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Behavior of Transistor Switching in AC Chopper Circuit

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Synopsis

In this paper, an AC chopper circuit, using a power transistor, is described which chops the AC voltage with a commercial frequency. The circuit is composed of a diode bridge and a power transistor in series with a load and capable of adjusting the switching frequency, f_c, and the time ratio, $\tau=t_{on}/(t_{on}+t_{off})$. The switching frequency and the time ratio of the AC chopper circuit depend on switching-times, that is, delay time, rise time, carrier storage time and fall time, especially in the high frequency. The upper limit of the switching frequency (about 150kHz) and the output characteristics of the circuit are investigated.

1. Introduction

Recently for significant advances in the electronics, transistors have been developed in their power handling capability. Therefore, in some industrial applications, for example, inductive motor loads, circuits using power transistors have been studied[1)2)3)]. By using power transistors the power control circuits are expected to be smaller size and lighter weight, furthermore improvements in controllability and reliability also expected.

Because of transistor's unidirectional switching property, the circuit is composed of a diode bridge and a power transistor. The circuit has

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abilities to adjust the switching frequency, f_c, and the time ratio, $\tau=t_{on}/(t_{on}+t_{off})$. The switching frequency and the time ratio depend on switching-times (delay time, rise time, carrier storage time and fall time)[4], especially in the high frequency.

In this paper, the upper limit of the switching frequency and the output characteristics of the AC chopper circuit with a resistive load are described.

2. AC Chopper Circuit

Fig.1 shows an AC chopper circuit using a power transistor. A main circuit with a resistive load is composed of a diode bridge and a power transistor, since a transistor is an unidirectional switching element. A driving circuit consists of an astable multivibrator, a differentiation circuit and a monostable multivibrator. By means of these circuits, the AC voltage with a commercial frequency is chopped.

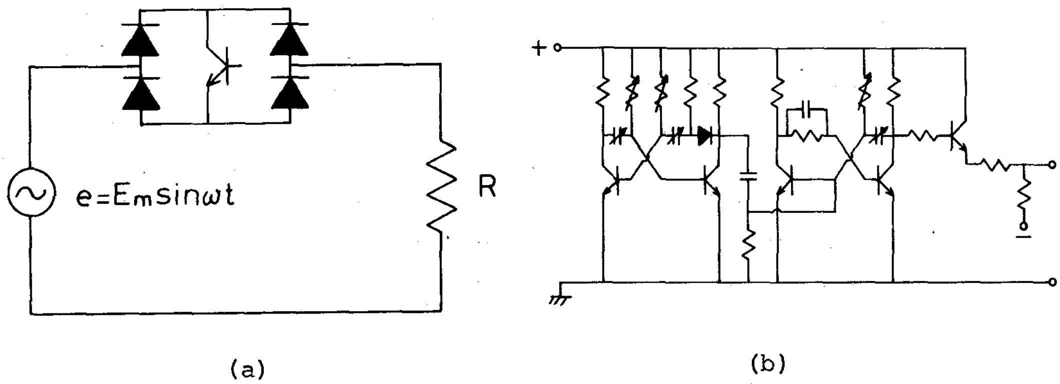


Fig.1. AC chopper circuit.
(a) Main circuit.
(b) Driving circuit.

3. Behavior of Switch

3.1 Behavior of Transistor

Fig.2 shows the behavior of a transistor. In this figure, each

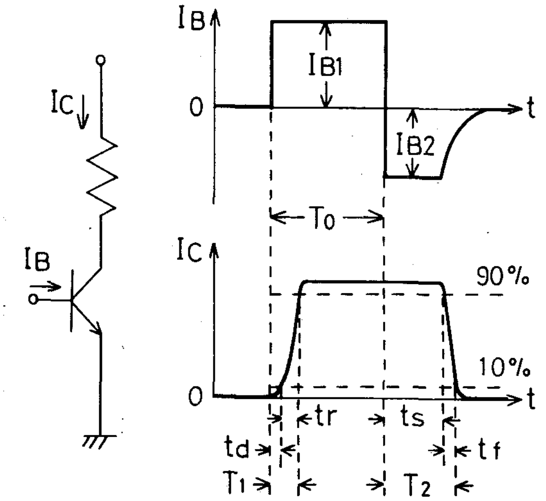


Fig.2. Behavior of transistor.

is defined as follows:

t_d(delay time):the period of time required for the current to reach 10 per cent of its current saturation.

t_r(rise time):the period of time required for the current to reach from 10 per cent to 90 per cent of its current saturation.

t_s(carrier storage time):the period of time for the current to reach 90 per cent of its current saturation after the base current is removed.

t_f(fall time):the period of time required for the current to decay from 90 per cent to 10 per cent of its current saturation.

Using a transistor as a switch, it is necessary to supply a large base current enough for a transistor to be saturated, namely $I_C < h_{FE} I_{B1}$. Each period depends on I_{B1}, I_{B2} and the characteristics of transistors[4].

3.2 Behavior of AC Switch

Fig.3 shows the behavior of the AC switch using a diode bridge and a power transistor. The ratings of a transistor and a diode in this circuit are given in Table 1 and 2, respectively. The behavior of this switch is similar to that of the transistor, because its behavior depends prominently on the transistor. When the base current is set, switching-times of the transistor are effected by the external circuit, which determines the collector current in the collector current saturation. It is necessary for the time t_{on} to be shorter than the switching period so that the switch perfectly turns on and

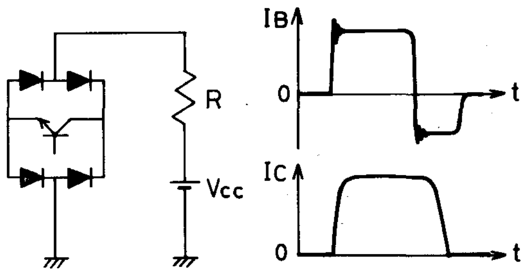


Fig.3. Behavior of AC switch, experimental result.

Table.1. Rating of transistor (2SD641).

Term	Symbol	Rating	Unit
Collector to base voltage, dc, emitter open	V_{CBO}	600	V
Collector to emitter voltage, dc, base open	V_{CEO}	400	V
Emitter to base voltage, dc, collector open	V_{EBO}	5	V
Collector current, dc	I_C	15	A
Emitter current, dc	I_E	-15	A
Base current, dc	I_B	5	A
Collector power dissipation	P_C	150	W
Junction temperature	T_j	150	^0C
Storage temperature	T_{stg}	-65~150	^0C

Table.2. Rating of diode (SR30C-10).

Term	Symbol	Rating	Unit
Repetitive peak reverse voltage	V_{RRM}	500	V
Non-repetitive peak reverse voltage	V_{RSM}	600	V
Reverse voltage, dc	$V_R(DC)$	400	V
RMS forward current	$I_F(RMS)$	47	A
Average forward current	$I_F(AV)$	30	A
Surge forward current	I_{FSM}	500	A
Junction temperature	T_j	-40~125	^0C
Storage temperature	T_{stg}	-40~150	^0C

off. In the AC chopper circuit, the perfect switching function is prevented in the neighborhood of a zero of the sinusoidal supply voltage. When I_{B1}=100mA and I_{B2}=67mA, each time, $T_1(=t_d+t_r)$ and t_f, is shorter than 1.0μs.

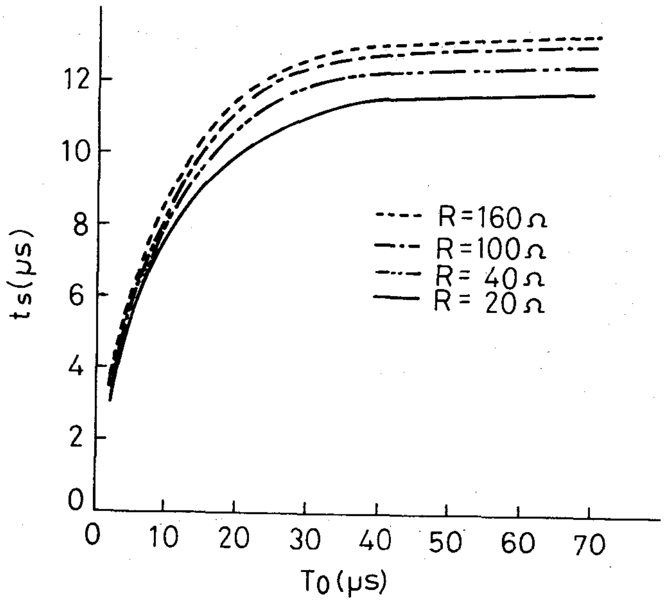


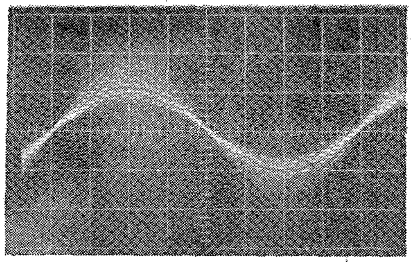
Fig.4. Carrier Storage time t_s vs. T_0, experimental result, V_{CC}=10V.

Fig.4 shows the storage time t_s vs. T_0, where V_{CC}=10V. In f_c=50kHz and R=100Ω, T_0 must be shorter than 10μs in order that this switch operates perfectly. The time T_0 is longer than T_1 in order for this switch to turn on, that is, the time T_0 must be longer than 2.0μs. On that occasion, since t_s=3.5μs and t_f=1.0μs, the upper limit of the switching frequency is about 150kHz.

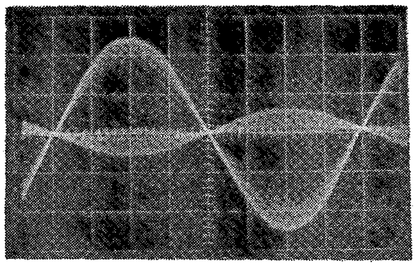
It will be necessary to take notice of characteristics of a driving circuit in the higher frequency.

4. Characteristics of AC Chopper Circuit

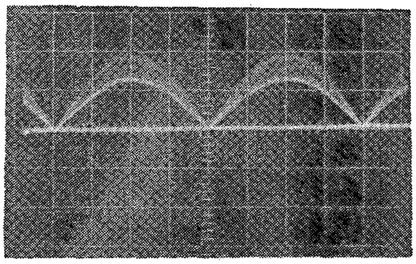
Fig.5 shows oscillograms of voltage waveforms. If diodes and a transistor are assumed to be ideal elements, RMS load voltage, RMS current, power, power factor and distortion factor are represented



(a)



(b)



(c)

Fig.5. Oscillograms of voltage and current waveforms, E=40V, f_C=10kHz, R=40Ω, timebase: 2ms/div.
(a) Supply voltage waveform, 50V/div.
(b) Load voltage waveform, 20V/div.
(c) Transistor voltage waveform, 50V/div.

as follows:

RMS load voltage	$V_L=E\sqrt{\tau}$.
RMS current	$I=V_L/R=E\sqrt{\tau}/R$.
Power	$P=E^2\tau/R$.
Power factor	$P.F.=\sqrt{\tau}$.
Distortion factor	$D.F.=\sqrt{\frac{1-\tau}{\tau}} \times 100$.

Fig.6 shows RMS load voltage and RMS current calculated and measured, respectively. Due to the switching characteristics of transistors as described in the previous section and the switching loss, errors between the calculated and the measured are large in the high frequency

The load voltage waveform is expanded in a Fourier series as follow:

$$v_L(t) = \tau E_m \sin\omega t + \sum_{n=1}^{\infty} \frac{E_m}{\pi n} \sin n\pi\tau [\sin\{(n\omega_C+\omega)t-n\pi\tau\}-\sin\{(n\omega_C-\omega)t-n\pi\tau\}]$$

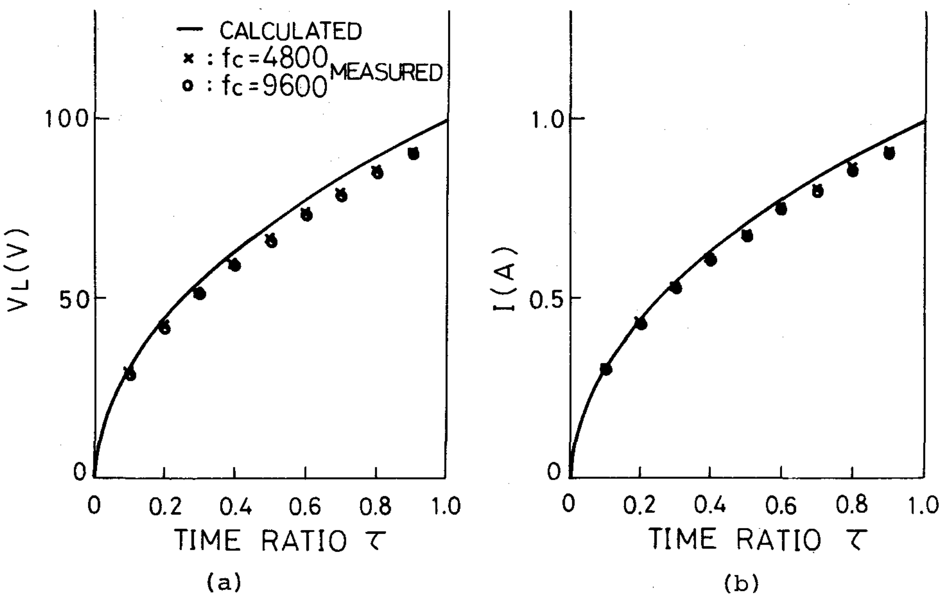


Fig.6. RMS load voltage and RMS current, E=100V and R=100Ω.
(a) RMS load voltage.
(b) RMS current.

where $\omega_C=2\pi f_C$, $\omega=2\pi f$.

Hence, a fundamental power factor is always 1.0 and it is found that lower components of higher harmonics don't appear.

5. Conclusions

In this paper, the AC chopper circuit using a power transistor is described. The switching characteristics of the AC switch depend on switching-times of a transistor, especially in the high frequency. Also switching-times are effected by the external circuit. When I_{B1}=100mA and I_{B2}=67mA, the upper limit of the switching frequency is about 150kHz.

It will be necessary to take account of characteristics of a driving circuit in the higher frequency.

References

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