Modified Thyratron Amplifier and Measuring Device for the Characteristics

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Abstract

In the present paper, the first part deals with the analyses and the experimental results of "Modified Thyratron Amplifier" having no d.c. component in its output current in contrast with the fact that the output of the original thyratron amplifier is composed of a.c. and d.c. one as shown in an earlier paper of this series. It goes without saying that the modified thyratron amplifier reported in this paper can do the linear amplification of the ultra low frequency signal without distinction of the waveform of a.c. power supply voltage as well as the original thyratron amplifier.

In the latter part, the principle and the circuit of the measuring device which is available for the characteristics of both modified and original thyratron amplifier are described, together with the experimental results.

1. Introduction

In the previous paper[1] of this series, it was shown on the thyratron amplifier which is able to perform the linear amplification of the ultra low frequency signal without distinction of the waveform of a.c. power supply voltage.

The modified form of the original thyratron amplifier[2], which is able to do the similar function except that the modified one has no d.c. component in its output current, was originated and named "Modified Thyratron Amplifier".[3]

The measuring device for the characteristics of thyratron amplifiers is able to attain the purpose by transforming the thyratron amplifier output voltage waveform to a pulse, of which magnitude is proportional to the average value of the former during the half cycle period comprehending the output voltage waveform.

The measuring circuit reported in an earlier paper[1] is not available for the characteristic measurement of the modified thyratron amplifier of which the polarity of the output current changes in accordance with that of ultra low frequency signal to be amplified.

Then, the analyses and the experimental results are described on the circuit that is available for the measurement of both original thyratron amplifier and modified one.

2. Modified Thyratron Amplifier

Fig. 1 shows the basic circuit of the modified thyratron amplifier. Two pairs of thyratrons, A_1, A_2, and B_1, B_2, are employed and those in each pair are connected in the single-phase full-wave rectifier type so that the output current of each pair in the resis-

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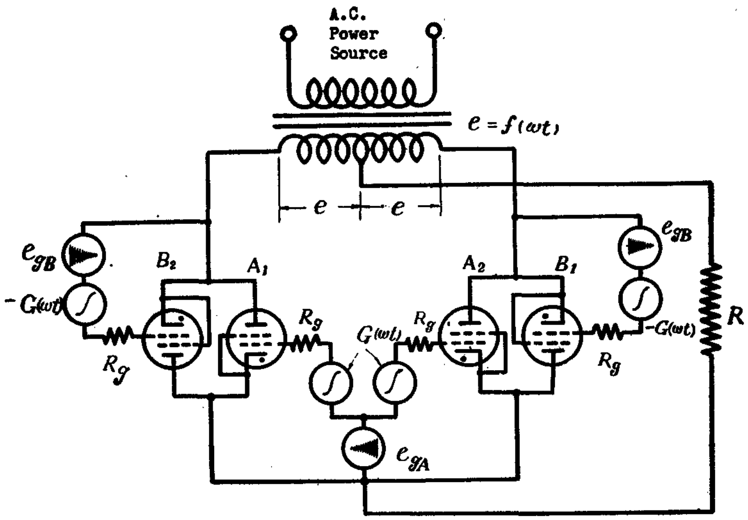


Fig. 1. Basic Circuit of Modified Thyratron Amplifier.

tance load may flows in the reverse direction each other. In Fig. 1, R and e represent, respectively, the load resistance and the instantaneous value of a.c. plate voltage, shown as $f(\omega t)$, having an arbitrary waveform and a period $2\pi/\omega$. The two amplitude modulated voltages, shown as e_{gA} and e_{gB}, being modulated with the ultra low frequency signal to be amplified, of which phases are reverse each other,

$$e_{gA} = C(1+m\sin\alpha t)\sin\beta t \tag{1}$$

and

$$e_{gB} = C(1-m\sin\alpha t)\sin\beta t \tag{2}$$

are fed into the grid circuits of A group thyratrons and B group thyratrons respectively. In Eq. (1) and Eq. (2), α and β represent the angular frequency of ultra low frequency signal and carrier wave voltage, respectively. Their relations are $\beta \gg \omega$ and $\omega \gg \alpha$ as reported in details in the previous paper of this series.

Then we consider that $G_A(\omega t)$ or $G_B(\omega t)$ given by Eq. (3) or Eq. (4) is applied to A group or B group thyratrons respectively, as a specified bias voltage to the thyratron working under the p-th half cycle being counted from $t=0$ and thyratrons are controlled by one of these two amplitude modulated wave voltages given in Eq. (1) and Eq. (2).

if $\sin\alpha t > 0$,

$$G_A(\omega t) = \frac{(-1)^p}{k}\int_{\omega t}^{p\pi} f(\omega t)\cdot d\omega t - C = g(\omega t) - C \tag{3}$$

if $\sin\alpha t < 0$,

$$G_B(\omega t) = \frac{(-1)^{p-1}}{k}\int_{\omega t}^{p\pi} f(\omega t)\cdot d\omega t + C = -g(\omega t) + C \tag{4}$$

where

$$g(\omega t) = \frac{(-1)^p}{k}\int_{\omega t}^{p\pi} f(\omega t)\cdot d\omega t\,.$$

Since the first term in Eq. (3) gives the specified bias voltage, $g(\omega t)$, in the original thyratron amplifier, $G_A(\omega t)$ represents the voltage which $g(\omega t)$ was shifted to the negative direction by the amplitude of carrier wave voltage as shown in Fig. 2 which illustrates the relations of the voltages of various parts in the modified thyratron amplifier working under the positive portion of the ultra low frequency signal. Also $G_B(\omega t)$ given by Eq. (4) represents the voltage which $g(\omega t)$ was reversely phased and shifted to the positive direction by the same value in a case of $G_A(\omega t)$.

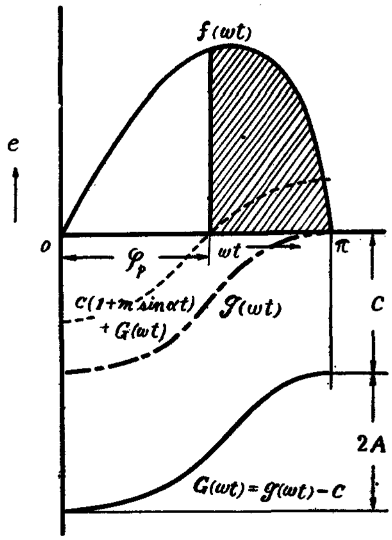


Fig. 2. Grid Control of A-Group Thyratron.

As will be seen from Fig. 2, the firing angle, φ_p, in an arbitrary p-th half cycle of a.c. power supply voltage should satisfy the next relation.

$$0 \leqq \varphi_p \leqq \pi . \tag{5}$$

Therefore, thyratrons of A group are to fire if $\sin \alpha t > 0$, and those of B group are to do so if $\sin \alpha t < 0$.

In this case, it is absolutely impossible that thyratrons of both groups will be fired at the same time.

Given these facts, either A or B group thyratron is to fire at such instant, $t = t_p$, in the p-th half cycle, as satisfy the following relations;

if $\sin \alpha t > 0$,

$$-G_A(\omega t) = C(1 + m \sin \alpha t) \sin \beta t \tag{6}$$

if $\sin \alpha t < 0$,

$$G_B(\omega t) = C(1 - m \sin \alpha t) \sin \beta t . \tag{7}$$

Referring to Eqs. (3), (4), (5), (6) and (7), the average value of load current during the p-th half cycle, I_{mp}, is shown as follows:

if $\sin \alpha t > 0$,

$$I_{mp} = \frac{(-1)^{p-1}}{\pi R} \int_{(p-1)\pi + \varphi_p}^{p\pi} f(\omega t) \cdot d\omega t = \frac{kC}{\pi R} \cdot m \sin \alpha t_p \tag{8}$$

if $\sin \alpha t < 0$,

$$I_{mp} = \frac{(-1)^{p}}{\pi R} \int_{(p-1)\pi + \varphi_p}^{p\pi} f(\omega t) \cdot d\omega t = \frac{kC}{\pi R} \cdot m \sin \alpha t_p . \tag{9}$$

Eq. (8) and Eq. (9) are reasoned on the following hypotheses:

1. The angular frequency of controlling carrier, β, is very larger than ω as previously mentioned.
2. The critical grid voltage and arc-voltage drop of the thyratrons are neglected.

In either case, consequently, the average value of load current during any half cycle period of a.c. power supply voltage is proportional to the instantaneous value of the ultra low frequency signal voltage at the instant that the thyratron fires, and the load current changes its direction in accordance with the sign of ultra low frequency signal voltage.

By making use of the following relations,

$$\omega t_p = (p-1)\pi + \varphi_p$$

$$S = \frac{\omega}{\alpha} \quad (S\text{: positive integer})$$

$$\varphi_p = \varphi_{S+p}$$

the Fourier expansion of the instantaneous load current is shown as

$$i = a_0 + \sum_{n=1}^{\infty} a_n \cos n\alpha t + \sum_{n=1}^{\infty} b_n \sin n\alpha t . \tag{10}$$

If the plate voltage of thyratron is represented by $f(\omega t)$, the Fourier coefficients are shown as follows:

$$a_0 = 0 \tag{11}$$

if n is even,

$$a_n = b_n = 0 \tag{12}$$

if n is odd,

$$a_n = \frac{2}{S\pi R} \sum_{p=1}^{S} \int_{\varphi_p}^{\pi} f(\omega t) \cdot \cos \frac{n}{S}\left\{(p-1)\pi + \omega t\right\} d\omega t . \tag{13}$$

$$b_n = \frac{2}{S\pi R} \sum_{p=1}^{S} \int_{\varphi_p}^{\pi} f(\omega t) \cdot \sin \frac{n}{S}\left\{(p-1)\pi + \omega t\right\} d\omega t . \tag{14}$$

If a function $f(\omega t)$, having a period $2\pi/\omega$, is such that

$$f(\omega t) = E_{\max} \sin \omega t \tag{15}$$

and n is odd, the Fourier coefficients are shown as follows:

$$a_n = \frac{2E_{\max}}{\pi R} \cdot \frac{1}{S^2 - n^2}\left[-S + \sum_{p=1}^{S} \left\{ S \cos \varphi_p \cdot \cos \frac{n}{S}\left(\overline{p-1}\pi + \varphi_p\right) + n \sin \varphi_p \cdot \sin \frac{n}{S}\left(\overline{p-1}\pi + \varphi_p\right)\right\}\right] \tag{16}$$

$$b_n = \frac{2E_{\max}}{\pi R} \cdot \frac{1}{S^2 - n^2}\left[S \cot \frac{n\pi}{2S} + \sum_{p=1}^{S} \left\{ S \cos \varphi_p \cdot \sin \frac{n}{S}\left(\overline{p-1}\pi + \varphi_p\right) - n \sin \varphi_p \cdot \cos \frac{n}{S}\left(\overline{p-1}\pi + \varphi_p\right)\right\}\right] \tag{17}$$

$$a_S = \frac{E_{\max}}{S\pi R} \sum_{p=1}^{S} (-1)^p \sin^2 \varphi_p \tag{18}$$

$$b_S = \frac{E_{\max}}{S\pi R} \sum_{p=1}^{S} (-1)^{p-1} \{\pi - \varphi_p + \sin \varphi_p \cdot \cos \varphi_p\} . \tag{19}$$

In this case, the firing angle, φ_p, in the p-th half cycle of a.c. plate supply voltage is given by the next equation.

$$1 + \cos \varphi_p = \pm 2m\eta \sin \frac{1}{S} \{(p-1)\pi + \varphi_p\} . \tag{20}$$

In Eq. (20), plus or minus sign follows to that of $\sin \alpha t$ and the firing angle, φ_p, satisfy the relation given by Eq. (5). It is also noticed that η and $2A$ are given by the following relations.

$$\eta = \frac{C}{2A} \leqq 1 \tag{21}$$

$$2A = \frac{1}{k}\int_0^\pi f(\omega t)\cdot d\omega t = \frac{2E_{max}}{k}. \tag{22}$$

In the case of $S \geqq 6$, Eq. (10) may be transformed into

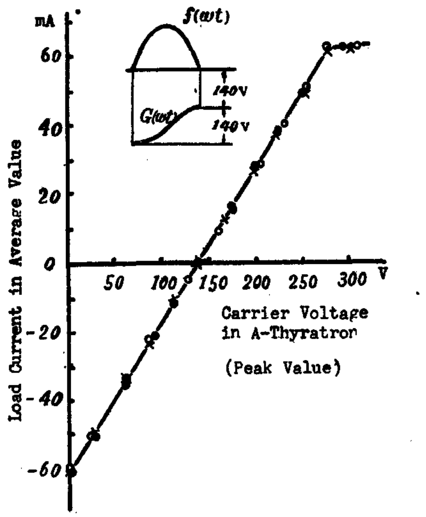
$$i \simeq \frac{kC}{\pi R} m \sin \alpha t + \sum_{n=q}^{\infty} a_{2n-1} \cdot \cos\{(2n-1)\alpha t\} + \sum_{n=q}^{\infty} b_{2n-1} \sin\{(2n-1)\alpha t\}. \tag{23}$$

where q is represented as follows,

if s is even, $\quad q = \frac{s}{2}$

if s is odd, $\quad q = \frac{s+1}{2}$

Accordingly, the component affected by the angular frequency of the signal to be amplified is represented by the first term in Eq. (23) and then the amplification of the ultra low frequency signal voltage is performed linearly without d.c. component. The load current characteristics with respect to the controlling carrier wave voltage which is fed into the grid circuits of the thyratrons are illustrated in Fig. 3. As shown in Fig. 3, the experiments were done by employing such a.c. power supply voltages that have various waveforms and equal mean values, which attained to identical results. It is to be noted that the positive and the negative current illustrated in Fig. 3, show the current of the A group thyratrons



Measuring Point	Waveform	E_m (V)	$\omega/2\pi$ (c/s)	$\beta/2\pi$ (c/s)
×	Sinusoidal Wave	222.5	60	5000
•	Rectangular Wave	222.5	60	5000
∘	Distorted Wave	222.5	600	30000

Fig. 3 Load Current Characteristics of Modified Thyratron Amplifier.

and that of the B group thyratrons respectively. Furthermore, from Fig. 3, it is evident that the identical linear characteristics are obtainable if only the mean values of a.c. power supply voltages are equivalent, even in such cases that they have different waveforms.

3. Principles of Characteristic Measurement

As mentioned above, the fundamental component of the amplified signal in the load current of the modified thyratron amplifier having resistance load, is given by the first term in Eq. (23).

Provided that the magnitude of the fundamental component at $t=t_p$ is denoted by A_p, it is given by,

$$A_p = \frac{kC}{\pi R} m \sin \alpha t_p \,. \tag{24}$$

Then, Eq. (24) yields the following equation by making use of Eq. (8) and Eq. (9).

$$I_{mp} = A_p \,. \tag{25}$$

By making use of the relations given by Eqs. (3), (4), (8) and (9), A_p is shown as follows:

if $\sin \alpha t > 0$,

$$A_p \backsim -g(\omega t) \tag{26}$$

if $\sin \alpha t < 0$,

$$A_p \backsim g(\omega t) \,. \tag{27}$$

In other words, the magnitude of A_p is proportional to the instantaneous value of the first term in Eq. (3) or Eq. (4) at $t=t_p$, according to positive or negative value of $\sin \alpha t$.

Therefore, the magnitude of each pulse generated according to the instantaneous value of $g(\omega t)$ or $-g(\omega t)$ at each time when the thyratron fires, is proportional to that of A_p. The envelope of the train of pulses obtained by the above manner, varies in accordance with the fundamental component, together with the sign, of the thyratron amplifier output current, of which the average value during each half cycle period of a.c. plate source is proportional to the ultra low frequency voltage to be amplified.

4. Measuring Device for the Characteristics and Experimental Results

The block diagram of the device for measuring the characteristics of both original thyratron amplifier and modified one is shown in Fig. 4.

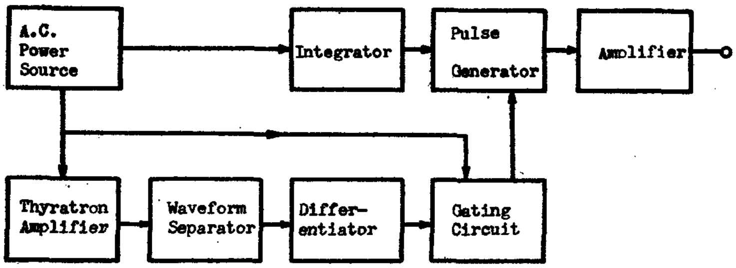


Fig. 4. Block Diagram of Measuring Device.

The output voltage from the thyratron amplifier is applied to the waveform separator circuit, where it is sorted out according to its polarity, and differentiated in order to generate the pulse at the leading edge of its waveform. Then, the differentiated pulses turn into the gating pulses by being assorted into four groups once again so that they may be suitable for generating the pulses in the next stage.

On the other hand, the voltage waveform being proportional to the value of $g(\omega t)$, is generated with the a.c. source voltage of the thyratron amplifier in the integrator circuit and applied to the pulse generator. Then, the output voltage waveform is sorted into four groups, properly phased and shifted to the positive or negative direction in the pulse generator. In the same stage, these voltages transformed into pulses in cooperation with the output of the gating circuit, of which magnitude varies in accordance with the average

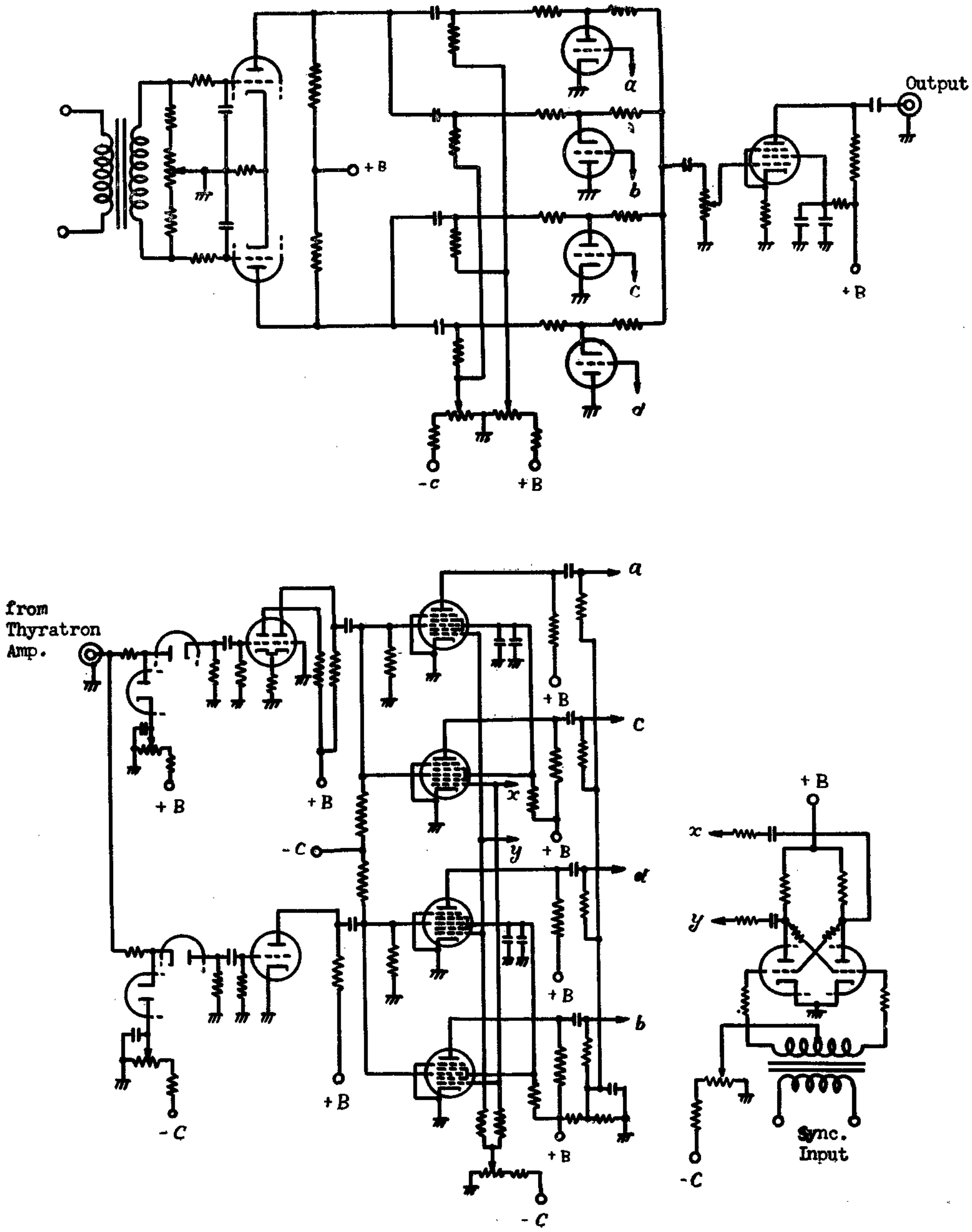


Fig. 5. Circuit of Measuring Device.

output current of the thyratron amplifier. The output of the pulse generator is amplified to a proper magnitude by the amplifier stage.

The circuit of this device is shown in Fig. 5. In a case of the characteristic measurement for the original thyratron amplifier, the gating pulse appears at (a) and (c) terminals and so the output pulse having only positive magnitude is observed at the output terminal of this device.

Oscillogram shows the experimental results obtained with this circuit for the modified thyratron amplifier working under the sinusoidal a.c. power source. In Oscillogram, (a), (b) and (c) are explained as follows:

(a) : amplitude modulated wave for controlling A group thyratrons in the modified thyratron amplifier, of which the carrier and the signal frequency are 10,000 c/s and 1.5 c/s respectively.

(b) : load current of modified thyratron amplifier.

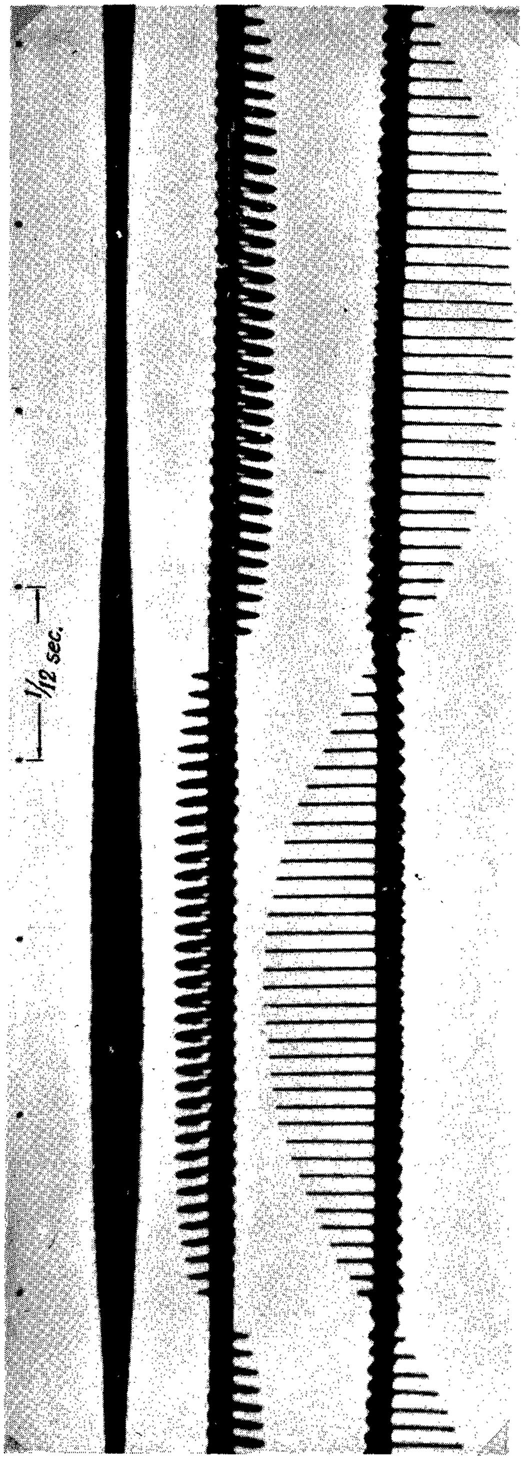
(c) : output pulse of measuring device.

In the oscillogram, the envelope of the train of pulses illustrates the fundamental component in the output voltage of modified thyratron amplifier, which varies in the same manner as the ultra low frequency signal to be amplified, together with the polarity.

5. Conclusions

The modified thyratron amplifier and the measuring device for the characteristics of both original and modified one were described above in outline.

The linear power amplification, containing no d.c. component, of the ultra



(a) (b) (c)

Oscillogram

low frequency signal can be obtainable by the modified thyratron amplifier if any wave-form voltage may be supplied to the plate of the thyratron.

Furthermore, the characteristics of both original and modified thyratron amplifier can be easily observed with the measuring device mentioned above.

It is accordingly conceivable that the application of modified thyratron amplifier will develope into the fields of the automatic control systems, the frequency changer and others.

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