Fast Response SCR Amplifier

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(Received November 30, 1964)

This paper, in the first place, gives the detailed aspect of the response of SCR amplifier withan inductive load together with the instantaneous load current. From this figure, the principles to let SCR amplifier fulfil the fast response for the inductive load are discussed. In thenext place, the theoretical analysis of the fast response SCR amplifier, of which response is improved by adjusting SCR's anode voltages during the transient period is presented. The latter place explains the SCR amplifier composed on the basis of represented analysis and the experimental results which are also satisfactory in the theoretical one. Finally, the Fourier coefficients of the instantaneous load current and the conversion efficiency of this amplifier for the steady state operation are expressed.

1. Introduction

The SCR amplifier having the superior characteristics of small size, longevity, fast switching, low gating power, low voltage drop and high current rating up to 100 amperes to the thyratron amplifier is more useful for the power amplification of DC and ultra low frequency signals, as shown in the previous paper[1]. However, the response of SCR amplifier feeding its output through a smoothing filter to the load in order to improve the efficiencies of it or applying to the inductive load directly becomes rather undesirable owing mainly to the time constant of filter or load. In general, it is well known that the fast response of amplifier in control systems is required. One type of the fast response SCR amplifier of which response is performed in the rate of requirement and its tentative circuit in order to progress the investigation are presented.

2. Transitional load current for inductive load of SCR amplifier

Fig. 1 (a) shows the basic circuit of inductive load SCR amplifier. In this figure, the angular frequencies of the AC source and the signal to be amplified, which are indicated by ω and u respectively, have a relation $\omega/u \geq 6$ given in the previous paper. It is assumed that the impedances of AC source transformer as well as voltage drops of SCR's and diode for discharge are negligible during conduction. Then, the SCR fires at specific firing angle in each half-cycle of AC source voltage and the instantaneous load current during p-th and $(p+1)$-th half-cycles makes a continuous pattern as illustrated in Fig. 1 (b).

In Fig. 1 (b), the firing angle, $\varphi_p=\omega t'_p-(p\text{-}1)\pi$, in the p-th half-cycle is given by

$$-g(\omega t_p) = -g[\varphi_p+(p-1)\pi] = \frac{(-1)^{p-1}}{k}\int_{(p-1)\pi+\varphi_p}^{p\pi} E(\omega t)\,d\omega t = E_s(ut_p) \qquad (1)$$

and the instantaneous load current $i_L(\omega t')|_p$ is expressed as follows;

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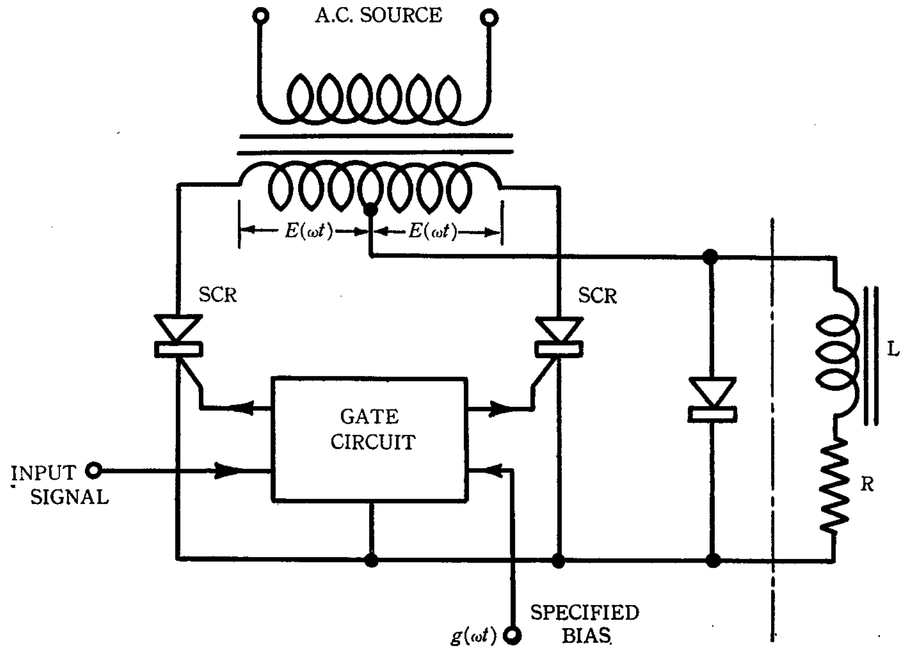


Fig. 1 (a). Basic Circuit of SCR Amplifier.

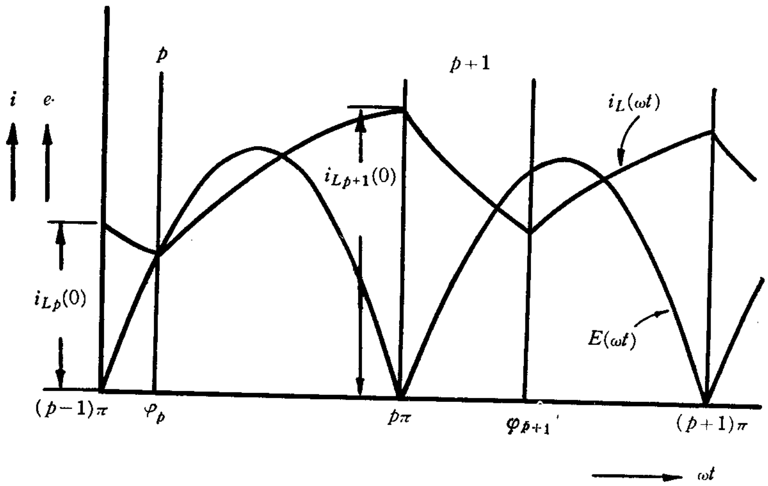


Fig. 1 (b). Anode Voltage and Instantaneous Load Curent.

Region: $0 \leq \omega t' \leq \varphi_p$

$$i_L(\omega t')|_p = i_{L_p}(0)\varepsilon^{-\gamma_L \omega t'} \tag{2}$$

Region: $\varphi_p \leq \omega t' \leq \pi$

$$i_L(\omega t')|_p = i_{L_p}(0)\varepsilon^{-\gamma_L \omega t'} + \frac{\gamma_L}{R}\varepsilon^{-\gamma_L \omega t'}\int_{\varphi_p}^{\omega t'} E(\omega\tau)\varepsilon^{\gamma_L \omega\tau}\, d\omega\tau \tag{3}$$

where, $\omega t' = \omega t - (p-1)\pi$, $\gamma_L = R/\omega L$,

$i_{L_p}(0)$: the initial value of instantaneous load current in p-th half-cycle

Assuming that the sinusoidal voltage $E_m \sin \omega t$ is employed as the AC source voltage, Eq. (2) and Eq. (3) are represented as follows;

Region: $0 \leq \omega t' \leq \varphi_p$

$$i_L(\omega t')|_p = i_{L_p}(0)\varepsilon^{-\gamma_L \omega t'} \tag{4}$$

Region: $\varphi_p \leq \omega t' \leq \pi$

$$i_L(\omega t')|_p = i_{L_p}(0)\varepsilon^{-\gamma_L \omega t'} + \frac{E_m}{R}\cos\phi[\sin(\omega t' - \phi) - \sin(\varphi_p - \phi)\varepsilon^{-\gamma_L(\omega t' - \varphi_p)}] \tag{5}$$

where,
$$\phi = \tan^{-1} 1/\gamma_L = \tan^{-1}(\omega L/R) \tag{6}$$

While, $i_{L_p}(0) = i_L(\pi)|_{p-1}$ is established at the starting and end points of each half-cycle because of the continuity of load current. Indicating the half-cycle of AC source, in which the input signal is applied, as $p=1$, the initial value of instantaneous load current in the first half-cycle, $i_{L1}(0)$, is zero and the initial value in the p-th half-cycle, $i_{L_p}(0)$, is expressed as follows;

$$i_{L_p}(0) = \frac{E_m}{R}\varepsilon^{-\gamma_L(p-1)\pi}\left[\frac{1}{2}\sin 2\phi\,\varepsilon^{\gamma_L \pi}\frac{1-\varepsilon^{\gamma_L(p-1)\pi}}{1-\varepsilon^{\gamma_L \pi}} - \cos\phi\sum_{n=1}^{p-1}\sin(\varphi_n - \phi)\varepsilon^{\gamma_L\{\varphi_n + (n-1)\pi\}}\right] \tag{7}$$

Inserting this relation and $\omega t = \omega t' + (p-1)\pi$ into Eq. (4) and Eq. (5),

Region: $(p-1)\pi \leq \varphi \leq (p-1)\pi + \varphi_p$

$$i_L(\omega t)|_p = \frac{E_m}{R}\varepsilon^{-\gamma_L \omega t}\left[\frac{1}{2}\sin 2\phi\,\varepsilon^{\gamma_L \pi}\frac{1-\varepsilon^{\gamma_L(p-1)\pi}}{1-\varepsilon^{\gamma_L \pi}} - \cos\phi\sum_{n=1}^{p-1}\sin(\varphi_n - \phi)\varepsilon^{\gamma_L[\varphi_n + (n-1)\pi]}\right] \tag{8}$$

Region: $(p-1)\pi + \varphi_p \leq \varphi \leq p\pi$

$$\begin{aligned} i_L(\omega t)|_p = {} & \frac{E_m}{R}\varepsilon^{-\gamma_L \omega t}\left[\frac{1}{2}\sin 2\phi\,\varepsilon^{\gamma_L \pi}\frac{1-\varepsilon^{\gamma_L(\varphi-1)\pi}}{1-\varepsilon^{\gamma_L \pi}} - \cos\phi\sum_{n=1}^{p-1}\sin(\varphi_n - \phi)\varepsilon^{\gamma_L(\varphi_n + (n+1)\pi)}\right] \\ & + \frac{E_m}{R}\cos\phi\Big[\sin(\omega t - p\pi + \pi)\cos\phi - \cos(\omega t - p\pi + \pi)\sin\phi \\ & - \sin(\varphi_p - \phi)\varepsilon^{-\gamma_L(\omega t - p\pi + \pi - \varphi_p)}\Big] \end{aligned} \tag{9}$$

From Eq. (8) and Eq. (9), the average load current during p-th half-cycle, I_{m_p}, is given by

$$\begin{aligned} I_{mp} = \frac{E_m}{\pi R}\Bigg[\Bigg[& \frac{1}{\gamma_L}\varepsilon^{-\gamma_L(\varphi_p + p\pi - \pi)}\Big[\frac{1}{2}\sin 2\phi\,\varepsilon^{-\gamma_L \pi}\frac{1-\varepsilon^{\gamma_L(p-1)\pi}}{1-\varepsilon^{\gamma_L \pi}} \\ & - \cos\phi\sum_{n=1}^{p-1}\sin(\varphi_n - \phi)\varepsilon^{\gamma_L(\varphi_n + (n-1)\pi)}\Big] \\ & - \frac{1}{\gamma_L}\varepsilon^{-\gamma_L(\varphi_{p+1} + p\pi)}\Big[\frac{1}{2}\sin 2\phi\,\varepsilon^{\gamma_L \pi}\frac{1-\varepsilon^{\gamma_L(p-1)\pi}}{1-\varepsilon^{\gamma_L \pi}} - \cos\phi\sum_{n=1}^{p-1}\sin(\varphi_n - \phi)\varepsilon^{\gamma_L[\varphi_n + (n-1)\pi]}\Big] \\ & + \frac{1}{\gamma_L}\cos\phi\sin\phi + \cos\phi[\cos(\varphi_p - \phi) + \cos\phi] - \frac{1}{\gamma_L}\cos\phi\sin(\varphi_p - \phi)\Bigg]\Bigg] \end{aligned} \tag{10}$$

When the DC input voltage is applied to the SCR amplifier, SCR's are fired at identical phase angle, φ_s, in each succeeding half-cycles and the average load current I_{m_p} is given by the following expression, in which φ_p in Eq. (10) is relpaced by φ_s.

$$I_{m_p}(\varphi_s) = \frac{E_m}{\pi R}\sin\phi\left[\left[\sin\phi\,\frac{1-\varepsilon^{-\gamma_L\pi}}{1-\varepsilon^{\gamma_L\pi}}\varepsilon^{-\gamma_L(\varphi_s+p\pi-2\pi)} - \sin(\varphi_s-\phi)\frac{1-\varepsilon^{-\gamma_L\pi}}{1-\varepsilon^{\gamma_L\pi}}\varepsilon^{-\gamma_L(\varphi-1)\pi}\right.\right.$$
$$\left.\left. +\sin\phi+\gamma_L[\cos\phi+\cos(\varphi_s-\phi)]-\sin(\varphi_s-\phi)\right]\right] \tag{11}$$

Taking a limit of p in Eq. (11), average load current, I_m, in steady state operation is derived by bringing on the gate condition given by Eq. (1)

$$I_{m_{p\to\infty}}(\varphi_s) = \frac{E_m}{\pi R}\sin\phi\left\{\sin\phi+\gamma_L\cos\phi+\gamma_L\cos(\varphi_s-\phi)-\sin(\varphi_s-\phi)\right\}$$
$$= \frac{E_m}{\pi R}(1+\cos\varphi_s) = \frac{1}{\pi R}\int_{\varphi_s}^{\pi} E_m\sin\omega t\, d\omega t = \frac{kE_s}{\pi R} = I_m \tag{12}$$

It is noted that the average load current during half-cycle in steady state operation is proportional to the input signal.

By making use of the relation in Eq. (12), Eq. (11) is represented as follows;

$$I_{m_p}(\varphi_s) = I_m\left\{(1-\varepsilon^{-\gamma_L p\pi}) - \frac{1}{2}\sin\phi\,\frac{E_{s\,\max}}{E_s}\varepsilon^{-\gamma_L p\pi}[(\varepsilon^{\gamma_L(\pi-\varphi_s)}-1)\sin\phi-\gamma_L\cos\phi\right.$$
$$\left. -\gamma_L\cos(\varphi_s-\phi)]\right\} \tag{13}$$

where, $E_{s\,\max}=2E_m/k$

Since this equation has expressed the response of the average load current it is apparent, graphically from Fig. 2 which gives the relation between the ratio of I_{m_p} to I_m and the

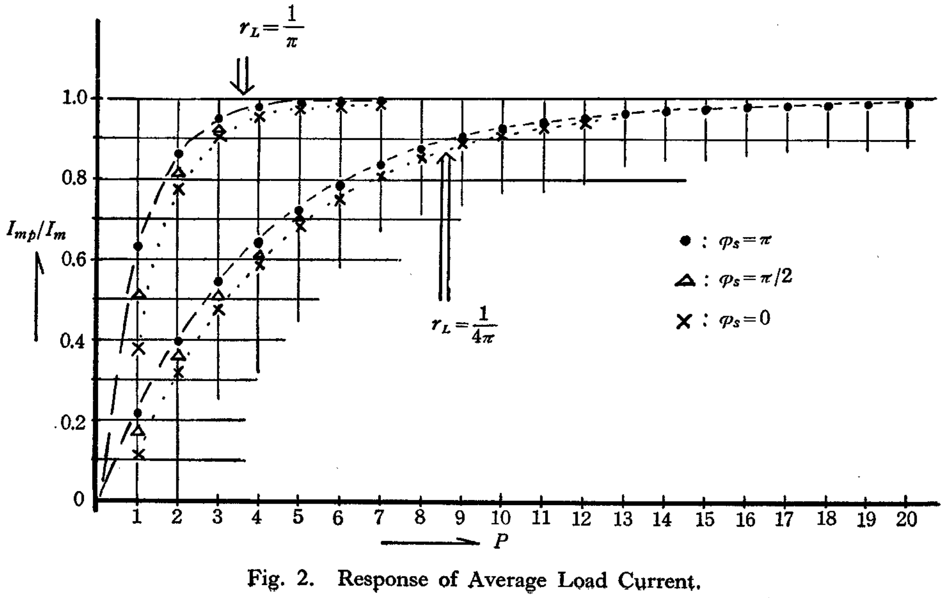


Fig. 2. Response of Average Load Current.

half-cycle number p to meet with Eq. (13) for the two values of load constant $1/\gamma_L$, that the greater the time constant of the load composed of L and R, or the less the firing angle given in Eq. (1), the worse response does the SCR amplifier become.

3. Fast response SCR amplifier

The improvement of the response of SCR amplifier having the inductive load may be performed by equivalently increasing the value of γ_L, as shown in Eq. (13) and Fig. 2. But this means that a resistance for the rate of demands must be connected in series with the load to achieve the fast response and therefore the decrease of load current can not be avoided essentially. The presenting method in this paper is one of the useful method for improving the response, without decreasing of the load current, against all of the input signal voltages of which linear amplification is performed.

(1) Principles

In case the SCR fires at a certain angle φ_s over succeeding half-cycles of the anode supply voltage and the initial value of the instantaneous load current in the 2nd half-cycle is $I_{steady}(0)$ which is the initial value of the instantaneous load current in steady state operation, the average load current during the 2nd half-cycle is given, by making use of Eq. (2) and Eq. (3), as follows;

$$I_{m2} = \frac{1}{\pi}\left[\int_{\varphi_2=\varphi_s}^{\pi} i_L(\omega t')\,d\omega t' + \int_0^{\varphi_3=\varphi_s} i_L(\omega t')\,d\omega t'\right] = \frac{1}{\pi}\left[\int_{\varphi_s}^{\pi}\left\{I_{steady}(0)\varepsilon^{-\gamma_L\omega t'} + \frac{\gamma_L}{R}\varepsilon^{-\gamma_L\omega t'}\int_{\varphi_s}^{\omega t'} E(\omega\tau)\varepsilon^{\gamma_L\omega\tau}\,d\omega\tau\right\}d\omega t' + \int_0^{\varphi_s} i_{L3}(0)\varepsilon^{-\gamma_L\omega t'}\,d\omega t'\right] \tag{14}$$

Referring to the continuity of the instantaneous load current as shown in Fig. 1 (b), the following relation with respect to the initial value in the 3rd half-cycle is to be satisfied.

$$i_{L3}(0) = i_L(\pi)|_2 = I_{steady}(0)\varepsilon^{-\gamma_L\pi} + \frac{\gamma_L}{R}\varepsilon^{-\gamma_L\pi}\int_{\varphi_s}^{\pi} E(\omega\tau)\varepsilon^{\gamma_L\omega\tau}\,d\omega\tau = i_L(\pi)|_{steady} = I_{steady}(0) \tag{15}$$

Inserting this relation into Eq. (14)

$$I_{m2} = \frac{1}{\pi}\left[\int_{\varphi_s}^{\pi}\left\{I_{steady}(0)\varepsilon^{-\gamma_L\omega t'} + \frac{\gamma_L}{R}\varepsilon^{-\gamma_L\omega t'}\int_{\varphi_s}^{\omega t'} E(\omega\tau)\varepsilon^{\gamma_L\omega\tau}\,d\omega\tau\right\}d\omega t' + \int_0^{\varphi_s} I_{steady}(0)\varepsilon^{-\gamma_L\omega t'}\,d\omega t'\right] = I_m \tag{16}$$

By using the same way, the average load current during the optional n-th half-cycle, I_{mn} ($n>2$) is equal to I_m.

Making summary of above results, the average load current after the 2nd half-cycle is given by the same term as in the steady state provided that the SCR fires at the certain angle φ_s and that $i_{L2}(0)$ is equal to $I_{steady}(0)$. The firing angle φ_s is expressed as follows;

$$\varphi_s = \cos^{-1}\left\{\frac{kE_s}{E_m} - 1\right\} \tag{17}$$

where, Em: The amplitude of the AC source voltage,
Es : The input signal voltage,
k : Constant of the specified bias voltage

After all, it is desirable to be satisfied the next condition in earlier succeeding half-cycles after impression of signal voltage for the fast response operation.

$$i_{Ln}(0) = I_{steady}(0) \tag{18}$$

where, $i_{Ln}(0)$; The initial value of instantaneous load current in n-th half-cycle

(2) Method

Figure 3 shows the block diagram of the fast response SCR amplifier. To establish the condition of Eq. (18), the output voltage of the amplifier is applied to a source gate circuit through a CR integrating circuit of which time constant is equal to that of the load. This gate circuit having a gate action and generating the trigger pulse is set so that the SCR anode voltage may be kept on $(1+K)\cdot E(\omega t)$ during $i_{Ln}(O)$ is less than the steady state initial value $I_{steady}(0)$ for the same input voltage. When $i_{Ln}(0)$ is equal to $I_{steady}(0)$, the SCR anode voltage is changed into $E(\omega t)$ with the help of AC voltage selector.

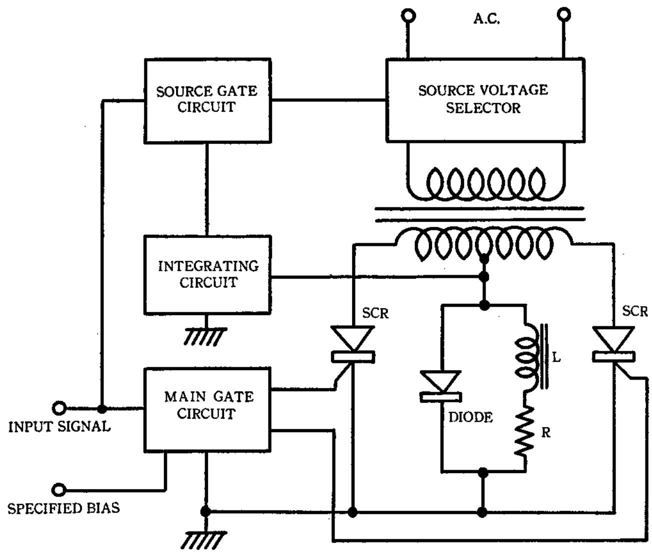


Fig. 3. Block Diagram of Fast Response SCR Amplifier.

Assuming that the impedances of power transformer as well as the voltage drops in SCR's and diode for discharge are negligible during conduction, the load current during the transient period, i_L, is given by a solution of next equation.

For period, $0 \leq \omega t' \leq \pi$

$$i_L R + \omega L \frac{di_L}{d\omega t'} = (1+K) E(\omega t') U(\omega t' - \varphi_s) \tag{19}$$

where, $\omega t' = \omega t - (p-1)\pi$,

φ_s : The firing angle of the main SCR's,

$U(\omega t' - \varphi_s)$: A step function of which starting point is in keeping with $\omega t' = \varphi_s$ and K is the constant.

The initial load current $i_{L2}(0)$ in the next half-cycle is given by

$$i_{L2}(0) = i_L(\pi)|_1 = (1+K)\frac{\gamma_L}{R}\varepsilon^{-\gamma_L\pi}\int_{\varphi_s}^{\pi} E(\omega\tau)\varepsilon^{\gamma_L\omega\tau}\,d\omega\tau \tag{20}$$

Supposing that the SCR amplifier behaves in steady state at the starting point of the 2nd half-cycle of the AC source, following equations should be satisfied with respect to the initial load current in the very half-cycle.

$$\begin{aligned} i_{L2}(0) &= (1+K)\frac{\gamma_L}{R}\varepsilon^{-\gamma_L\pi}\int_{\varphi_s}^{\pi} E(\omega\tau)\varepsilon^{\gamma_L\omega\tau}\,d\omega\tau \\ &= I_{steady}(0) = I_{steady}(0)\varepsilon^{-\gamma_L\pi} + \frac{\gamma_L}{R}\varepsilon^{-\gamma_L\pi}\int_{\varphi_s}^{\pi} E(\omega\tau)\varepsilon^{\gamma_L\omega\tau}\,d\omega\tau \end{aligned}$$

Therefore, K must have the value given by Eq. (21)

$$K = \frac{1}{\varepsilon^{\gamma_L\pi} - 1} \tag{21}$$

In general, for the case that (n-1) half-cycles of AC source are needed for SCR amplifier of Fig.3 to get the steady state operation, K has to take the value of next Eq. (22)

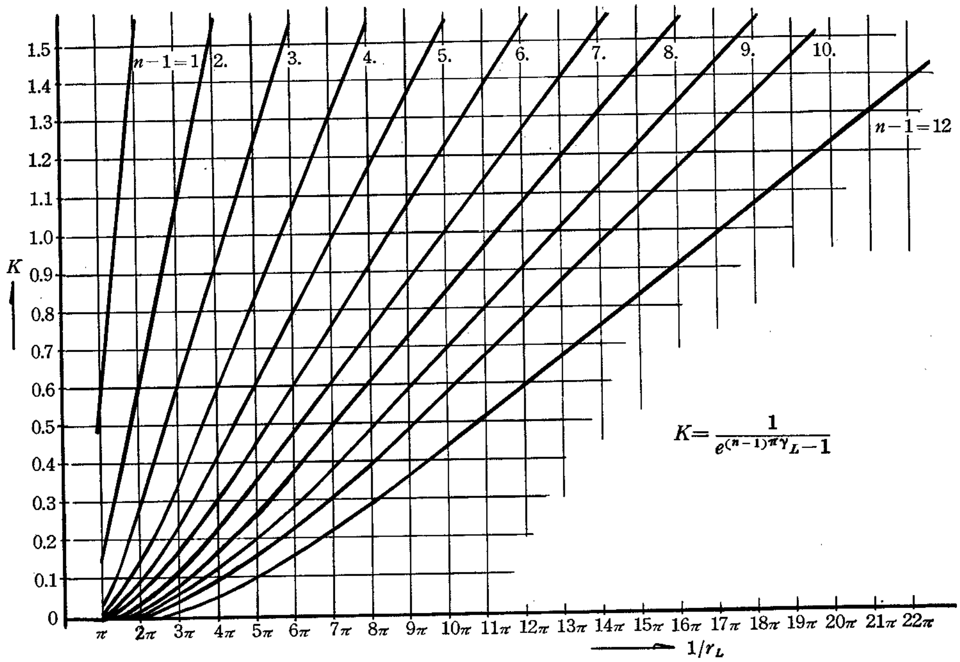


Fig. 4. Theoretical Curves of Eq. (22).

$$K=\frac{1}{\varepsilon^{(n-1)\pi\gamma_L}-1} \tag{22}$$

The first problem, when designing the fast response SCR amplifier, consists of determining the number of half-cycles for getting to the steady state as occasion demands. The next step, by using the curves in Fig. 4 which gives the relation of Eq. (22), is to get the value of K. This is fixed by the curve corresponding to the number in problem and the time constant of the load. In the last step, the voltage selector is adjusted so that the anode voltages of SCR_1 and SCR_2 are supplied with $(1+K)E(\omega t)$ during transient state operation.

Adjusting in such way, the average load current during p-th half-cycle in the transient period is expressed as follows;

$$I_{m_p}=(1+K)I_m\Big\{(1-\varepsilon^{-\gamma_L p\pi})-\frac{1}{2}\varepsilon^{-\gamma_L p\pi}\frac{E_{s\,max}}{E_s}\sin\phi[(\varepsilon^{\gamma_L(\pi-\varphi_s)}-1)\sin\phi$$
$$-\gamma_L\cos\phi-\gamma_L\cos(\varphi_s-\phi)\Big\} \tag{23}$$

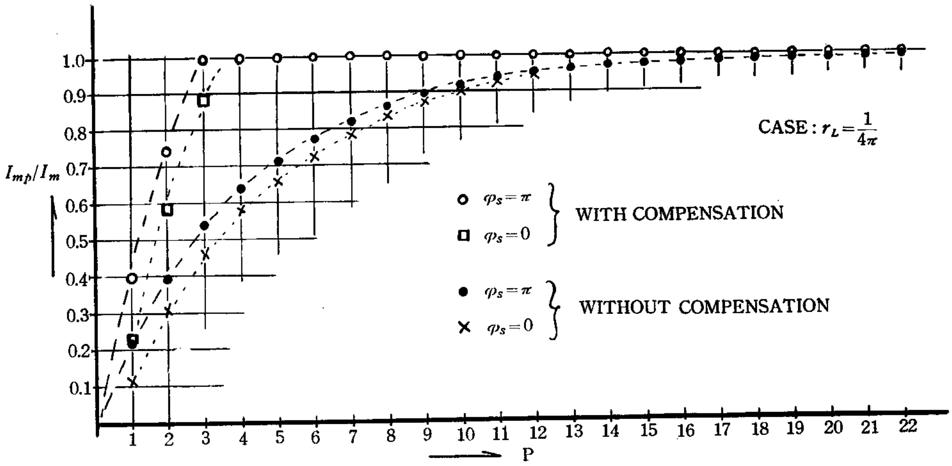


Fig. 5. Response Forms.

That graph is shown in Fig.5, in case of $\gamma_L=1/4\pi$, which schemes to compare I_{m_p}/I_m of Eq. (23) with that of Fig.2. From this graph, it is found that the response is improved without decreasing of the load current for all firing angles.

(3) Experimental results

Fig. 6 shows the circuit diagram of the fast response SCR amplifier designed to perform the method in above investigation.

The silicon unijunction transistor (UJT) is ideal device for use in SCR firing circuits. It has the advantages of a stable firing voltage, a very low firing current, operation over a temperature range of $-55°C$ to $+140°C$ and a peak current rating of 2 amperes. The main SCR gate circuit using the UJT is a pulse gating circuit not only with low power consumption, but also with a high effective power gain and reliability in phase control circuit. And the linear amplification for all firing angles is achieved from the input signal of 0.5 volts order.

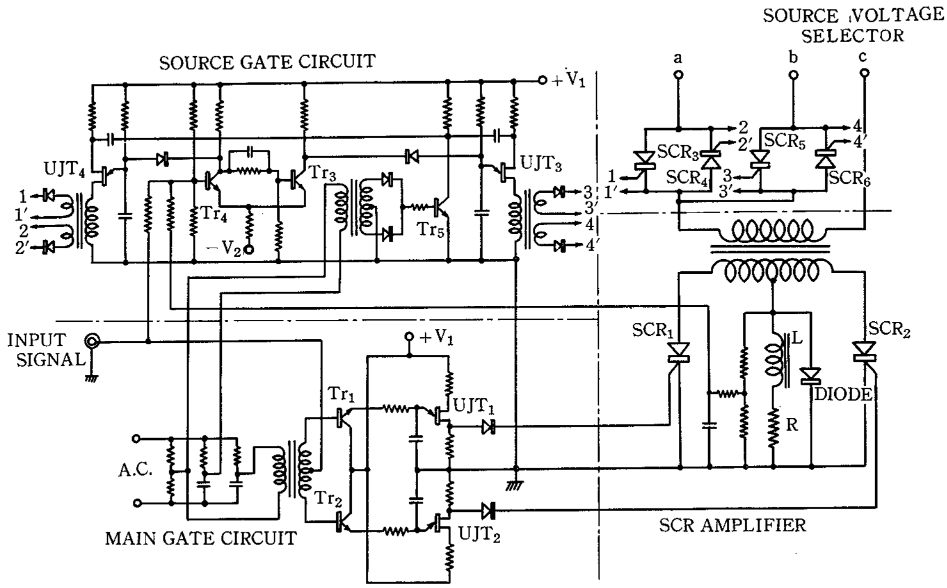


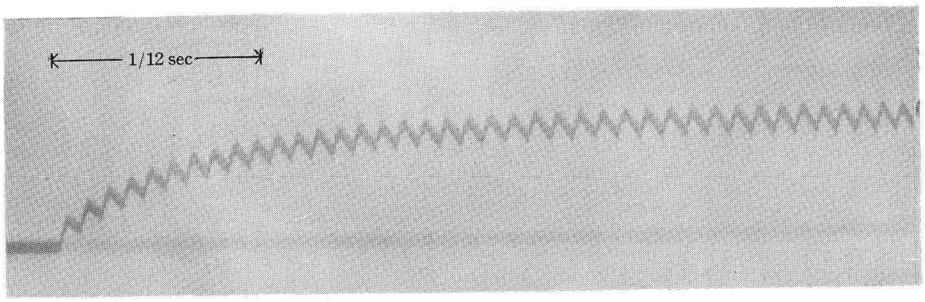
Fig. 6. Circuit Diagram of Fast Response SCR Amplifier.

The Schmitt trigger circuit is often used to obtain the constant output voltage for the fixed input voltage level. The source gate circuit consists of the UJT$_3$, UJT$_4$ and Schmitt trigger circuit composed of Tr$_3$ and Tr$_4$, biased by a negative voltage to avoid the difference of the fixed input level that depends upon the state of Tr$_4$. The collector voltages of Tr$_3$ and Tr$_4$ are given in opposite phase and applied through diodes, to the emitters of UJT$_3$ and UJT$_4$ respectively. As the UJT$_3$ and UJT$_4$ are synchronized by a clock pulse made by clamping the rectified full wave of the AC source, the trigger pulse of the source gate circuit is generated in the UJT$_3$ or UJT$_4$ at which the clock pulse is applied.

The AC voltage selector is composed of two pairs of SCR's as shown in Fig. 6. When the load current is less than the steady state value corresponding to the identical input signal of SCR amplifier, the input voltage of the Schmitt trigger circuit becomes greater than the fixed level. And UJT$_3$ generates the trigger pulse at the starting point of succeeding half-cycles of the AC source. Then, SCR$_5$ and SCR$_6$ fire and AC source is connected between b and c so that the anode voltages of main SCR's may be $(1+K)\,E(\omega t)$, SCR$_3$ and SCR$_5$, however, are released from AC source, because the input of UJT$_4$ is less than the emitter peak voltage for the relaxed oscillation. On the contrary, in such case that the load current is greater than the average load current, in steady state operation, corresponding to the input signal, SCR$_4$ and SCR$_3$ fire at the zero firing angle and AC source is connected between a and c.

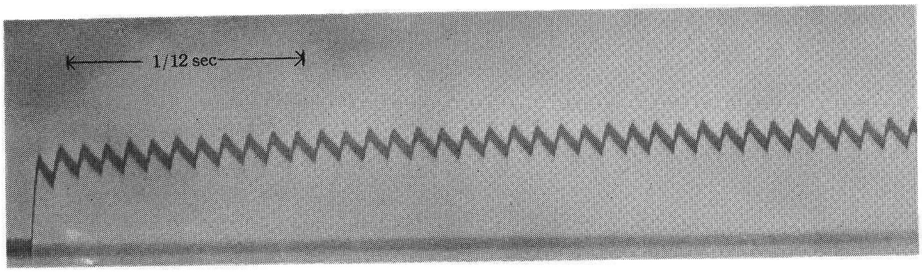
An example of the response improved by this method is shown in Fig.7.

Fig. 7 (a) shows the response of the original one. Fig. 7 (b) shows the response obtained from the tentative circuit for the same load, $\gamma_L=1/3\pi$, the same current as that of Fig. 7 (a) and $K=2.5$. And theoretical relation shown in Eq. (22) was established between K and γ_L for each (n-1) which indicates the number of half-cycles for getting to the steady state.



a

(a) Response of Load Current of Original SCR Amplifier.



b

(b) Improved Response.

Fig. 7. Oscillogram of Load Current against Step Input Voltage.

(4) Fourier coefficients of the instantaneous load current

In the fast response SCR amplifier of Fig. 6, the source gate circuit generates a pulse, which is applied to the source voltage selector, at each starting point of succeeding half cycles of AC source voltage owing to the clock pulse and the voltage comparison between the input signal and feedback voltage, through the integrating circuit, having the same wave form as the load current.

When the sinusoidal input signal is applied to this SCR amplifier in steady state operation, the anode voltage of SCR is supplied with $E(\omega t)$, during the period being equal to one half of a period of the input signal and with $(1+K)\,E(\omega t)$ during the rest period. Now, assuming that the input signal $E_s(ut)$, AC source voltage $E(\omega t)$ and the specified bias voltage $g(\omega t)$ are represented as follows;

$$E_s(ut) = E_s \sin ut \tag{24}$$

$$E(\omega t) = E_m \sin \omega t \tag{25}$$

where, $\omega \gg u$ and $\omega/u=s$ is integer

$$g(\omega t) = \frac{(-1)^p}{k}\int_{\omega t}^{p\pi} E(\omega t)\, d\omega t \tag{26}$$

where, k is constant.

The instantaneous load current under the steady state operation may be expressed by the next Fourier series representation

$$i_L = \frac{a_0'}{2} + \sum_{n=1}^{\infty} A_n' \cos(nut-\theta_n) + \sum_{n=1}^{\infty} B_n' \sin(nut-\theta_n) \tag{27}$$

and Fourier coefficients are given as follows;

$$a_0' = a_0 + \frac{KE_m}{\pi R}\left(1+\frac{1}{s}\sum_{p=1}^{s}\cos\varphi_p\right) \tag{28}$$

$$A_{n=s}' = A_{n=s} + \frac{KE_m}{4S\pi R}\frac{R}{\sqrt{R^2+\omega^2L^2}}\sum_{p=1}^{s}(-1)^{p-1}(\cos 2\varphi_p - 1) \tag{29}$$

$$B_{n=s}' = B_{n=s} + \frac{KE_m}{4s\pi R}\frac{R}{\sqrt{R^2+\omega^2L^2}}\sum_{p=1}^{s}(-1)^{p-1}(\sin 2\varphi_p - 2\varphi_p + 2\pi) \tag{30}$$

$$A_{n\neq s}' = A_{n\neq s} + \frac{KE_m}{\pi R(S^2-n^2)}\frac{R}{\sqrt{R^2+(nuL)^2}}\sum_{p=1}^{s}\left\{s\cos\varphi_p\cos\frac{n}{s}[(p-1)\pi+\varphi_p]\right.$$
$$\left.+n\sin\varphi_p\sin\frac{n}{s}[(p-1)\pi+\varphi_p]\right\} \tag{31}$$

$$B_{n\neq s} = B_{n\neq s} + \frac{KE_m}{\pi R(s^2-n^2)}\frac{R}{\sqrt{R^2+(nuL)^2}}\sum_{p=1}^{s}\left\{s\cos\phi_p\sin\frac{n}{s}[(p-1)\pi+\varphi_p]\right.$$
$$\left.-n\sin\varphi_p\cos\frac{n}{s}[(p-1)\pi+\varphi_p]\right\} \tag{32}$$

where, $\theta_n = \tan^{-1} nuL/R$

$a_0 = 2E_m/\pi R$, $A_{n=s}$, $B_{n=s}$, $A_{n\neq s}$,

$B_{n\neq s}$: Fourier coefficients of the origiral one having inductive load[2].

In case of $S \gg 1$, this fast response SCR amplifier is able to perform the linear amplification of ultra low frequency signal in the same way as the original one. From Eq. (32), the signal frequency component in the load current of this SCR amplifier is greater than that of original one.

The conversion efficiency is given by

$$G = \frac{B_1'}{E_s} = \frac{B_1}{E_s} + \frac{KE_m}{E_s\pi R(s^2-1)}\frac{R}{\sqrt{R^2+(uL)^2}}\sum_{p=1}^{s}\left\{s\cos\varphi_p\sin\frac{1}{s}[(p-1)\pi+\varphi_p]\right.$$
$$\left.-\sin\varphi_p\cos\frac{1}{s}[(p-1)\pi+\varphi_p]\right\} \tag{33}$$

The value of this conversion gain is higher than that of original SCR amplifier.

4. Conclusions

The fast response SCR amplifier mentioned in this paper is not only able to preform the response of occasional demands by empoying the SCR anode voltage of $(1+K)$

times during the transient state period, but also able to amplify the DC and ultra low frequency signal in similar manner with the original SCR amplifier. And the value of K which is necessary to establish the fast response is easily determined from Fig. 4 according to the load constant and the rate of the response. Consequently, it is expected that this amplifier will display its superior characteristics in more extensive engineering realms.

References

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