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By

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Abstract

The radio noises caused by fluorescent lamps were investigated in connection with high frequency oscillations in fluorescent lamps, and the mechanisms of oscillations were considered with some experimental results.

Reignition oscillation, the waveform of which is irregular and consists of train of fine pulses, is sensitive to external heating of the filament and magnetic field near the cathode. Its frequency spectrum is nearly flat in broadcast band, and its noise level is 62 db (20W lamp) and 50 db (40W lamp) respectively in mean value of symetric quasi-peak voltage at 1MC, and is reduced by 30 db with 0.005 μF capacitor conncted between lamp terminals.

The twin oscillation, the waveform of which is regular and nearly sinusoidal, has the frequency spectrum which is similar to the resonance curve, and in many cases the peak of its spectrum is found in broadcast band.

The high frequency oscillation is observed also in DC discharge, and its characteristics are just the same with those of the twin oscillation. The frequencies of these oscillations vary nearly in proportion to the square root of the lamp current, and are affected by interterminal capacitor.

The cause of reignition oscillation is the fluctuation of ionization in increasing and decreasing period of space charge during transient time on reversing of the lamp current.

The origin of twin oscillation is the oscillatory behavior of ionized medium with suitable accelerating field at the cathode surface, and for generation of the oscillation it is necessary that some conditions of the feedback from the boundary of the medium to the cathode are satisfied.

1. Introdution

As a consequence of the remarkable popularization of the fluorescent lamp, the resulting radio-frequency noise, especially one in the broadcast band, is rapidly increasing. In many field measures have been taken up against the noise, while extensive studies are being carried on its mechanism of generation.(1)(2)(3) The present authors have investigated problems ranging from approaches against the radio interference to its mechanism of generation.(4)~(7) In the course of our study, we were able to clarify, among others, the relations between the high frequency oscillation of the fluorescent lamp and the corresponding noise, and further to know several characteristics of the oscillation. In this report, the authors will classify the noises appearing on the broadcast band with regard to the causes of their oscillation, thus defining their characteristics as oscillations; on the other hand, we will describe experimental results on the nature of the oscillation, along with the considerations upon its mechanism.

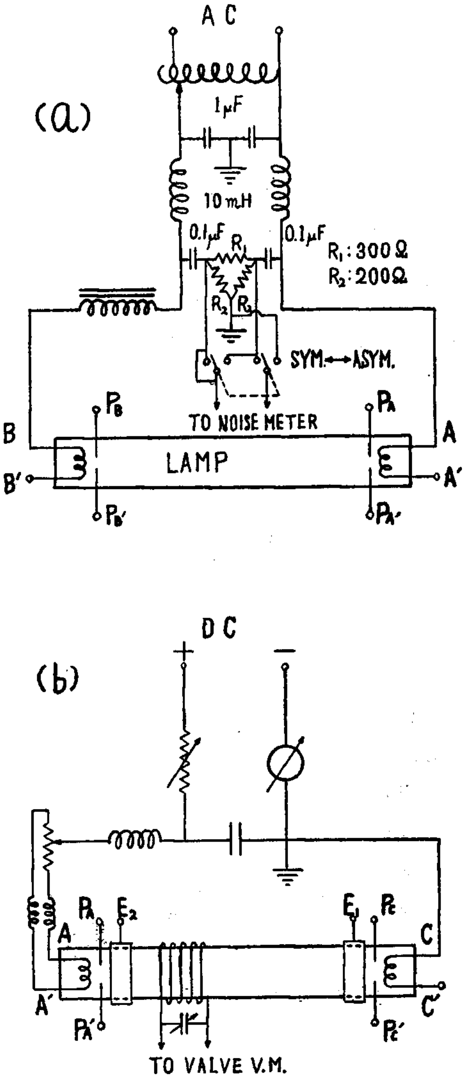

Fig. 1 Experimental arrangement
(a) for AC discharge
(b) for DC discharge

The principal oscillation phenomena in the fluorescent lamp are the anode and cathode oscillations, about the former of which great deal of stude has been already made(2)(8)(9); but as to the latter, few investigations have been done, without sufficient outcome. In the higher frequency band than about 500kc, however, the fluorescent lamp noise is practically produced by the cathode oscillation; the anode oscillation takes part very trivially. As this fact can be readily confirmed experimentally we will treat the cathode oscillation only.

Cathode oscillations can be generally classified into: reignition oscillation(1) or breakdown oscillation(3), and twin oscillation(3) or hollow cathode oscillation.(1) Furthermore, in most cases, the reignition oscillation is accompanied by the extinction oscillation.(3) These oscillations can be easily observed by means of the wide-Band oscillograph. Wave-forms shown in Photo 1 (b) are generally obtained by applying to C-R differential circuit the voltage wave form at the terminal of a fluorescent lamp.

The authors used in these experiments an NHK type 4 radio-noisemeter and a Heath Brown-tube oscillograph, along with that combination of a valve voltmeter and a L-C resonance circuit couppled with a fluorescent lamp, which works as a sort of wave-meter. Fluorescent lamps to be tested, when not specified, are 20W T12 lamps. In addition to these test pieces, we prepared those with probe inserted near the electrodes, and those with indirect heated cathode (both of them are of 20W). Fig. 1 shows the measuring circuits; (a) for AC discharge and (b) for DC discharge respectively. As for the noise voltage, we measured quasi-peak values of the symmetric and asymmetric voltage, in compliance with the measuring method, and by means of the above-mentioned measuring apparatus, (NHK type 4) based upon the written reply to the Radio Technical Investigation Committee of Japanese Government. The unit adopted for the measurement is $1\mu V = 0$ db.

2. Reignition Oscillation

The reignition oscillation is necessarily generated in the AC discharge of the fluorescent lamp at the early period of every half cycle, and is mostly accompanied by the extinction oscillation at the end of the same half cycle. W. Culp,(1) R. Miura,(2) and others have made studies upon this type of oscillation, but no conclusion has been thus far reached. Culp attributes the reignition oscillation to the rapid building up of ionic space charge in front of the cathode; Miura holds that it is a regular relaxation oscillation which is essentially a kind of intermittent discharge, with it generating conditions being satisfied in the transient state of the discharge. The results obtained by us, to the contrary, show that the reignition oscillation consists substantially of train of irregular pulses. Our results will be explained in the following articles.

2.1. Wave Form

By comparing the terminal voltage wave form of a fluorescent lamp and its differentiated wave form with each other, we observe that the reignition and extinction oscillation are generally the train of fine pulses, which individually change always in width, hight, and position. Photo. 1 (a) and (b) represent the voltage wave form at the terminal and its differentiated wave form, respectively; and (c) and (d) the enlargement of the reignition oscillation in (a) and (b).

There are, however, such remarkably regular wave forms as are composed of saw-teeth wave forms shown by Photo. 2, (a)-(d). Photo. 2 (e)-(h) show the wave forms produced when the lamp tube is turned by 180° around its cylindrical axis: that is, when A and B are respectively replaced by A′ and B′ in Fig. 1, (a).

Though on the same fluorescent lamp, completely different wave forms are obtained. The difference just mentioned is brought forth by that of the conditions of cathode spot: (a)-(d) show the cathode spot moved towards the middle of the filament still in lighted condition after about 3,000 hours of continuous lighting; (e)-(h) the cathode spot still remaining on the tip of the filament, just in the same condition with brand-new fluorescent lamps. These examples denote that wave forms of, and in the vicinity of the reignition oscillation vary prominently with the lamps used and their lighted time thus far.

In appearance, these changes occur corresponding to conditions of the cathode spot, with those to be influenced by time proceeding on in a similar manner. To expatiate upon the matter, the voltage wave forms around the turn of the current direction hence around the reignition oscillation, at the early period of lighting are generally smooth as shown in Photo. 2, (g), and the oscillation is wholly irregular. The oscillation at the midway period produces steps (to be called discontinuity hence forth) in the wave forms, becoming saw-teeth-shaped Photo. 2, (c)). Lastly at the final stage, the discontiunity develops itself remarkably and the saw-teeth waves disappear in many cases Photo. 1, (c)).

It is evident from the facts explained above that the reignition oscillation and its near by wave forms depend upon the cathode spot. Further to say, the reginition oscillation, which is engendered with A-A′ filament as the cathode, does change when replacement is made between A and A′ with B unexchanged in Fig. 1, (a); but not with B-B′ glament as cathode. This shows that the reignition oscillation is an attribute to the cathode spot, the electron emission of which controls the former.

2.2. Effect by Filament Heating

When the filament is heated by direct current during the lighting, the oscillation conditions vary with respect to the direction and the intensity of the heating current. When so heated as to add the cathode-phase current (A is positive), the oscillation diminishes at first with the current increase and the wave form in that period becomes smooth. Heating current up to about 0.3A shows this tendency, while sometimes the oscillation becomes hardly noticeable in the voltage wave form at the terminal. Irregular oscillation, however, can be seen in the differntiated wave form even in this case. Photo. 3 explains the effect of heating upon the reignition oscillation. If the current is further increased beyond this state, local discharge takes place at the both end of the filament generally causing the oscillation to be increased. The increase in the current flow exerts about the same effect upon the saw-teeth wave oscillatin.

In another case, when the filament is heated in such a way as the current in cathode phase is offset (A is made negative), the cathode spot shifts on the filament as the current increases. Though the amplitude of the oscillation decreases more or less during shifting, it becomes again large when the cathode spot reaches the other end of the filament. The aspect of oscillation thus varies depending on the interrelation between the heating and the lamp current. To be more strict in our discussion, the cathode spot movement occurs in both cases. In still another case where no heating current is present, the cathode spot shifts towards the tip of the filament with the lamp current increasing, and towards the middle with that diminishing. Notwithstanding this, the variation in the amplitude can be considered as caused by the varying electron emission, even with the shift of the cathode spot taken into account, for the addition of heating current gives a filament temperature-lamp current ratio different from one given by increasing lamp current.

2. 3. Changes by Source Voltage

Changes in the source voltage cause those in the lamp current. The cathode spot, accordingly, shifts its position as we have described in the foregoing article. In this case, the duration of the oscillation is generally prolonged with the increase in the current flow. It is difficult to observe the amplitude because of this irregularity in the oscillation; the amplitude does not necessarily increase, but decreases in appearance. Fig. 2 show the relation between the current intensity and the duration of the oscillation, obtained through measurements with a 20 W and a 30 W fluorescent lamp. The saw-teeth wave oscillation is comparatively stable against the current change, but considerable variance is noticeable in the degree of stability depending upon individual lamps.

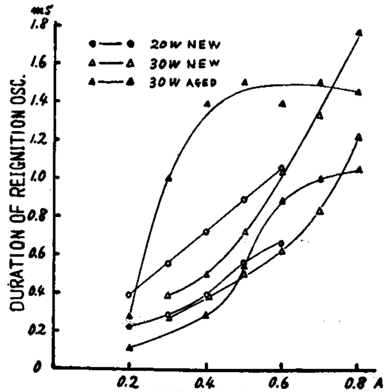

Fig. 2 Duration of reignition oscillation *vs* lamp current.

The duration of the oscillation is, with regard to a single electrode, related with current, but it depends upon the individual lamp taken up, and further upon the individual electrodes in the one to be examined. For constant current, a positive correlation can be traced between the filament temperature and the duration of the oscillation; but it cannot be affirmed due to small number of the measured values so far obtained.

2.4. Effect by Magnetic Field

Being applied in the vicinity of either electrode to the magnetic field perpendicular to the cylindrical axis of the lamp tube, the reignition oscillation as well as the anode oscillation is influenced by it. Reports about the relations between the noise and the magnetic field have been already published(10)(11); the numerical values on Table 1 are some of the results, which the authors obtained through

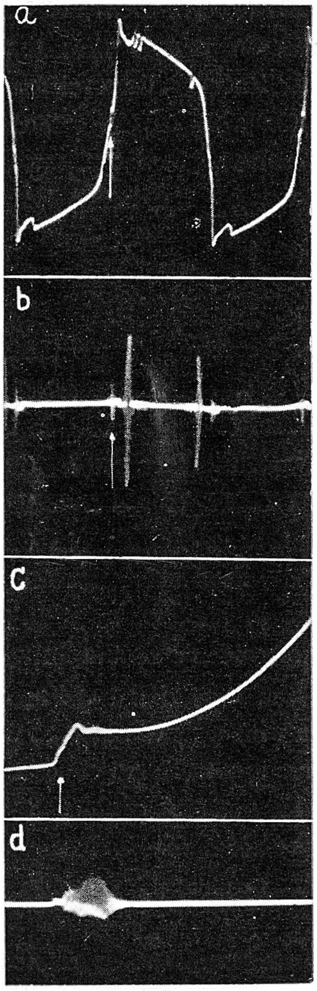

Photo. 1 Observed wave forms of a fluorescent lamp.

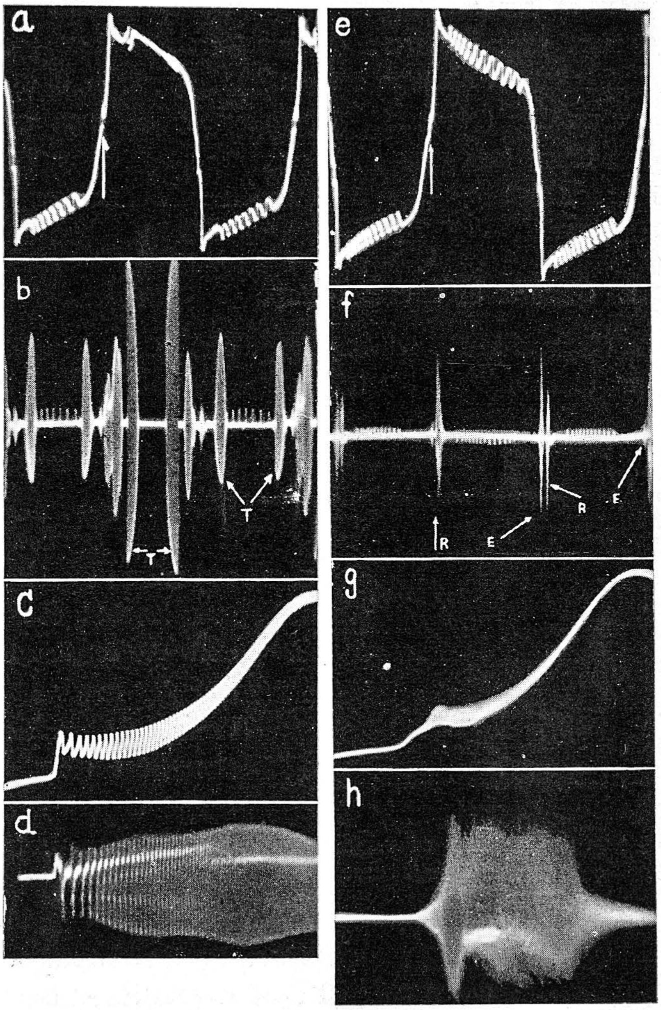

Photo. 2 The difference of wave forms due to the lighting position of a fluorescent lamp: (a)~(d) in aged position ; (e)~(h) in the opposite position.

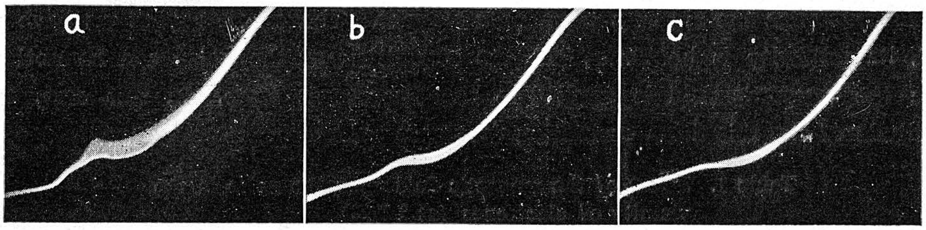

Photo. 3 Effect of the filament heating current on the reignition oscillation: heating current intensity is 0 A for (a), 0.2 A for (b) and 0.3 A for (c), lamp current is 0.36 A.

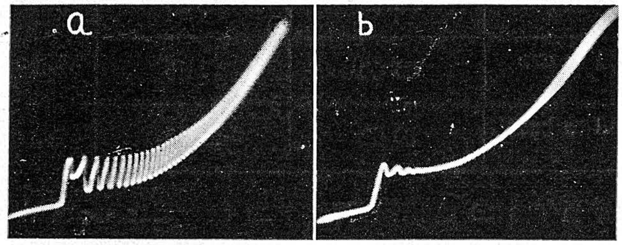

Photo. 4 Effect of the magnetic field on the saw-teeth oscillation; (a) without magnetic field, (b) with magnetic field.

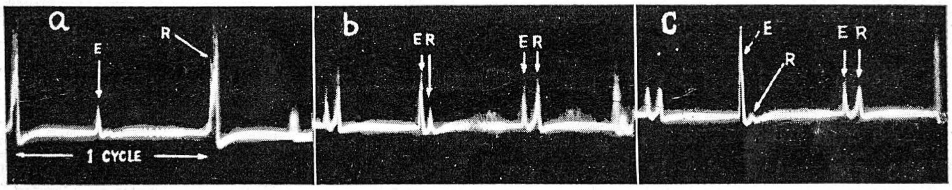

Photo. 5 Detected wave forms of reignition and extinction oscillation at several frequencies; (a) at 800kc, (b) at 1400kc, and (c) at 2000 kC. *R* and *E* mean reignition and extinction noise respectively.

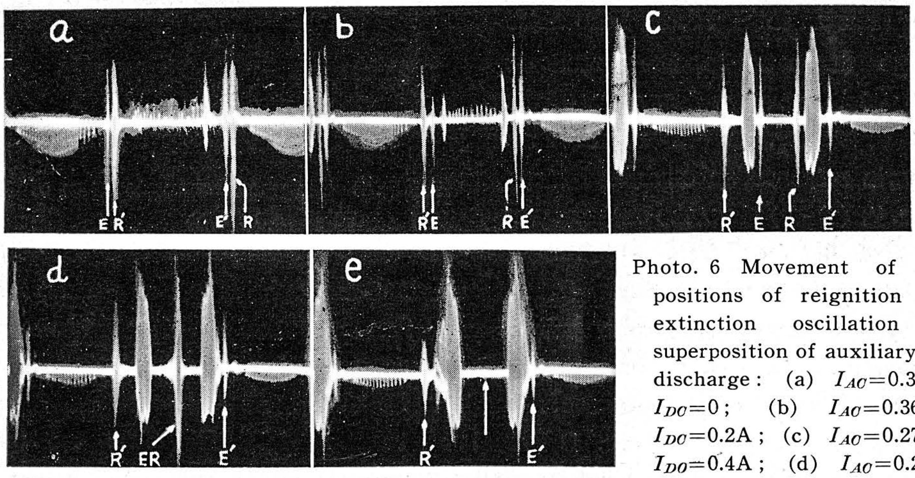

Photo. 6 Movement of the positions of reignition and extinction oscillation by superposition of auxiliary DC discharge: (a) $I_{AC}=0.36$ A, $I_{DC}=0$; (b) $I_{AC}=0.365$A, $I_{DC}=0.2$A; (c) $I_{AC}=0.275$A, $I_{DC}=0.4$A; (d) $I_{AC}=0.24$A, $I_{DC}=0.46$A: (e) $I_{AC}=0.21$A, $I_{DC}=0.46$A. I_{AC} and I_{DC} mean AC discharge and DC discharge current respectively.

experiments with the aid of a permanent magnet. The magnet what we have on hand, its intensity is unknown, but the diminition of the noise can be noticed when the magnetic field is applied to the fluorescent lamp. In this case, the amplitude of the reignition oscillation decreases evidently.

Table 1. Effect of the magnetic field upon the noise in the vicinity of electrodes (at 1 MC)

	without a capacitor	with a 0.01μF capacitor
Magnetic field not applied	69 db	33 db
Magnetic field applied to one electrode	65 db	29 db
Magnetic field applied to both electrodes	59 db	24 db

The saw-teeth wave oscillation is not so much affected as irregular oscillations, though its initial stage disappears. Photo. 4 shows how the oscillation diminishes by the action of the magnetic field.

2.5. Noise Level and Its Frequency Characteristics

The authors measured, by means of the measuring circuit shown on Fig. 2, (a), the noise voltage of the fluorescent lamps which generate the reignition oscillation only. The results are, as shown in Fig. 3, that the noise voltage fluctuates in the broadcast band yet it is rather flat, with slight level difference, in comparison with the twin noise to be explained later. Photo. 5, (a)-(c) show the output wave forms of detector, from which we can see that the reignition and extinction oscillations are by far stronger than the anode oscillation. It is also evident from the figures that the reignition and the extinction oscillation are different as to the frequency characteristics: namely, the former is generally prominent in the lower frequency range of the broadcast band, while the latter is so in the higher frequency range. Therefore, it would be readily understood that the level difference in the broadcast band is small with respect to thr quasi-pesk values of noise voltage.

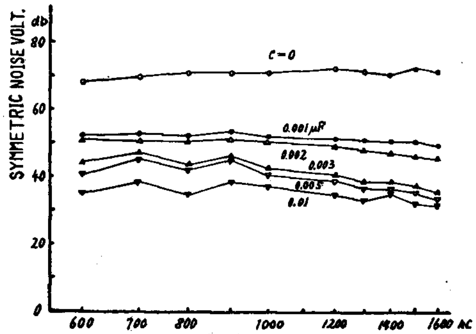

Fig. 3 Frequency characteristics of reignition noise.

The measurements of the noise voltage, which the authors have done thus far upon many fluorescent lamps manufactured by several makers, lead to the result that the noise voltage forms a nearly normal distribution, the average values of which are as shown on Table 2.

From the table, we know that the noise level is higher 20 W lamps than in 40 W T 12 lamps, and that the symmetric voltage is higher than the asymmetric one.

2. 6. Suppressive Effects by Capacitor

The most inexpensive and effective method for suppression of the radio noise caused by the fluorescent lamp is to connect a capacitor with both terminals of a fluorescent lamp. The suppressive effect by the capacitor is not only to shortcircuit the oscillation through the capacitor but also to change the oscillation frequency hence the oscillation itself. Fig. 3 is also accompanied by the suppressive effect of capacitors used. The noise level lowers itself almost uniformly with the increasing capacity of the condenser. This is the very manner in which the reignition and the extinction oscillation differ substantially from the twin noise to be treated later.

Table 2. Average values of quasi-peak noise voltages of fluorescent lamps (at 1 MC)

	Symmetric voltage	Asymmetric voltage
40 W	50 db	38 db
20 W	62 db	43 db

Note. 1. The values on the 40W line are the average among 45 lamps made by 4 manufacturers.

Note. 2. The values on the 20W line are the average among 30 lamps made by 3 manufacturers.

Table 3. Noise-suppressive effect of the capacitor inserted between terminals (at 1 MC)

	capacity of condenser μF unit db	C=0	C=0.001	C=0.005	C=0.01
40 W	average value of noise	51.5±3.84	37.0±3.55	22.0±2.01	
	average value of supprossive effect		14.5±2.69	29.5±3.45	
20 W	average value of noise	62.3±7.2	46.9±8.4	33.0±9.0	31.6±9.1
	average value of suppressive effect		15.4±5.2	29.3±5.9	30.7±5.6

Table 3 shows the results of the measurement which the authors carried on the suppressive effect of capacitor with numerous fluorescent lamps. As is evident from the table, the difference of the suppressive effect between 0.005 μF and 0.01 μF is slight. Endorsed by actual measurements, this fact indicates that, despite the connection of a larger capacity, a corresponding effect can hardly be expected. Naturally, a certain limitation is imposed upon the suppressive effect by this method. The suppressive effect does not increase so much, even if the condenser capacity is augmented upwards of 0.01 μF. Moreover, the wave form at the crest of the terminal voltage varies remarkably with the capacitor more than 0.05 μF or so, recognizably tending to shorten the lamp life. The deformation in the crest is attributed to the lowering of the residual ion density due to decrease in the build up ratio of the recovery voltage caused by the capacitor inserted. The decrease of the residual ion density is also regarded to accelerate the wearing-out of the cathode.

2. 7. Effect by Auxiliary Direct Current Discharge

When a direct current discharge between PA and A is superposed to the alternating current discharge between A and B in the circuit shown in Fig. 1, (a), the differentiated wave form of the terminal voltage changes with the ratio of the direct to the alternating current as is shown in Photo. 6. In other words, the reignition and extinction oscillations pertaining to the electrode A first enter into the anode phase of the electrode A, then both merging themselves into one, disappear. The phenomenon is explicated as follows: the direct current discharge has always A as the cathode, while for the alternating current discharge there exists a phase in which A takes the place of the anode. The current then in A is given direction by the relative current intensity of both kinds of discharges. Accordingly, the zero current time occurs within the phase where A works as the anode for the alternating current discharge; then the time in which current flows out of A becomes shorter with the direct current increasing, until the cathode spot on A comes to hold on despite the continuation of the alternating current discharge. From the above-mentioned the proof is given that the reignition and the extinction oscillation are generated at the turn of the current direction. In this case, it goes without saying that the reignition and extinction oscillations as to the electrode B are not affected by the direct current discharge.

2. 8. Reignition Oscillation in Indirect Heating Type Cathode.

When a filament and an indirect heated cathode alike are set within one fluorescent lamp, the wave forms of the reignition oscillation by both of them differ, as Photo. 7 shows, in smoothness. When we further strengthen the cathode heating current by keeping the lamp current constant, the reignition oscillation shifts towards the middle of the cathode phase. Under this condition, remarkable discontinuities are seen in the probe potantial (voltage between PA and cathode) as Photo. 8 shows, and oscillations take place in front of the discontinuity (Photo. 8, (C), (c) ; (D), (d)). If the heating current is increased, the discontinuity shifts towards the middle, then disappears. At this time, the glow which has been surrounding the cathode sleeve fades away, but the oscillation intensifies itself (Photo. 8, (B), (b)). If the heating current is further increased beyond this condition, the glow near the cathode departs from it, with the oscillation being weakened as well (Photo. 8, (A), (a)). The entire half cycle oscillation, as Photo. 8 (b) shows, can be produced with direct current, and indicate just the same aspect in the changing of the glow, etc., as in alternating current.

These phenomena occurring in the indirect heated cathode may be explained as follows: Let us suppose that i_L denotes the lamp current and i_S is the thermionic emission current of the cathode. When $i_L < i_S$, the glow surrounding the cathode does not appear with the electric field in front of the cathode being negative, and the trough of potential is formed, which causes the prode potential to be lowered; on the contrary, when $i_L > i_S$, the electron emission by ionic collision and electric field is added to that of the cathode, making it necessary that the cathode should be surrounded by glow. The probe potential, therefore, becomes high. Thus, in case, that $i_L = i_S$, the glow should approach the cathode and form ion sheath rapidly, when discontinuity appears on the probe potential.

The oscillation produced in front of the discontinuity is a phenomenon peculiar to the condition that $i_L \fallingdotseq i_S$; for when the temperature rise at the cathode extinguishes the discontinuity, the glow separates from the cathode, and further when put in the same condition with the above, the direct current discharge itself can produce a oscillation. Moreover, as this phenomenon can not be distinguished essentially from the reignition oscillation of the indirect heated cathode, it is considered to be due to the ionization caused by the glow approaching the cathode in accordance with the increase in the lamp current. This phenomenon conforms with the experiments done by Culp; and it justifies the fact that the oscillation is generated the moment the negative glow reaches the cathode surface. It is premature, however, to apply this conclusion to the oscillation on the filament cathode. Accordingly, we refrain from describing further than that the phenomena are very similar to each other. For example, when the heating current supply is stopped short during the heating of filament, as was explained in 2.2, there appears transiently such a discontinuity as is observed on the indirect heated cathode; and the situation is that the reignition oscillation has occurred before the discontinuity which interrupts the former. By the foregoing, the fact may well be explained that the discontinuity appears in fluorescent lamps used for long time.

2. 9. Considerations On The Reignition Oscillation

The facts that the generation of the reignition oscillation is a phenomenon peculiar to the alternating current lighting, and that it depends upon the conditions of the cathode spot, indicate that this kind of oscillation is controlled uniquely by the electron emission at the cathode spot and the variation with time of the space charge distribution. In addition, the fact that the reignition oscillation consists

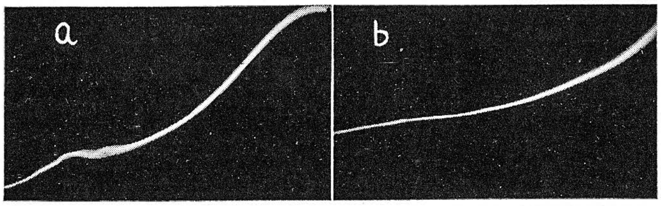

Photo. 7 Wave form difference between the filament (a) and indirect heated cathode (b).

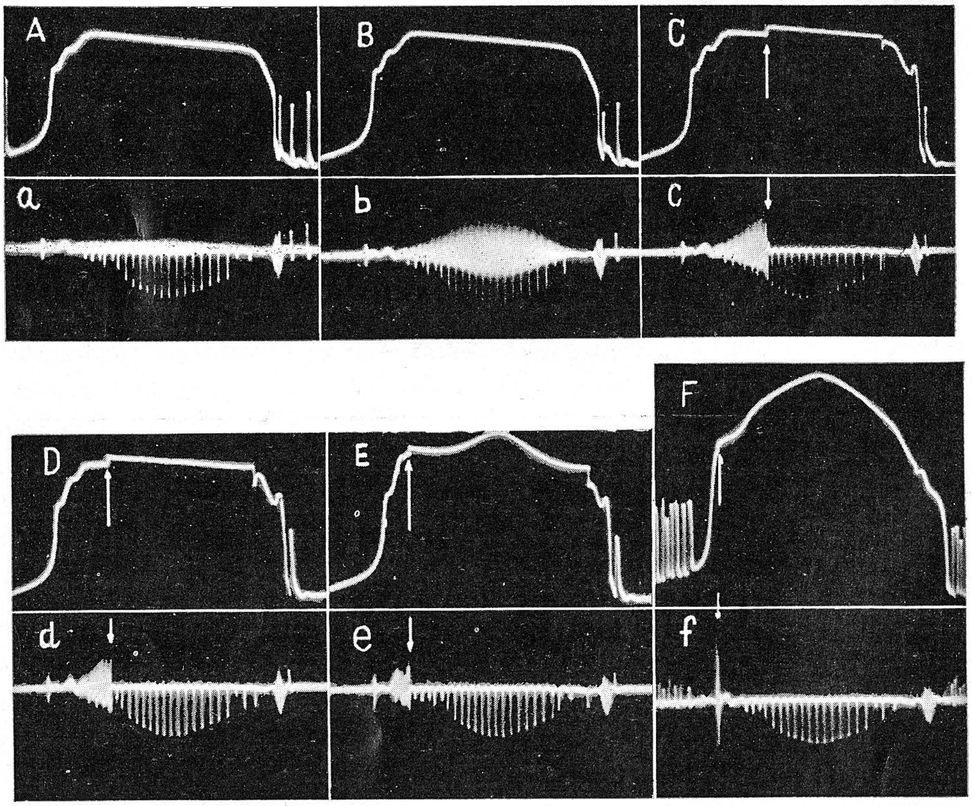

Photo. 8 Probe potentials and the differentiated wave forms of terminal voltage in respect of the indirect heated cathode lamp; lamp current: 0.36A. (A)$\sim$(F) show probe potentials and (a)$\sim$(f) differentiated wave forms. Heating current is 0.46, 0.4, 0.35, 0.3 and 0 A for (A) to (E). (F) and (f) are shown in the case of filament cathode, the arrows show the discontinuity (C)$\sim$(E).

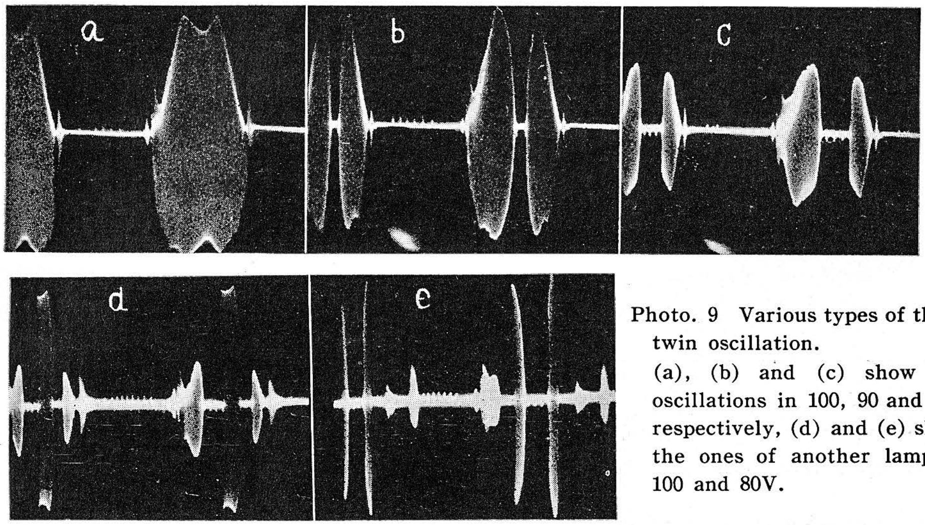

Photo. 9 Various types of the twin oscillation. (a), (b) and (c) show the oscillations in 100, 90 and 80V respectively, (d) and (e) show the ones of another lamp in 100 and 80V.

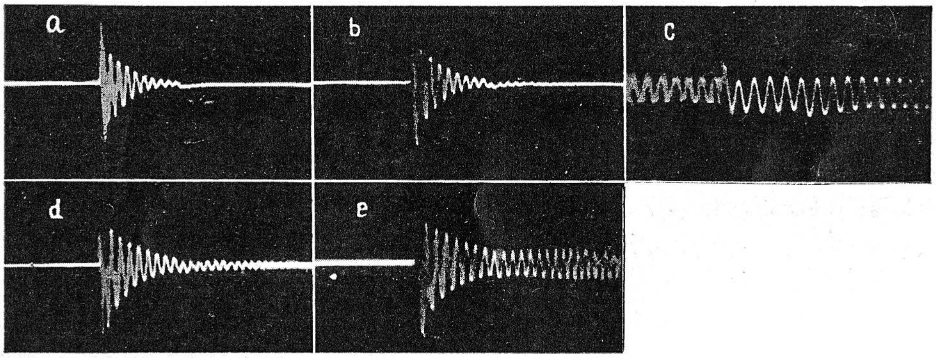

Photo. 10 Pulse responses in DC discharge; (a) lamp current 0.45 A frequency 1595 kC, (b) 0.4 A, 1430 kC, (c) 0.2 A 850 kC with interterminal capacitor of 100 pF, (d) 0.45 A, 1460 kC connected E_1 to C, (e) 0.4 A, 1325 kC connected E_1 to C.

essentially of irregular pulses, justifies regarding it as one due to the fluctuation in density of the space charges with the glow movement, not as their mass motion. In other words, the reignition oscillation can be supposed to be caused by the ionization occurring as the space charges increase or decrease, or by the space charge fluctuation.

The gradual increase of the amplitude, which is observed in the oscillation in the indirct heated cathode during its transition to the discontinuity, is considered to be due to the same mechanism with the shot noise occuring in vacuum tubes. The reason for this is as follows: the inequality $i_L < i_S$ stands before the discontinuity and the potential trough in front of the cathode becomes gradually shallow with the value of i_L nearing that of i_S; consequently, so-called alleviating action of space charges to the noise becomes weaker.

The amplitude therefore takes the maximum value when $i_L = i_S$. It seems that the shielding effect by ion sheath causes the oscillation to be extinguished at the same time with the discontinuity.

Among cathode oscillations, one which is composed of the saw-teeth waves is generally extremely stable and regular. Upon the shift of the cathode spot, this type of oscillation disappears, turning into on irregular oscillation. In the lamp whose cathode spot is constantly moving about, it takes place only when a specified position is taken by the cathode spot.

The oscillation of this type should be distinguished from the reignition oscillation, because, as we will describe in the following chapter the characteristics of the relaxation oscillation are just the same with those of the hollow cathode oscillation.

3. Twin Oscillation

The twin oscillation, as the term implies, is one which is produced in pair symmetrically to the extreme value of any of half cycles.

Classified under the twin oscillation are: one joined continuously with the reignition oscillation, a pair of twin combined together in the middle of a half cycle, one occurring in double or triple pairs, or, rarely to ocurr, one occurring during a full half cycle. The twin oscillation is very regular and periodical, with a definite frequency spectrum. The function of current is the frequency, which increases with the current. Accordingly, the frequency of the oscillation at thd beginning and the end of a half cycle lies beneath that of the broadcast band, thus being given less significance with regard to the radio-interference; but the oscillation produced in the middle of a half cycle extends its frequency within the region of the broadcast band. with its disturbing effect reaching an extreme degree.

The twin oscillation occurs in the case of the direct current lighting as well, and its charasteristics are the same as in the alternating current lighting.

Furthermore, this type of oscillation is one peculiar to the filament cathode.; it does not occur on the indirect hested cathode.

Still furthermore, as the generation of this oscillation can be controlled by external conditions, it is possible to completely suppress it through proper design and structural modification of the cathode.

3.1. Wave Form

Photo. 9 represents twin oscillations produced under various conditions. It is clear from the figure that the envelope to the oscillation is very definite and indicates the regularity of the oscillation. The oscillation, through saw-teeth shaped at the beginning of a half cycle, approximates to sinusoidal wave as it moves towards the middle of the half cycle.

3.2. Conditions for Generation in the Case of Alternating Current Lighting.

The twin oscillation is liable to occur in fluorescent lamps lighted for long period, and seldom in new ones. Even in the lamp in which this oscillation is occurring, it disappears with the current increasing. To the contrary, if the current is decreased in the lamp in which no oscillation exists, it appeare often. Furthermore, there are cases that it takes place transiently when the current intensity is abruptly changed. By means of a lamp with no fluorescent material coated on its tube wall, we can readily affirm that such transition is caused by the shift of the cathode spot and that it occurs upon specified position the cathode spot takes. Moreover, for the lamp with its auxiliary anode and filament separately lead out. there exists a critical state where the oscillation is generated when both are connected with each other, and extinguished when not connected. In this case, too, the oscillation is accompanied by the shift of the cathode spot. Thus, this type of oscillation is also apparently a characteristic attendant upon the cathode spot; the occurrence of the oscillation ceases even in the same lamp if, as shown in Photo. 2, (b), (f) the cathode spot shifts on the electrode.

There is another instance that the oscillation is decreased or extinguished by connecting the electrode with the probe extremely near it through a capacitor. The twin oscillation can also easily be extinguished through the superposition of auxiliary discharge, high frequency electrodeless discharge, and so on. The heating of filament exerts considerable influences; it generally extinguishes the oscillation, but, to the contrary, it generates sometimes.

In conclusion. the twin oscillation seldom occurs when the current is intensified and the filament temperature is high; and it disappears with artificial changes of the space charges. Therefore, the oscillation of this kind can be said to take place only when some particular conditions are satisfied.

3.3. Oscillation in Direct Current Discharge

In direct current discharge, too, the twin oscillation can be produced, with its wave form approximating to sinusoidal wave. The oscillation under this condition is very regular. When the power source is fed by the rectified alternating current, the ripples in the current modulate the wave form with respect to the amplitude and frequency. On case that the oscillation is weaker, the oscillation is given rise at the trough of the current ripples. If the anode oscillation is present in this instance, it occurs accordingly with the frequency of the anode oscillation as the recurrent frequency. In the case of direct current, the lamp current capable of generating the oscillation ranges from 100 to 500 mA; rarely the oscillation holds on to 600 mA.

3.4. Pulse Response in Discharge Space

The above-mentioned oscillations due to alternating and direct current being very regular, they are thought to be characteristic of the discharge space. Therefore, with views to clarify, according to the theory of plasma oscillatson, how the local agitation in the discharge space appears at the terminals, we have studied changes in the wave form between terminals by applying the pulse and the output of high frequency oscillator, to be described in the following article, to the terminals Pc-C in Fig. 1, (b). The width of the pulse applied is of the order of 3 to 15 μS; it is applied to Pc through a condenser of 100 pF. Therefore, the equilibrium potential of the probe Pc is a wall potential. The consequence is, as shown in Photos. 10 and 11, that damped oscillation appears at the terminals only when the electrode considered becomes cathode. As for the alternating current lighting, the pulse is applied to the terminals between PA-A in Fig. 1, (a). Photo. 11 shows the oscillation produced in the case of the alternating current discharge,

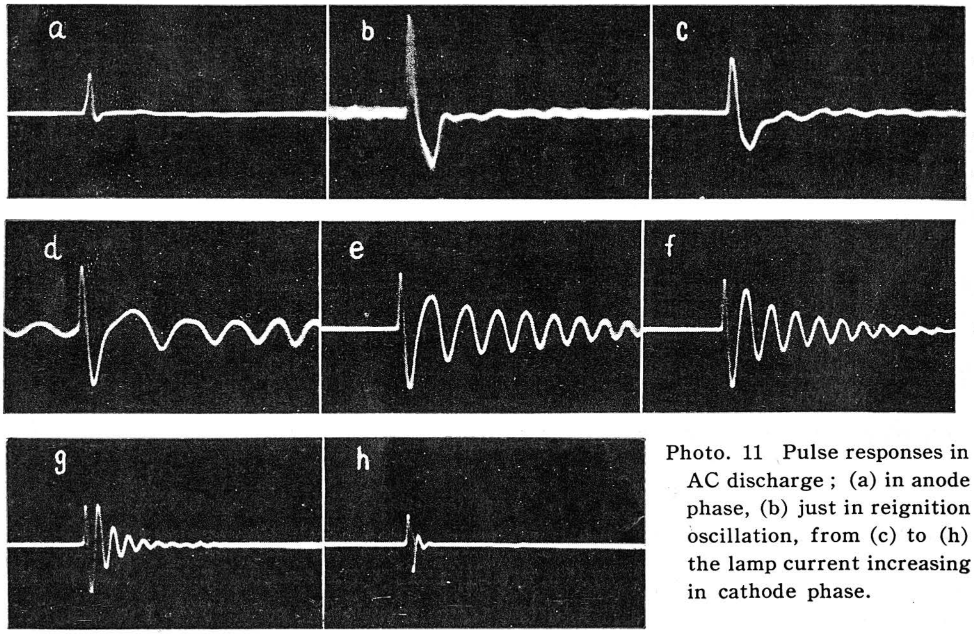

Photo. 11 Pulse responses in AC discharge; (a) in anode phase, (b) just in reignition oscillation, from (c) to (h) the lamp current increasing in cathode phase.

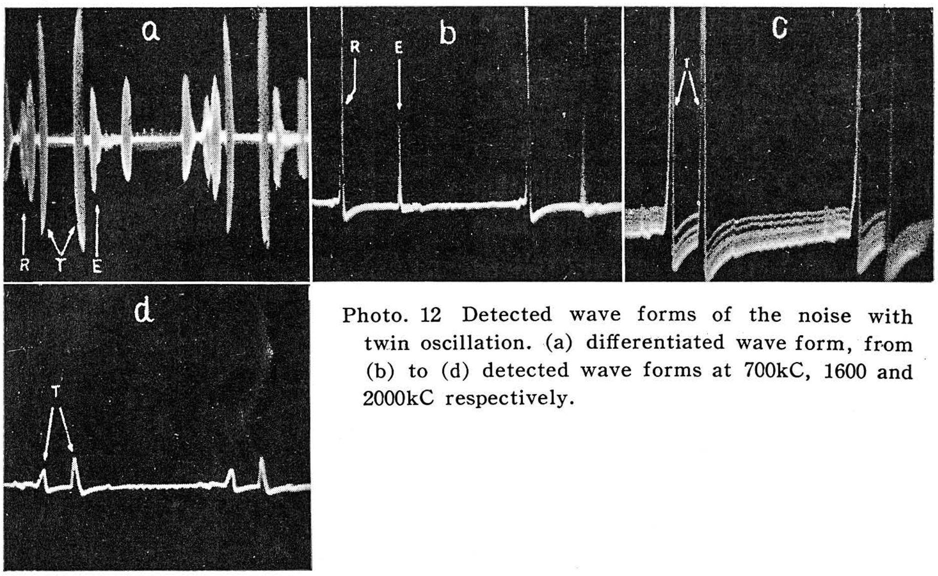

Photo. 12 Detected wave forms of the noise with twin oscillation. (a) differentiated wave form, from (b) to (d) detected wave forms at 700kC, 1600 and 2000kC respectively.

where the terminal voltage wave form is differentiated in oredr to filter off the power supply frequency.

What is to be marked in this experiment, is that, as well be explained in 3.5, the oscillation occurs between terminals when the pulse is applied between the probe and the cathode, but that a single pulse only appears as shown in Photo. 11 (a) when it is applied between the probe and the anode. Further in this case, the variation of the frequency with the lamp current is just the same with that described in 3.2 and 3.3. Of this we will discuss comprehensively in 3.6.

In this experiment, the pulse is not necessarily appied exclusively to the probe; the same result is obtained by applying the pulse between the cathode and the metallic band E_1, which is foiled around the exterior wall of the lamp, as is shown in Fig. 1, (b). The output voltage varies with the surface area and the distance from the cathode of the metallic band (to be called "exterior conductor" hence forth); the larger its area is, and the nearer to the cathode it is; the greater the amplitude becomes.

With a view to ascertaining possible effects by induction and other phenomena upon the experiment of pulse application, the authors have investigated the combinations of pulse generator with the lamp, and the power source and other cases, but we could not detect any oscillation except when the lamp was lighted. This type of oscillation, therefore, is concluded to be due to the characteristics of the discharge space in a fluorescent lamp. It is, however, not observed in the indirect heated cathode; on this fact a detailed description will be given in 3.7.

3.5. Frequency Response in Discharge Space

When a high frequency voltage is applied between the probe and the cathode, what is in essence the same with the pulse response, the oscillation due to it appears between the lamp terminals, and the high frequency voltage at the terminals varies with the input frequency. As the detective device for this oscillation, a combination of a LC resonator and valve-voltmeter is used, with the indication of the latter being read. The correlation between the frequency and the resonance voltage of the L-C circuit presents resonant characteristics, for a constant high frequency input voltage shown in Fig. 4. The resonant frequency changes with the lamp current I. However, even if the lamp current is kept constant, the resonant frequency changes with the interterminal capacitor C as is shown in Fig. 5. Further, the oscillation propagates itself from the cathode to the anode; to the contrary, the output of the high frequency voltage applied between the probe and the anode does not appear between the terminals of the lamp. It is thus made clear that local disturbance is necessarily transferred towards the anode.

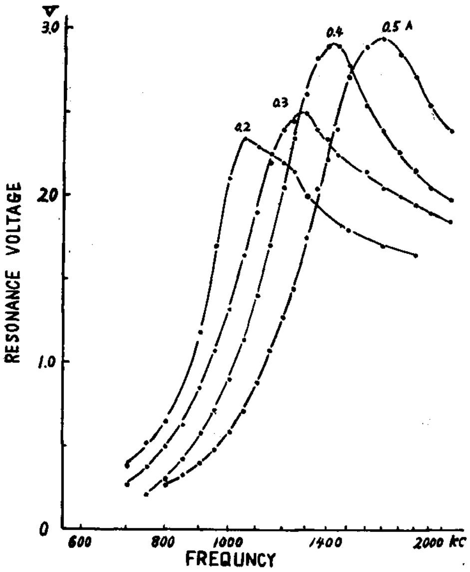

Fig. 4 Frequency response of DC discharge with variation of lamp current.

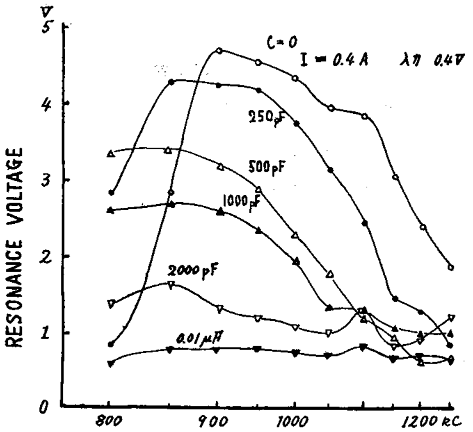

Fig. 5 Frequency response of DC discharge with interterminal capacitor.

3.6. Frequency Characteristics

As we have mentioned above, the twin and the direct current oscillation, and the oscillatory characteristics of the discharge space have the same characteristics: that is to say, their frequency changes with the lamp current as well as with the capacity of the condenser connected between the terminals. Let us take for an

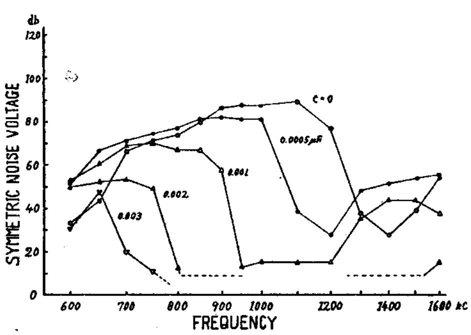

Fig. 6 Frequency characteristics of twin noise, lamp NE-1; power supply 80V.

example a case where the twin oscillation is going on: in the case of the alternating current lighting, the frequency characteristics of the noise voltage, measured by a noise-meter, has often a remarkable peak in the broadcast band as Figs. 6 to 8 show. Photo. 12 shows the relation existing between the dffierentiated wave form (a) and the detection wave form at the receiver (b)-(d), which evidently vary with the frequency. Fig. 9 shows the frequency characteristics of the direct cnrrent oscillation described in 3.3. For detecting device, the wave meter described in 3.5. was used. The completely same curves will be obtained by a noise-meter.

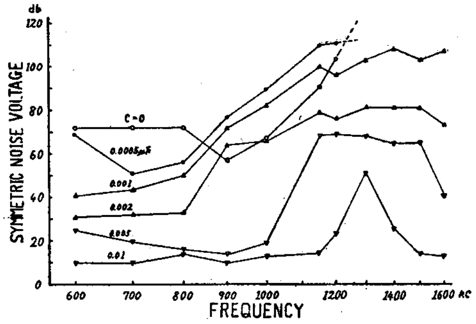

Fig. 7 Frequency characteristics of twin noise lamp NE-1 power supply 100V.

Putting together these characteristics are Figs. 10 and 11. The former shows the relation between the lamp current I and the frequency, and the latter that between the condenser capacity C between the terminals and the reciprocal of the squared frequency, each showing respectively the same propensity. Further, the dotted line in Fig. 10 is the straight line representing

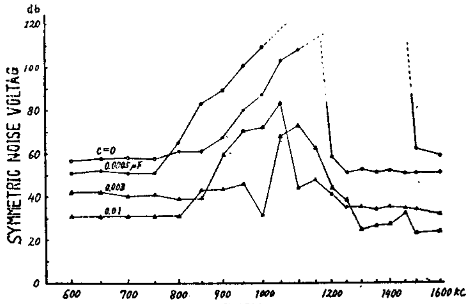

Fig. 8 Frequency characteristics of twin noise, lamp NA-1; power supply 100V.

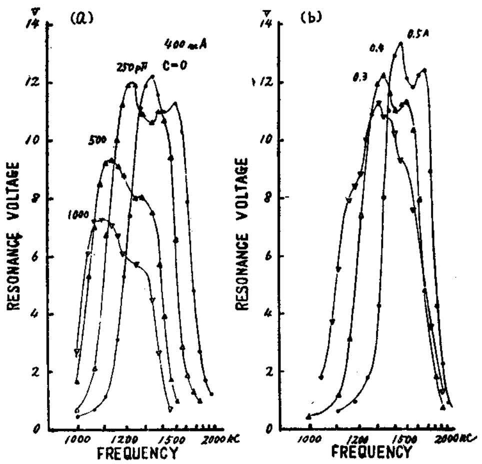

Fig. 9 Frequency shift of the oscillation of DC discharge by the interterminrl capacitor (a) and by the lamp current (b).

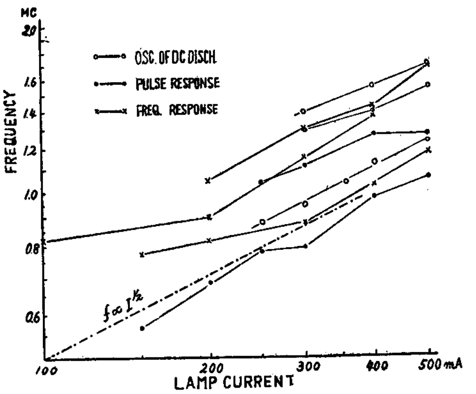

Fig. 10 The frequency *vs* lamp current.

the relation $f \propto I^{1/2}$. That almost all curves are parallel to this line seems to indicate that these oscillations are the plasma ion oscillation.

As is evident from the differentiated wave form of the terminal voltage and Figs. 6–8, it is very significant that the twin oscillation has a very great intensity, with its frequencies covering the broadcast band. Though, fortunately, levels of most of them can be lowered by means of about 0.01 μF condenser, there are cases, as shown in Fig. 8, where as much as about 70 db in noise level lingers even with the 0.01 μF condenser, making almost impossible the reception of the broadcast on that frequency.

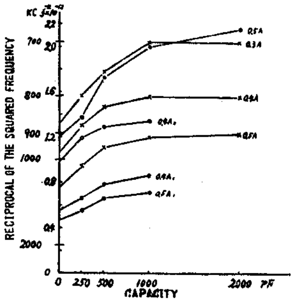

Fig. 11 The frequency shift by the interterminal capacitor.

3.7. Characteristics of Direct Current Oscillation

According to the conclusion explained above, nothing exists to distinguish substantially the twin and direct current oscillation from each other. Therefore, the authors have attempted to study the characteristies in the direct current lighting.

3.7.1. Frequency of Oscillation

The frequency change of this type of oscillation with the current has enough to remind us of the plasma ion oscillation. Accordingly, for the purpose of investigating the nature of the element controlling the frequency, the authors have examined the frequency changes following that of the ratio of the auxiliary current I_A to the main discharge current I_m, by generating both with common cathode, by means of the circuit shown in Fig. 12. The result is, as is shown in

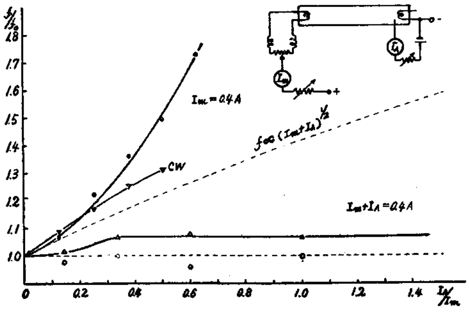

Fig. 12 The frequency shift by superposition of auxiliary discharge.

the figure, that the frequency hardly changes with a constant total current $I_A + I_m$; the changes in frequency is observed only when the auxiliary discharge current I_A is increased, with the main discharge current I_m being kept constant. The above result indicates that the frequency change is controlled in the vicinity of the cathode.

3. 7. 2. Amplitude

One of the major factors to govern not merely the amplitude of, but also the generation and extinction of the oscillation is the effect of the conductor on the exterior wall of the lamp. As is shown by Fig. 1 (b), the oscillation is intensified when the exterior conductor E_1 and the cathode C are connected directly or through a condenser, and extinguished or damped when they are connected through an inductance. Fig. 13 shows the change of the oscillation characteristics occurring both when E_1 and C are directly linked and when they are not; the changes in amplitude is by far more remarkable than that in frequency. To be specifically mentioned is that even a lamp, which does not produce oscillation under normal conditions, does when E_1 and C are connected. Fig. 14 shows the result obtained by measuring the changes of the probe potential near the cathode and the oscillation potential under this condition. The oscillating voltage in this case is that measured between E_2 and C by a valve voltmeter. The anode oscillation is of course suppressed in this case. It is eviednt from the figure that if the oscillation takes place the probe potential becomes lower.

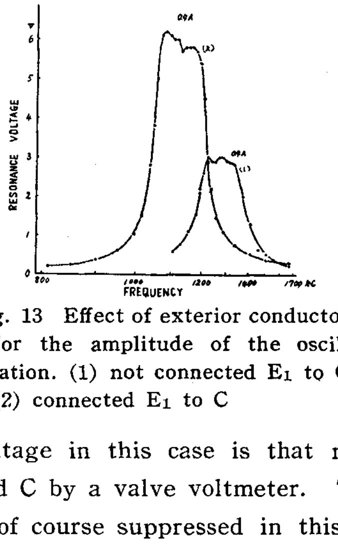

Fig. 13 Effect of exterior conductor for the amplitude of the oscillation. (1) not connected E_1 to C (2) connected E_1 to C

Even in the case where the connection of the exterior conductor E_1 with C does not cause the oscillation to be generated, the decrease in the attenuation constant of the damped oscillation is evident from the pulse response. Photo. 10. (d) and (e) present, in contrast to (a) and (b), the change under this condition.

It is a matter of course that these changes are dependent upon the area of the conductor and its

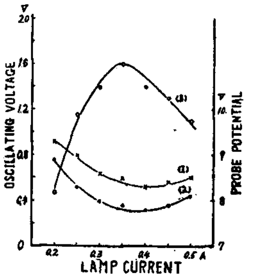

Fig. 14 The wall potential of the probe and the oscillating voltage *vs* lamp current (1) the wall potential without and (2) with the oscillation, (3) oscillating voltage.

distance from the cathode; they occur in the same manner as was stated in 3.4.

3.7.3. Indirect Heating Type Cathode

Though we examined the pulse response by the indirect heating type cathode, explained in 2.8, in the lamp current range of 0.1 to 0.6A, we could not obtain any sign of oscillation. Therefore, we have measured the probe characteristics for the comparison with the filament cathode. The result obtained is that the wall potential is much lower, as Table 4 shows, than in the filament cathode, with the electric field in front of the cathode being very weak within the normal range of use.

Table 4. Prode characteristies in indirect heated type and filament cathode

	Indirect heated cathode lamp current I=0.4 A				Filament cathode I=0.4 A
Heater current (A)	0.52	0.48	0.385	0.19	
Wall potential of the probe (V)	−3.0	−1.5	−0.11	2.81	9.65
Saturated ion current (μA)	30	150	190	610	3800

3.8. Considerations upon Twin Oscillation

Let us proceed on considering upon the basis of the results thus far obtained. Accorting to the theory of plasma ion oscillation,(12) the limit frequency of the space charge wave in the ionized space is given as follows:

$$\omega_p=\sqrt{\frac{e^2n}{M\varepsilon}} \quad \cdots\cdots(1)$$

where e denotes the ion charge, n the ion density, M the ion mass and ε the dielectric constant, with MKS rationalized units being adopted. According to the measurement done by Nakamura,(13) the ion density in the positive column is nearly proportional to the current I; consequently, we obtain from the equation (1),

$$f_p=kn^{\frac{1}{2}}=k'I^{\frac{1}{2}} \quad \cdots\cdots(2)$$

where k and k' are both proportional constants.

Now, let us take Hg^+ ion for example, the equation (2) is transcribed as:

$$f_p=1.48\times10^{-2}\sqrt{n} \quad \cdots\cdots(3)$$

With Nakamura's value taken up, $n=4\times10^{17}m^{-3}$ at $I=0.3A$, hance $f_{p0.3}=9.3MC$ while according to our measurement $n=2.5\times10^{17}m^{-3}$ at $I=0.5A$, hence $f_{p0.5}=7.4MC$, which is greater by almost one figure. It is still uncertain, and yet to be studied whether this discrepancy is a substantial one or is due to neglecting the ionic collision with gas atom.

What has been mentioned in 3.7 is the features of this oscillation and also is the phenomena important to know its nature. In other words, the fact that the factors governing the frequency rest on the cathode, indicates that the oscillation is generated at the cathode and is transferred to the anode without modification; while the potential fall of the probe, which occurs at the same time with the generation of the oscillation, shows that the magnitude of fhe cathode fall is related with this oscillation. In the light of the notion of the space charge wave, it is reasonable that this oscillation does not occur at the indirect heated cathode, and that the cathode fall is involved in its generation; but, the effects of the condenser inserted between terminals, and that of the exterior conductor can not be explained.

To the contrary, the effects of the exterior conductor show that this oscillation is controlled by the boundary conditions of the discharge space. They further show, together with the effects by condenser, that this oscillation is governed by conditions of both discharge space and external circuits. Anyhow, it is characteristic of the filament cathode as is evident from the pulse response, and the presense of a considerable accelerating electric field in front of the cathode, would be the necessary condition to produce it.

The hollow cathode noise, treated by Culp, is quite analogous to this oscillatton; especially, the saw teeth wave mentioned before must be due to the hollow cathode oscillation itself. Both twin oscillation and direct current oscillation are generated when the cathode spot occupies a specified position. This fact may be a proof that the hollow cathode appears on that position. It is difficult, however, to explain the effect of the exterior conductor by this fact.

The generating mechanism of this oscillation has not yet been substantially elucidated; but, to put together the results thus far obtained, the necessary condition for generating the oscillations explained in this article, is the presence of the accelerating electric field in front of the cathode. The oscillation seems to be generated through the effect of that accelerating field upon the cathode which is modified by the ionic oscillation at boundaries. The feed-back action from them is evident from the effect of the exterior conductor explained in 3.7.

4. Conclusion

By classifying and studying the relations between fluorescent lamp noises and their oscillations according to their origins, we have thus far clarified their features and characteristics; and further we have obtained evident facts which explain the mechanism of their generation through numerous experiments upon it. In short, our experimental results are as follows:

(1) The reignition oscillation is essentially irregular and its wave forms are composed of train of puleses.

(2) Its generation is controlled by the electron emission from the cathode, the density of residual ions, the ratio of increase of the lamp current, etc. It is also supposed, on the ground of the experiments upon the indirect heated cathode, when the electric field in front of the cathode is weak.

(3) Further, this oscillation is the major cause of the noise in the broadcast band, with the quasi-peak values of the noise voltage in average being 50 db on 40 W lamp, and 26 db on 20 W (both being the symmetric voltage).

(4) The noise voltage mentioned above is attenuated by about 30 db in average by a 0.05 μF condenser between the terminals. By the way, it is to be mentioned that the installing of 0.006 to 0.01 μF condenser in the lighting unit of fluorescent lamp has been recently stipulated in JIS(14) (Japan Industrial Standard).

(5) The twin and direct current oscillations are very regular, with their wave forms approximating the sinusoidal wave near the middle of a half cycle and forming saw-teeth wave in its early period. In the case of the direct current, the wave form is almost sinusoidal independently of the current intensity.

(6) The frequency of this oscillation is changed regularly by the lamp current and the capacitance of the condenser between the terminals.

(7) From the outcomes of the pulse reponse and other ones, this oscillation is concluded to be due to the feedback from the boundaries to the accelerating electric field in front of the cathode.

(8) The twin noises occur frequently in the aged lamps. Though their level is remarkably high, they can be mostly extinguished by 0.01 μF condenser: But some of them cannot be eliminated with the condenser of the above capacitance.

(9) Under normal conditions, most noises in the broadcast band are caused by the reiguition and the twin oscillation; the anode oscillation seldom matters.

On concluding this report, the authors appreciate the valuable assistance given us by the Radio Interference Investigating Committee, Kansai Branch of Institute of Electrical Engineering of Japan, and the Subcommittee on Discharge Lamps, Investigating Committee on Illumination, Kansai Branch of Institute of Illuminating Engineering of Japan. Further, we gratefully acknowledge the courtesy of the Receiver Section, Osaka Central Broadcasting Station NHK, in connection with the noise-meter, and of the Fluorescent Lamp Section New-Nippon Electric Company, Ltd., in preparing discharge lamps. We received Ministry of Education Grant for Scientific Research for the fiscal 1955 in carrying on this study, for which we are also grateful. Finally, to Mr. Yamato, of Japan Storage Battery Co. Ltd., Kyoto, we express our gratitude for his kind assistance.

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