electron motion in terms of plasma oscillations can be obtained by a suitable series of canonical transformations. The complete Hamiltonian for a collection of inter-acting charges is re-expressed as the sum of three terms. One involves the collective field co-ordinates which act like waves in an enclosure and which express the degree of excitation of plasma oscillations. The other terms correspond to the kinetic energy of free electrons and to the residual inter-particle forces which are found to be approximately screened coulomb forces of a very short range. This result shows that the effective collision cross section between electrons in a dense assembly is much less than the calculated on the basis of the individual particle approximation. A quantum-mechanical theory of plasma oscillations is now under investigation and applications to the inter-actions between electrons in a metal and to super-conductivity will be discussed."

74

OSCILLATION PHENOMENA IN GAS DISCHARGES OF DIFFERENT KINDS

By F. Schroeter

"Zeits f. Techn. Phys.," Vol. 6, Page 404, (In German), 1925

A general account of the work on the subject, the various experimental arrangements and results are shown in diagramatical form.

REFERENCES:

Geffcken, "Phys. Zeits.," Vol. 26, Page 241, (1925).

Taylor and Clarkson, "Proceedings of the Physical Society of London," Vol. 36, Page 269, (1924).

Shroeter and Viewey, "Archiv. f. Elektrotechnik," Vol. 12, Page 358, (1923).

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THE SPHERICAL ELECTROMAGNETIC PROPER OSCILLATION OF SPACES WHICH CONTAIN PLASMA

By W. O. Schumann, "Z. Naturforsch," 4A, Pages 486 to 491, (In German)
October, 1949

For the cases of a spherical enclosure filled with plasma, of a dielectric and a conducting sphere in an atmosphere of plasma, and of a sphere of plasma in air, this paper examines the effect of the frequency dependent permittivity on the oscillations, and the extent to which the possibility of a negative permittivity makes new types of oscillation possible.

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79

ONE ELECTRODE HIGH FREQUENCY DISCHARGE OF PRESSURES FROM A FEW MM Hg TO ATMOSPHERE AT FREQUENCIES OF 31.7 MC

By G. S. Solmtsev, M. Z. Khokhlov and E. A. Rodena

"Zh. Eksper. Teor. Fiz.," Vol. 22, Page 406 (In Russian), 1952

A continuous flow water calorimeter was used to measure the power developed as a function of pressure for air, N and A Atmospheres. The critical electrode potentials and the frequencies of secondary oscillation observed in the range 3 to 100 kc were measured. The place of the "torch" discharge in relation to other types of high frequency discharges was established.

HOT CATHODE ARCS AND CESIUM VAPOR

By Richard K. Steinberg,
Research Laboratory of Electronics, MIT.
Journal of Applied Physics, Vol. 21, #10, Pages 1028 to 1035
October - 1950

In an effort to explain how positive ions are produced in a gas, Steinberg included research dealing with ionic oscillations. He found that "there was a rather limited range of arc currents under which reliable probe measurements could be made. Oscillations with frequencies in the range from 1,000 to 10,000 cycles per second would occur in the arc when the arc current was reduced below a certain critical minimum value. This minimum was a function of vapor pressure (cesium temperature) and was lower at the higher pressures. The amplitudes of these oscillations depended upon several parameters, including vapor pressure, cathode temperature, and arc current, but they usually had an amplitude of the order of one volt. The oscillations could not be eliminated by circuit modifications."

No high frequency oscillations were observed. Equipment capable of detecting oscillations up to 10,000 mc per second was employed, yet nothing except the previously mentioned low frequency oscillations was detected.

10

MOVING STRIATIONS AND ANODE SPOTS IN NEON TUBES

By T. Takamine and T. Suga and A. Yanagihara, "Science Papers
of the Institute of Physical and Chemical Research, Tokio,"
Vol. 20, Page 63, 1933 (#403)

The article discusses experiments done in attempting to correlate moving striations and the variance of the intensity of the anode spots. They used a tube 25 mm in diameter and 80 cm long. They recorded on photographic plates (of which two are shown in the article) the striations and anode spots, and a time-pulse used for measurement. The tube pressure was about 10 mm of a mercury and a current of about 410 ma. They noticed electrical oscillations existed, but were not sure that these were not caused by the dc generator. The article shows two plates on which these oscillations were recorded. The authors reached the general conclusion that the electrical pulsations do not directly correspond to the moving striations and the anode spots. However, in concluding, the authors decided that there was definitely some correlation between the oscillation striations and anode spots, and mentioned the related works, which are listed in the bibliography.

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- "Nature," Vol. 115, Page 385, 1926, Vol. 126, Page 470, 1930.
- "Journal of the Franklin Institute," Vol. 204, Page 707, 1927.

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Thompson and Duffendack, "Physical Review," Vol. 23, Page 1093, 1929.

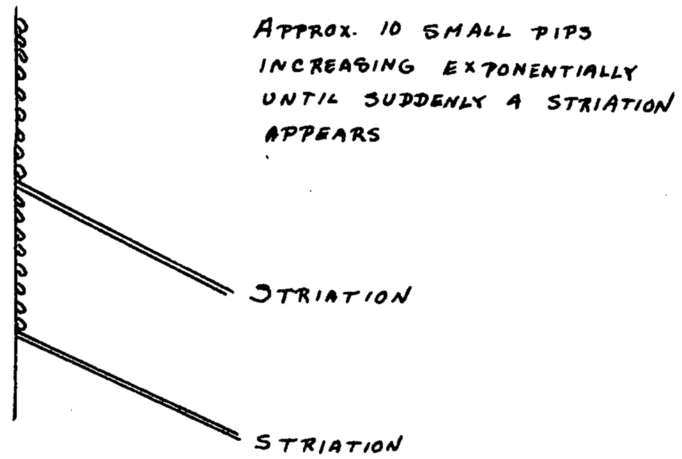
11

THE INFLUENCE OF A MAGNETIC FIELD ON ANODE SPOTS

By T. Takamine, T. Suga and A. Yanagihara
"Science Papers of the Institute of Physical and Chemical Research,"
Tokio, #425, Vol. 21, Page 26, 1933

This article followed the one of the last abstract.

The authors, in continuing their research, investigated the influence of the magnetic field on the anode spots. The main part deals with a change in light intensity caused by a longitudenal magnetic field. The last half of the article is of more direct interest. The authors took high-speed pictures of the anode spots by means of falling plate photography. They published one of the pictures (magnified four times). The picture showed striations leaving the anode every 1/1160 of a second. They stated that there may be an interference between the moving striae and also some kind of disturbance coming against them from the cathode.



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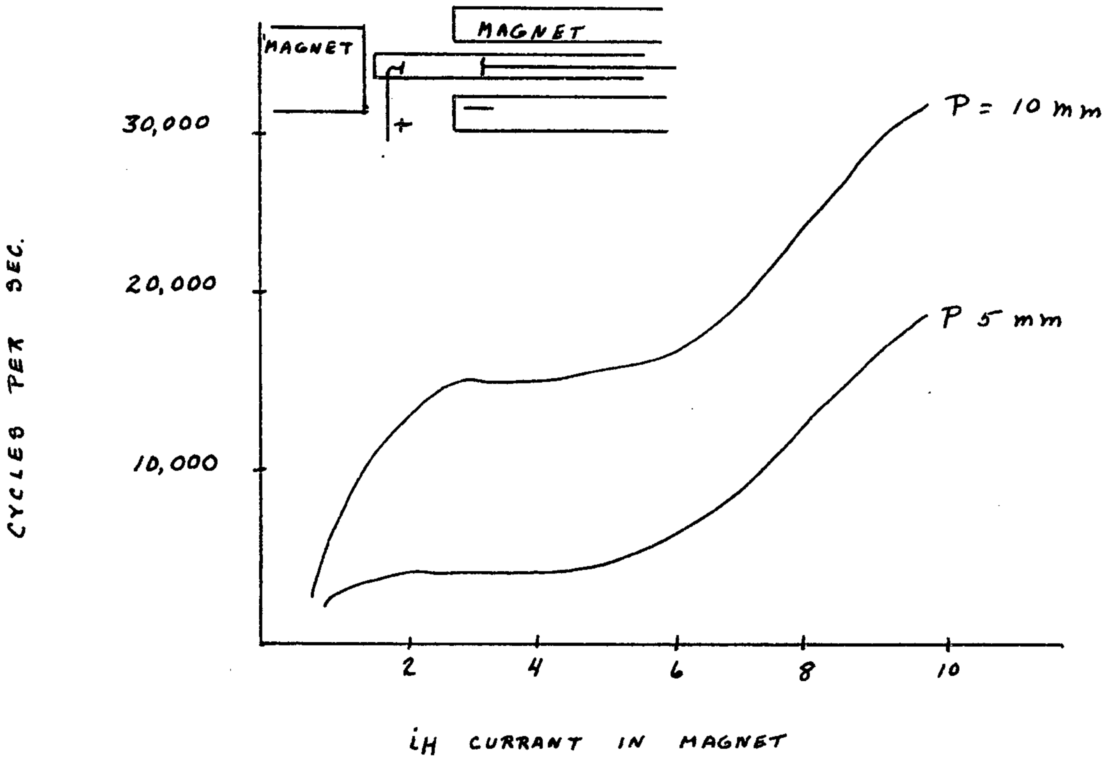
THE INFLUENCE OF A MAGNETIC FIELD ON A GLOW DISCHARGE

By T. Takamine, T. Suga and A. Yanagihara
"Science Papers of the Institute of Physical and Chemical Research,"
Tokio, #454, Vol. 22, Page 70

This article describes in more accurate detail the further experimental work of the authors. The main part of the article showed graphs that related the increase in the magnetic field to the increase in light intensity of discharge. They stated that the effect in general of an increasing field was the same as the effect of an increase in pressure. On page 85 the following graph shows variation of the frequency of anode spots with increasing magnetic field. The authors stated the graph may not be quite accurate because of the occurrance of two spots during the experiment.



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75

OSCILLATIONS DUE TO CORONA DISCHARGE ON WIRES

By R. E. Tarpley, J. T. Tykocener and E. B. Paine
University of Illinois

Washington, D. C. Meeting of the American Physical Society,
April 30, May 1, 2, 1931
Abstract #49 from "Physical Review," Vol. 37, Page 1589 (1931)

An experimental arrangement was used in which the electric constants of the circuit containing a corona tube corresponded to much higher frequencies than could be recorded by a reflecting mirror oscillograph. By amplifying the corona currents 300 to 3,000 times it was found with this oscillograph, which was insensitive to circuit oscillations, that corona discharges produce a new type of oscillations whose chief characteristics are as follows:

The frequency (2,000 to 10,000 cycles per second) is independent of circuit constants; the amplitude decreases with increasing applied potentials; the wave has a complex form of distinct ripples super-imposed on the charging alternating current or upon the steady part of the implied direct current. The wave form depends on the pressure and the nature of the gas, and of the polarity of the wire. The wave form varies for different gases, but the character of the oscillations remains the same for air, CO_2 and N_2. The wave form becomes simpler with decreasing gas pressure, especially with CO_2. At high pressures the oscillations appear super-imposed on the corona humps of the charging current at moments when the wire is the cathode, but the lower pressure oscillations appear only when the wire is

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the anode. No oscillations are obtained with oxidized or corroded wire.

REFERENCES:

Abstract #52, "Physical Review," Vol. 39, Page 189, (1932).

Abstract #44, "Physical Review," Vol. 42, Page 912, (1932).

OSCILLATIONS IN IONIZED GASES

By Louis Tonks and Irving Langmuir
"Physical Review," Vol. 33, Page 195
1929

A simple theory of electric and ionic oscillations in an ionized gas has been developed. The electron oscillations are so rapid (ca 10^9 cycles) that the heavier positive ions are unaffected. They have a natural frequency $\nu_e = \left(\frac{ne^2}{\pi m}\right)^{1/2}$ and, except for secondary factors, do not transmit energy. The ionic oscillations are so slow (below 1.5 mc) that the electron density has its equilibrium value at all times. They vary in type according to their wave length. The oscillations of shorter wave length are similar to the electron vibrations approaching the natural frequency $\nu_p = \nu_e \left(\frac{m_e}{m_p}\right)^{1/2}$ as upper limit. The oscillations of longer wave length are similar to sound waves, the velocity approaching the value $v = \left(kT_e/m_p\right)^{1/2}$. The transition occurs roughly (i.e., to 5% of limiting values) within a 10-fold wave length range centering around $2\sqrt{2}\pi\ \lambda_d$, λ_d being the "Debye distance." While the theory offers no explanation of the cause of the observed oscillations, the frequency range of the most rapid oscillations, namely from 300 to 1,000 mc, agrees with that predicted for the oscillations of the ultimate electrons. Another observed frequency of 50 to 60 mc may correspond to oscillations of the beam electrons. Frequencies from 1.5 mc down can be attributed to positive ion oscillations. The correlation between theory and observed oscillations is to be considered tentative until simpler experimental conditions can be attained.

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IONIZATION PHENOMENA IN GASES

By A. Von Engle and G. Francis
"Nature" (London), Vol. 172, Pages 798 and 799
October 31, 1933

A summary of papers presented at the conference held in Oxford in July, 1953 sponsored by the Physical Society, the Institute of Physics, and the. Electrical Research Association.

OF SPECIAL INTEREST

"S. C. Brown (M.I.T.), injecting electrons into a low pressure mercury plasma, observed plasma oscillations only when ion sheaths were present around the electrodes. Their frequency depended upon the density of the electrons which oscillate in certain standing wave forms. From the variation of the frequency with the thickness of the sheath, it follows that a transit-time process causes these oscillations.

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OSCILLATIONS IN DISCHARGE AS A SOURCE OF TRAVELING LAYERS

By A. A. Zaitsev

"Dokl, Acad. Nauk S.S.S.R.," Vol. 79, Page 779, (In Russian), 1951

Traveling layers are explained in terms of oscillating processes in pure neon, Ne and argon with molecular admixtures in air.

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CONDITIONS FOR NATURAL OSCILLATIONS AND MOVEMENT OF LAYERS IN A (GAS) DISCHARGE

By A. A. Zaitsev

"Dokl. Akad. Nauk S.S.S.R.," Vol. 81, Page 41 (In Russian), 1952

These were investigated in neon-filled tubes with cold electrodes across which a variable potential could be super-imposed upon a normal constant one. Two kinds of natural oscillations (no external imposed variable potential) are distinguished; "hard," accompanied by a sudden increase in the average current passed by a tube, a change in the anode potential difference with the potential gradient down the positive column unchanged, and hysteresis; and "soft," characteristic of the cathode parts of the discharge, and fitting in gradually from quite small amplitudes. Natural oscillations can be "synchronized" to forced oscillations if the difference of frequency between them $\Delta \nu$ is small; here quasi stationary gas layers are formed. If $\Delta \nu$ is somewhat larger, beads are formed and there is a movement of the gas layer at the beat frequency. Various subsidiary phenomena are described but no attempt is made to account for any of them.

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A STRIATED DISCHARGE IN HYDROGEN AND HELIUM

By John Zeleny, Illinois University
"New York Meeting of the American Physical Society,"
February 26 and 27, 1927
Abstract #16 from "Physical Review," Vol. 29, Page 609
1927

The striated discharge between cold electrodes in H_2 exhibits the remarkable property that the distance between the striae for constant current in the tube passes through a sharp minimum as the pressure is increased and at a higher pressure passes through a maximum. The pressures at which these reversals occur and the magnitudes of the changes are dependent on the current through the tube and on some other factors. At pressures near that at which the minimum stria distance is observed, the Faraday dark space, which covers about 2 cm of length in most of the pressure region indicated, contracts and one or more striae leave the head of the positive column and move up to and surround the cathode. The stria distance in Helium was measured between pressures of 2.7 mm and 9.7 mm of a mercury, and for these two pressures was found to be 11.3 mm and 6.0 mm respectively, with a 6 ma current. The measurements made in Argon and air under the same conditions are also given, but the range of pressures in which striae was observed was much more limited.

81

CONNECTION BETWEEN THE MODES OF VIBRATION OF A PLASMA

By A. Schuelter

"Ann. d. Phys.," Vol. 10, Page 418 (In German), 1952

REFERENCE:

I. Langmuir, "Proceedings of the National Academy of Science," Vol. 14, Page 627, (1928).

H. Alfven, "Ark. Mat. Astr. Och Fysik.," Vol. 29-B, (1942).

PLASMA IN A MAGNETIC FIELD

By A. Schuelter

"Ann. d. Phys.," Vol. 10, Page 422 (In German), 1952

A mathematical treatment of the problem of inter-action of ionized matter (ions and electrons) in magnetic fields. These papers discussed hydrodynamic motions of plasma particles under the influence of magnetic field.

REFERENCE:

H. Alfven, "Ark. Mat. Astr. Och Fysik," Vol. 27-A, (1940).

R. Rompe and Steenbeck, "Erg. Ex. Naturwiss.," Vol. 18, Page 257, (1939).

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H. Fetz, "Ann. d. Phys.," Vol. 40, Page 579, (1941).

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Aug. 19, 1952 T. E. FAIRBAIRN **2,607,897**

OSCILLATOR

Filed June 13, 1946 2 SHEETS—SHEET 1

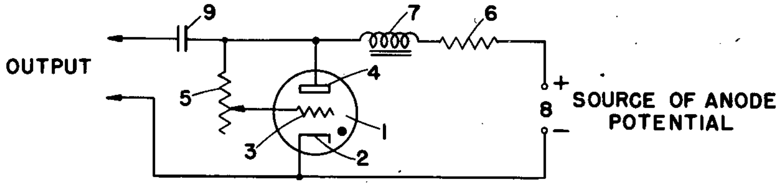

FIG. 1

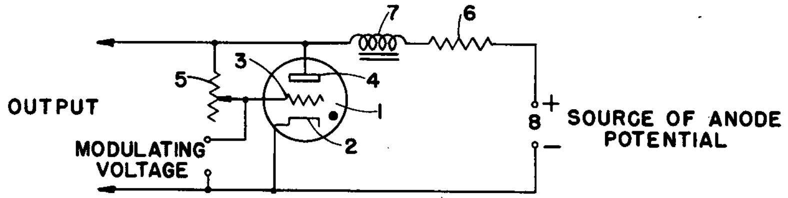

FIG. 2

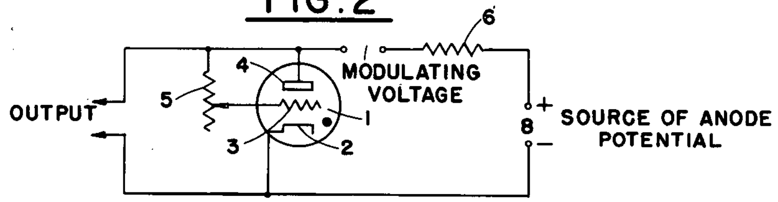

FIG. 3

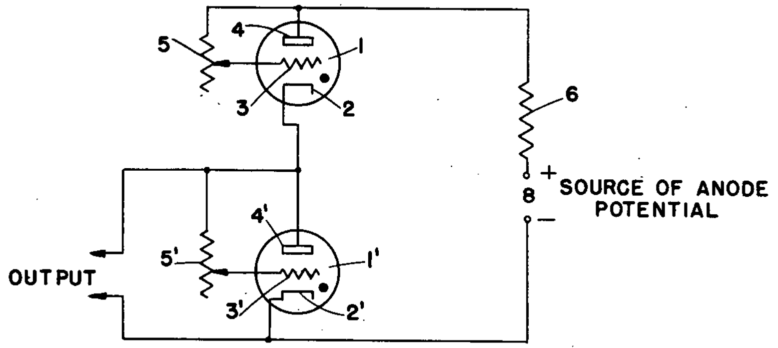

FIG. 4

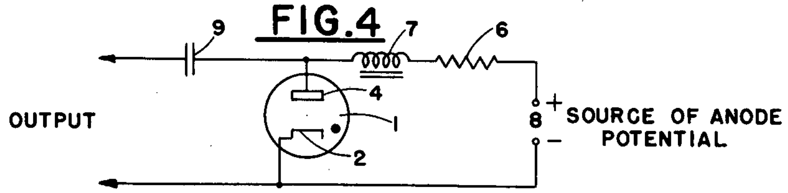

FIG. 5

INVENTOR.
THOMAS E. FAIRBAIRN

BY M.A. Hayes

Attorney

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Aug. 19, 1952 T. E. FAIRBAIRN **2,607,897**

OSCILLATOR

Filed June 13, 1946 2 SHEETS—SHEET 2

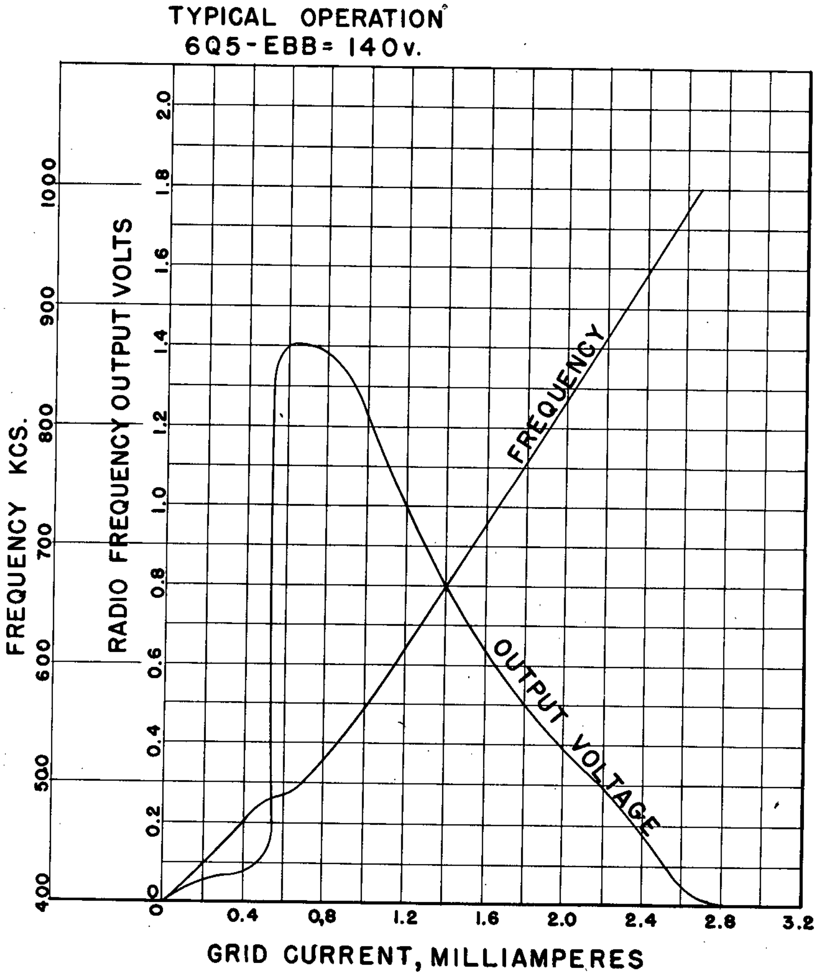

FIG. 6

INVENTOR.
THOMAS E. FAIRBAIRN
BY M. A. Hayes
Attorney

Patented Aug. 19, 1952 **2,607,897**

UNITED STATES PATENT OFFICE

2,607,897

OSCILLATOR

Thomas E. Fairbairn, Toledo, Ohio

Application June 13, 1946, Serial No. 676,390

13 Claims. (Cl. 250—36)

(Granted under the act of March 3, 1883, as amended April 30, 1928; 370 O. G. 757)

This invention relates to improvements in high frequency oscillators, and has special reference to gaseous tube oscillators.

One of the objects of this invention is to provide a stable high frequency oscillator, the frequency and voltage output of which are constant for wide variations in load impedance.

Another object of the invention is to provide an oscillator with the characteristics mentioned above which in addition is capable of being modulated by any alternating voltage.

A feature of my invention is extreme simplicity of construction.

In prior art devices employing gaseous discharge tubes, it has been customary to produce oscillations therein which are evolved by ionization and deionization of the gas, the frequency of the output of the tube being determined by a tuned tank circuit connected to the output of the tube or by the charging time of an external condenser as in a relaxation oscillator. The upper limit of frequency which can be produced by a gaseous tube oscillator generally does not exceed 50 kilocycles as the ionization and deionization of the gas is an off-on process which has a definite minimum time limit and cannot be reduced because of the presence of stray electrons even during the period of deionization.

I have found that the ionized gas in a discharge tube normally oscillates within the tube at a frequency between 500 and 1,500 kilocycles at low orders of ionization, the frequency being dependent on certain of the external circuit constants. This effect is somewhat akin to the inherent oscillations in a resonating crystal but with the added advantage of a much higher output. I employ this effect to produce a novel high frequency gaseous discharge oscillator which has a selective frequency output of high magnitude as will be disclosed hereinafter.

The novel features which I believe to be characteristic of my invention are set forth in the appended claims; the invention itself, however, will best be understood by reference to the following description taken in connection with the drawings in which I have indicated diagrammatically several circuit organizations whereby the various objects of my invention may be carried into effect. In the drawings:

Figure 1 shows the basic circuit for producing unmodulated high frequency alternating voltages.

Figure 2 shows a means for obtaining modulation of the generated high frequency alternating voltages by the application of a low frequency modulating voltage.

Figure 3 shows another circuit for obtaining low frequency amplitude modulation of a high frequency alternating voltage generated by a gaseous tube oscillator, by applying in series with

the anode voltage supply a low frequency modulating voltage.

Figure 4 shows a special case of the circuit of Figure 3 wherein the modulating voltage is supplied by a second oscillator of the same type as the high frequency oscillator.

Figure 5 shows the circuit applied to a diode type of gaseous discharge device.

Figure 6 is a graph showing the operation of the basic circuit of Figure 1 using the type 6Q5 tube as a typical gaseous triode.

Referring now to the accompanying drawings wherein like reference characters in the various figures designate similar circuit elements, there is shown in Figure 1 the basic circuit of my invention intended to supply unmodulated high frequency alternating voltages.

Referring specifically to this figure, there is shown a gaseous discharge device **1** containing a cathode **2**, a control electrode **3**, and an anode **4**. There is also shown a resistance **5** for limiting the current drawn by the control electrode **3**, a second resistance **6** for limiting the anode current, an inductance **7** for isolating the source of potential **8** from the high frequency voltages and an output circuit including a capacitance **9** in series for isolating the load from the direct anode potential. It should be noted that the inductance **7** and the condenser **9** perform no function towards tuning the output of the gaseous discharge device **1** as the initiation of oscillations is inherent in the ionized gas within the device **1** and the control of the frequency thereof is a function of the resistance **5** as will appear hereinafter.

The operation of the circuit is as follows:

The value of the anode current limiting resistance **6** is such that a small anode current is permitted to flow. If relatively large anode currents are permitted to flow, the oscillations in the ionized gas are thrown into erratic random currents at all frequencies thereby preventing oscillation of the ionized gas at a single frequency determined by the external control circuit and the physical constants of the tube. The value of this current for best operation is a function of the type of gas tube used.

When the circuit is connected as shown in Figure 1, a high frequency alternating voltage is developed at the terminals marked output by reason of the natural high frequency oscillations occurring in the ionized gas of the tube. The magnitude and frequency of this voltage is determined by the choice of the value of the grid current limiting resistance **5**.

It has been found that the magnitude and frequency of this voltage are substantially constant for wide variations in load impedance.

As a concrete example, consider the circuit of Figure 1 applied to a type 6Q5, tube, one of the types which readily lend themselves to use in this circuit. In this case, the value of anode current for production of sustained oscillation has been found to fall in the region between 3 and 30 milliamperes, with the greatest output occurring at approximately 9.2 milliamperes. In this example, the value of the anode current limiting resistance is 10,000 ohms and the grid resistance is a 500,000 ohm variable resistance, for an anode supply voltage of 140 volts. The actual results of operation of the circuit with this type tube are shown in the graph, Fig. 6. Reference to this graph will show the proper operating points for amplitude and frequency modulation.

The circuit arrangement of Fig. 2 shows a modification of the arrangement of Fig. 1 designed to produce modulated output voltage. By the application of a low frequency alternating voltage to the terminals marked modulating voltage any desired percentage of modulation may be obtained.

The circuit of Fig. 3 shows means for modulating the output of the oscillator by the insertion of a modulating voltage in series with the anode supply voltage source.

The circuit arrangement of Fig. 4 shows another embodiment wherein one tube aranged in my basic circuit is used to modulate a second tube similarly arranged but oscillating at a higher frequency. Each oscillator operates in a manner similar to that explained in connection with Fig. 1. The voltage appearing from anode to cathode of the low frequency oscillator tube 1 is the modulating voltage and corresponds to the voltage appearing across the output terminals of Fig. 1. The voltage appearing from anode to cathode of tube 1' is the useful output voltage and is modulated at the frequency generated by tube 1.

Figure 5 shows a circuit very similar to Figure 1 except that the tube is a diode and no control means other than anode current is provided.

While I have limited myself to description of my invention in certain preferred embodiments, I desire that it be understood that modifications may be made and that no limitations are intended other than those imposed by the scope of the appended claims.

The invention described herein may be manufactured and used by or for the Government of the United States of America without the payment of any royalties thereon or therefor.

Having described my invention, I claim:

1. A generator of substantially sinusoidal high frequency alternating voltage comprising a continuously conducting gaseous discharge device having a cathode electrode and an anode electrode, a direct current source across said electrodes, and resistance means arranged between said source and said anode electrode for limiting the anode current to a value ranging from 3 to 30 milliamperes, and an output connection between said cathode and anode electrodes, whereby a high frequency alternating voltage is developed across the cathode electrode and the anode electrode of said discharge device without the aid of any tuned tank circuit or external condenser.

2. A generator of substantially sinusoidal high frequency alternating voltages comprising a continuously conducting gaseous discharge device having a control grid and a cathode electrode and an anode electrode, a direct current source across said electrodes, a first means arranged between said source and said anode electrode for limiting the anode current to a value ranging from 3 to 30 milliamperes a second means in series with said first means, anode, electrode and source for isolating the high frequency voltages from said direct current source, said second means including an inductance connected to said anode electrode, and a modulating voltage connected to said control grid and cathode electrode, whereby a modulated high frequency alternating voltage is developed across the cathode electrode and the anode electrode of said discharge device without the aid of any tuned tank circuit or external condenser.

3. A generator of substantially sinusoidal high frequency alternating voltage without the aid of a tank circuit or condenser, comprising a continuously conducting gaseous discharge device having at least a cathode electrode and an anode electrode, a source of potential across said cathode and anode, a current limiting resistor between said anode and said source of potential, means for isolating the high frequency alternating voltage from the source of anode potential, said means including an inductance connected between the anode electrode and the source of anode potential, whereby a high frequency alternating voltage is developed between the cathode electrode and the anode electrode of said discharge device, and an output circuit connected between said cathode electrode and said anode electrode having in series a capacitor for isolating the direct anode potential from the load circuit.

4. A generator of sinusoidal high frequency alternating voltage comprising a continuously conducting gaseous discharge device having a cathode, an anode and a control electrode, a direct current potential across said cathode and said anode with the positive terminal of the potential connected to said anode and the negative terminal connected to said cathode of the discharge device, a current limiting resistance in series with and between said anode and said positive terminal and a variable resistance connected between said anode and said control electrode of the discharge device, and a modulating voltage connected to said control electrode and cathode whereby a modulator high frequency alternating voltage is generated across said anode and cathode of the device without the aid of any tuned tank circuit or external condenser.

5. A generator of sinusoidal high frequency alternating voltages comprising a continuously conducting gaseous discharge device having a cathode, an anode and a control electrode, means across said cathode and said control element for applying a modulation signal across said cathode and said control electrode, voltage and frequency control means comprising a variable resistance connected across the anode and said control electrode, a source of potential across said cathode and said anode and means between said anode and said source for limiting the anode current of the discharge device, and an output circuit across the anode and cathode whereby a high frequency alternating voltage is generated across said cathode and said anode.

6. A generator of modulated high frequency alternating voltages without the aid of a tank circuit or condenser, comprising a continuously conducting gaseous discharge device having a cathode electrode and other electrodes, including an anode and at least one control electrode, a source of anode potential, a current limiting resistance, a connection between the positive terminal of the source of anode potential and one

end of said current limiting resistance, a connection between the other end of said resistance and the anode of the discharge device, a connection between the negative terminal of the source of anode potential and the cathode of the discharge device, a source of low frequency alternating voltage connected in series with the anode supply circuit, a variable resistance connected between the anode and the control electrode of the discharge device, whereby a modulated high frequency alternating voltage is generated between the cathode and the anode of the discharge device, and an output circuit connected between said anode and cathode.

7. A generator for producing modulated high frequency alternating voltages without the aid of a tank circuit or condenser, comprising a first continuously conducting gaseous discharge device having at least a cathode, control electrode and anode, a second continuously conducting gaseous discharge device having at least a cathode, control electrode and anode, a source of anode potential, a current limiting resistance connected between the positive terminal of the source of potential and the anode of the first discharge device, a connection between the cathode of the first discharge device and the anode of the second discharge device, a connection between the cathode of the second discharge device and the negative terminal of the source of anode potential, variable resistances connected between the control electrode of each discharge device and the associated anode, whereby a high frequency alternating voltage, modulated at a low frequency, is generated between the cathode and the anode of the second discharge device, and an output circuit connected between the anode and cathode of the second discharge device.

8. A generator of alternating voltages comprising a continuously conducting gaseous discharge device having a cathode, an anode and a control electrode, a source of potential across said cathode and said anode, means between said anode and said source for limiting and controlling the anode current, and means across said anode and said control electrode for controlling the current drawn by the control electrode, said last mentioned means including a limiting resistance connected between said control electrode and the anode of the discharge device for determining the frequency of the alternating voltage.

9. An electronic device for generating sinusoidal high frequency alternating voltages without the aid of a tank circuit or condenser, comprising a continuously conducting gaseous discharge device having a cathode electrode and other electrodes including an anode and at least one control electrode, a source of anode potential having positive and negative terminals, a current limiting resistance connected between the anode of the discharge device and the positive terminal of the source of potential, a connection between the negative terminal of the source of potential and the cathode of the discharge device, a connection between the anode of the discharge device and one end of a variable resistance, a connection between the other end of said variable resistance and the primary control electrode of the discharge device, whereby a high frequency alternating voltage is generated between the anode and the cathode of the device, and an output circuit connected between said anode and said cathode including a capacitor isolating the direct potential of the anode from said output circuit.

10. A generator of sinusoidal high frequency alternating voltages comprising a continuously conducting gaseous discharge device having a cathode electrode and other electrodes including an anode and at least one control electrode, a source of anode potential, a current limiting resistance, one end of which is connected to the positive terminal of the source of potential, an inductance connected between the other end of the current limiting resistance and the anode of the discharge device, a connection between the negative terminal of the source of potential and the cathode of the discharge device, a connection between the anode of the discharge device and one end of a variable resistance, a connection between the other end of said variable resistance and the primary control electrode of the discharge device, mean for inserting a modulating voltage, and an output circuit whereby a high frequency alternating voltage is generated between the anode and the cathode of the device.

11. An electronic device for generating alternating voltages without the aid of a tank circuit or condenser, comprising a continuously conducting gaseous discharge device having electrodes including at least a cathode and anode, a source of anode potential, a current limiting resistor between said anode and said source of potential, and an output circuit connected between anode and cathode, said output circuit including a capacitor in series with the output lead connected to the anode.

12. An electronic device for generating alternating voltages without the aid of a tank circuit or condenser comprising a continuously conducting gaseous discharge device, said discharge device having at least a cathode and anode, a source of potential across said cathode and anode, a current limiting resistor between said anode and said source of potential, and an output circuit connected between said anode and cathode.

13. An electronic device for generating alternating voltages without the aid of a tank circuit or external condenser comprising a continuously conducting gaseous discharge device in which the ionized gas oscillates within the discharge device at low orders of ionization, said discharge device having at least an anode and cathode, a source of potential across said anode and cathode, a current limiting resistor between said anode and said source of potential, and an output circuit connected between said anode and cathode.

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GLOSSARY OF TERMS

1...Abnormal Glow Discharge (cold cathode):

Occurs in cold cathode tubes when the current becomes great enough that the whole cathode is covered with a glow and further increases in the current cause the tube drop voltage to increase. This occurs for a small region of currents just before the arc occurs.

2...Anode:

An electrode designed to attract electrons in an electronic tube.

3...Anode Spot:

A luminescent spot on the anode during glow discharge conditions.

4...Antinode:

A point of maximum variation in a standing wave.

5...Arc:

An electric current through a vacuum or gas.

6...Arc Discharge:

Occurs in both hot and cold cathode tubes. It is characterized by high currents and low voltage drops across the tube.

Arcs are sometimes divided into three main groups, describing the way in which electrons are released from the cathode:

Therminal Arcs: The cathode emits electrons because the positive ions knock off electrons and the cathode is heated by the bombardment and emits some electrons thermionically. This is the type of arc that usually occurs in cold cathode tubes.

Thermionic Arcs: The cathode emits due to indirect heating from a source outside the tube. This is the type of arc that always occurs in hot cathode tubes operating normally.

High Field Arcs: The cathode emits electrons because of a high potential electric field occurring near it.

7...Arc Drop:

The Arc Drop is the voltage maintained across an arc discharge.

8...Atomic Nucleus:

The center hard core of atoms. The nucleus comprises virtually all of the mass of the atom but has a diameter of one ten-thousandth the diameter of the atom. The nucleus is composed of positively charged protons and neutral neutrons.

9...Audio Frequency Oscillations:

Fluctuations of a frequency that the human ear can detect (20-20,000 cps).

10..Beam Electron:

An electron which is part of a current flowing in a vacuum tube.

11..Boltsmann's Constant:

Is the value of the universal gas constant per mole = 1.380×10^{-16} ergs per $^{\circ}$K.

12..Breakdown Potential:

Is the potential required to start the glow discharge. It is also referred to as the ignition potential. In this potential the ions in a cold cathode tube obtain enough energy to bombard the cathode and cause emission of electrons in large enough quantities to make the discharge self-maintaining.

In a hot cathode tube the "Breakdown Voltage" is the voltage required to initiate the arc discharge.

Occasionally the "Arc-back Voltage" is referred to as the breakdown voltage. This is a regretful misnomer and use should be avoided.

13..Capacitance:

The ability to store electrical energy.

14...Cathode:

An electrode designed to emit electrons.

15...Cathode Dark Space:

Next to the cathode glow toward the anode in a gas tube in discharge there is an area that little or no glow is given off from. This area is called "Cathode Dark Space" of Crookes' Dark Space." This area should not be confused with "Faraday's Dark Space," which occurs farther from the cathode.

16...Cathode Glow:

In a tube discharging through a gas in a glow discharge there is a sheet of luminosity around the cathode called the cathode glow.

17...Cathode Sheath:

It has been found tht a large number of positive ions accumulate around the cathode during glow or arc discharge. As a result, most of the space potential in a tube occurs in this region. This region is called the cathode sheath.

18...Cold Cathodes:

Cold cathode tubes conduct due to bombardment of the cathode by positive ions. In general, cold cathode tubes required larger voltage drop across them before arc conduction begins.

19...Coulomb Force:

The attractive force between two unlike electrical charges or the repelling force between two like electrical charges.

20...D_2:

A deuterium molecule.

21...D-C Discharge:

A direct current flowing through a gas tube.

22...Deuterium:

A form of hydrogen with one neutron and one proton in its atomic nucleus. Ordinary hydrogen has only one proton in its nucleus.

23...Discharge Tube:

A gas tube designed to conduct electricity by gaseous conduction.

24...Electrode:

A terminal of an electric source.

25...Electron:

An elementary particle of negative electricity.
Mass = 9.106×10^{-28} grams (at rest).

26...Electronic Oscillation:

Electronic oscillations are the high frequency oscillation occurring in a gas tube that are thought to be related to the free electron in a gas tube discharge.

27...Excitation Potential:

The excitation potential is the energy in electron volts that an atom must receive before an electron within the atom can be raised to an orbit farther away from the nucleus thereby making it possible for the atom to be ionized.

28...Faraday's Dark Space:

Just beyond the Negative Glow toward the anode is another dark space called "Faraday's Dark Space."

29...Field Gradient:

The rate of change of potential difference with distance taken in the direction of maximum rate of change.

30...Filament:

A thin wire, heated to incandescence, that is used to heat cathodes for thermionic emission.

31...Gas Diode:

A gas-filled electronic tube with two electrodes; the anode and the cathode.

32...Gas Pressure:

Gas pressure is measured in gas tubes in millimeters of mercury pressure or microns. For comparison it should be noted that atmospheric pressure is 760 millimeters of mercury or 760,000 microns.

33...Glow:

A visible light coming from a gaseous tube. It represents energy lost by electrons when they are captured by positive ions or jump to a lower energy level in the atom.

34...Glow Discharge (Cold Cathodes Only):

Is the discharge occurring immediately after the tube voltage has been raised past the saturation voltage for a Townsend discharge. The voltage will then drop in the tube and remain fairly constant over a wide range of current variation. This discharge only occurs in a cold cathode tube.

35...Grid:

An electrode consisting of a screen of very fine wires. It is used for the purpose of controlling current flow in an electronic tube.

36...Grid Bias:

A voltage applied to the grid to control current flow.

37...H_2:

A hydrogen molecule.

38...High Field Emission:

A type of emission of electrons from an electrode caused by a very high field gradient acting on the cathode. This field "pulls" the electrons away from the cathode.

39...Hot Cathodes:

Gas tubes are in general classified as hot cathode or cold cathode tubes. A hot cathode tube is one that has a cathode heated by an external circuit. It should be noted that a hot cathode tube conducts due to thermionic emission of electrons from the cathode.

40...Inductance:

That property of an electric circuit that resists variations in current flow. It tends to maintain a decreasing current and to suppress an increasing current.

41...Ion:

A charged atom.

A positive ion:	An atom charged positively by the removal of one or more electrons.
A negative ion:	An atom charged negatively by the addition of one or more electrons.

42...Ion Sheaths:

Dense collections of positive ions surrounding the cathode.

43...Ionic Oscillations:

Ionic oscillations are oscillations occurring in a gas tube that are thought to be caused by the ions in the discharge oscillating. These oscillations are in the low frequency range, usually up to about 5 megacycles.

44...Ionization Potential or Voltage:

Ionization voltage is the amount of energy in electron volts that an electron of a gas atom must receive before it can leave the atom and thereby cause it to be ionized. Since an Electron Volt is defined as the energy that an electron receives when moving between a potential difference of one volt, the voltage drop of a tube may be taken as a rough measure of the energy being received by the free electrons in the discharge. As a result, in most hot cathode tubes the breakdown voltage is only slightly higher than the ionization potential.

45...Kilocycle:

1,000 cycles.

46...Megacycle:

1,000,000 cycles.

47...Mercury Pressure:

A gas pressure measured in "n" millimeters of mercury will support a column of mercury "n" millimeters high.

48...Metastable State:

It has been observed that when electrons gain enough energy to be raised to certain orbit or energy levels, that they rarely return from these orbits to a lower orbit. This allows an atom to be ionized in two steps instead of one.

49...Negative Glow:

Just beyond the cathode dark space toward the anode is a region of luminosity called the "Negative Glow."

50...Neutron:

A nuclear particle that carries no electrical charge with a mass nearly 2000 times that of an electron.

51...Node:

A point of zero variation in a standing wave.

52...Oscillation:

A fluctuation above and below a mean value; as the oscillation of a pendulum.

53...Permittivity:

A measure of the relative strengths of electric fields in different mediums.

54...Photocell:

An electronic device that converts light waves into small electronic currents.

55...Photomultiplier Tube:

A device that amplifies currents generated by photocells.

56...Pinch Effect:

The phenomenon that restricts the cross-sectional area of a current to small values.

57...Plasma:

Plasma is defined as any area in a gas tube where the free electrons pressnt and the positive ions present are in equilibrium. Due to the occurrence of the cathode sheath potential drop most of the remainder of the gas tube is a plasma, especially the anode glow region. Due to the equilibrium conditions in the plasma, the potential difference across it is extremely small.

58...Plasma Oscillations:

Oscillations of current in a gas tube due to vibrating electrons or positive ions.

59...Positive Column:

From the Faraday Dark Space to the anode there is an area of continuous luminosity called the positive column of Anode Glow. Usually the positive column varies in length as the tube varies in length. The other four regions of the tube glow remain practically constant regardless of the length of the tube. For example, J. J. Thomson used a tube 15 meters long and as a result, almost all the tube was filled with the positive column.

60...Potential Gradient:

Potential gradient is the change of voltage across any given length under consideration.

61...Probe Measurements:

Measurements of charge density and voltage gradients inside a gas tube.

62...Probes:

Probes are special measuring devices that have inserted into different spots of gas discharges in order to measure the space potential and the electron concentration and other related matters of interest. Basically, the probe is a thin wire inserted into the tube, but the actual operation of probes and their associate measurements is very delicate and difficult.

63...Proton:

A small sub-atomic particle with a mass of nearly 2000 times the mass of an electron. It has a charge equal in magnitude to that of an electron but positive instead of negative.

64...Resonant:

The condition of an electrical circuit adjusted to allow the greatest flow of current at a certain frequency.

65...Secondary Emission:

Emission of electrons caused by the electrons being knocked out of the cathode by positive ions or out of the anode by other electrons.

66...Self-Inductance:

The ability of a varying electric current flowing through a coil to induce another current in the same coil that will oppose the original current.

67...Space Potential:

Space potential is the voltage potential in a given part of the gas tube in relation to the cathode or anode. Usually the space potential is measured with reference to the cathode.

68...Standing Waves:

A distribution of wave displacements with fixed maximum and minimum points that do not move in space; as in vibrating strings.

69...Striations:

Under certain conditions of pressure and current in a gas tube usually found under glow or arc discharge conditions the positive column exhibits a series of light and dark lines called striations. Striations have been observed stationary and moving. Many times there moving at such a rate that the positive column appears to be a continuous glow.

70...Superconductivity:

Certain metals, when lowered to temperatures within a few degrees of absolute zero, lose all measureable resistance to the flow of electric current. This phenomenon is called superconductivity.

71...Thermionic Emission:

Emission of electrons by their being "boiled" out of the cathode by high temperatures.

72...Torus:

A doughnut-shaped object.

73...Townsend Discharge (cold cathode):

Is the first region of discharge occurring in a cold cathode tube. It is a very low current discharge and is not a self-maintaining discharge.

74...Transit Time:

The time required for a particle to move from one electrode to another in an electronic tube.

75...Tube Drop:

Tube drop is the voltage across the tube at any time during the operation of a tube. Since in many cases the tube is discharging with an arc discharge, the term arc drop and tube drop are used interchangeably since they, in this case, mean the same voltage.

76...Wavelength:

The length between crests or troughs in a wave.