Magnetic-Amplifier Circuits Converting Half-Wave Input into Full-Wave Output with Transistor Switch

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Synopsis

Various types of magnetic amplifiers for operation with such low-level, low-impedance signal sources as thermocouples have recntly developed for use in automatic control system. In many cases, their output needs to be amplified by means of multistage magnetic amplifier. In some applications it is desired to obtain, from its output stage magnetic amplifier, an a-c output or a full-wave output.

Therefore, it is desirable, for the high performance amplification, the fast response, the simplicity of the circuits and the economy in cores, rectifiers and other parts to be used, that the half-wave flux reset type magnetic amplifier is used for the early low power amplifier stages and then the half-wave signal is converted into full wave output or a-c output in the power output stage.

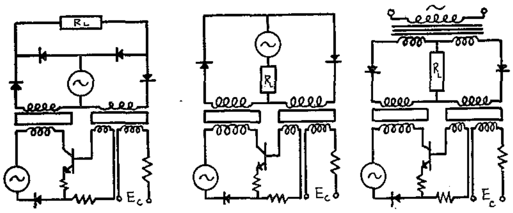
This paper presents the operating principle and the experimental results of these magnetic amplifier circuits which can be controlled by half-wave control signals. In the point of utilizing the transistor as switch, these circuits differ from the magnetic amplifiers, for this use, developed up to this time.

Converter Type Magnetic Amplifier Circuits

Some converter type magnetic amplifier circuits have been proposed by some researchers.(1)(2)(3) A basic type of circuits is shown in H. Lord's report.(1) Its outline, as shown in reference 1, is that the "slave action" caused by "slave winding" provides a full wave output or an a-c output.

It is noteworthy that he has shown such originality in this sort of research. However, it is necessary to make a careful investigation as to whether the magnetic amplifier with a "slave circuit" is applicable for the inductive or the capacitive load, because the interconnecting circuit which provides this slave action is exercised by the load voltage or the gate current of the master inductor.(4) It is also open to consideration that the circuit for an a-c output differs much from the circuits for a full wave output and has a third inductor.

On the other hand, the author's half-wave controlled magnetic amplifier circuits operate, to provide a full wave or an a-c output, in the way of flux resetting in which the firing angle of reset current for inductor B is controlled with transistor switches and the flux of this inductor is reset by the same amount as that set by the signal in the master inductor A. These basic circuits are shown in Fig. 1., which are applicable in the same way as the doubler type, center-tap doubler type and bridge type circuits and have a merit that there is no need for a complicated circuit. The operating principle of these circuits will be made clear as follows.

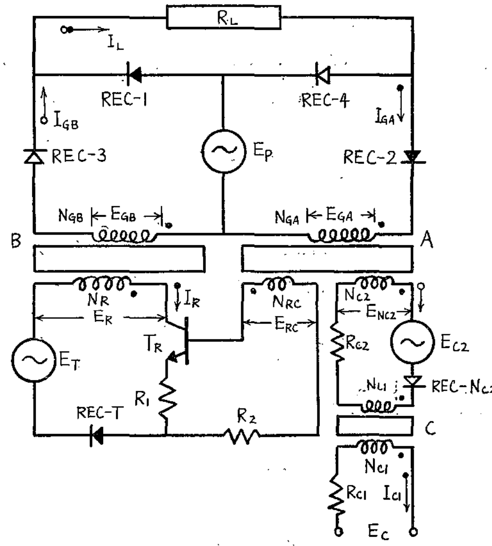


(a) (b) (c)

Eig. 1 Basic circuits of magnetic-amplifier for full wave output or a-c output with half-wave control signals.
(a) bridge circuit (b) doubler circuit
(c) center-tap circuit

Principle of Operation

Since this circuit is naturally used in the multistage magnetic amplifier, its connection with the input stage half-wave flux reset type magnetic amplifier is shown in Fig. 2. In this figure the black and the white symbols of currents and rectifiers, denoted by ●→, ○→, and →|−, −▷|−, respectively, show the mode of operation of rectifier arrangements, according to precedent.[5] That both cores (A, B) are identical and gate windings (N_{GA}, N_{GB}) have equal numbers of turns is the same with the commonly used magnetic amplifier circuits. But the number of turns of control winding (N_C) of master inductor A, which is controlled by half-wave signals from the preceding stage, is not always the same with the reset winding (N_R)



R_1 = 52 OHMS R_2 = 500 OHMS
R_{c1} = 1000 OHMS R_{c2} = 250 OHMS
T_R=Transistor 2 T85(N−P−N)
REC-1 ～ 4 =Germanium diode 2 GJ 2 B
REC-T = Germanium diode 1 T22
REC-Nc_2=Germanium diode
1 T22 × 2 (series)

Fig. 2 Two stage magnetic-amplifier for full wave output with half-wave signals.

of inductor B. In this case the magnetic characteristic of the core B needs not match that of the core A so closely as is required for conventional full-wave self-saturating magnetic amplifier.

Fig. 2 shows also the common emitter connection by which the NPN junction transistor is used as controlled switch. If a large enough base drive is applied to the transistor, it operates as the switch conducting only during the positive signals applied.(6)(7) That is, if the base is positive with respect to either emitter or collector, the NPN transistor conducts with very low resistance, and then its output resets the flux of core B. This period of duration is the gate half cycle of inductor A as well as the reset half cycle of inductor B. If the base is negative with respect to both emitter and collector, the transistor maintains non-conducting. This period is the gate half cycle of inductor B and the reset half cycle of inductor A at the same time.

Ultimately the transistor is drived by the voltage in the reset control winding (N_{RC}), which is caused by the ascent of flux level of core A only during the exciting interval of inductor A, and then its output resets the flux of core B by the same amount as that set by the signal in the master inductor core.

If the firing angle of master inductor A advances or retards, the firing angle of inductor B advances or retards likewise and the gate current of inductor B (I_{GB}) is not a bit different from the gate current of inductor A (I_{GA}).

Since the transistor conducts only during the reset half cycle of inductor B, the half wave rectified current (I_R) is supplied for the transistor from the source.

Experimental Results

A circuit similar to that of Fig. 2 was set up to demonstrate the operation of this type of the magnetic amplifier and a satisfactory performance was obtained.

(a) Wave Forms

The design data on the examined magnetic amplifier are shown in Table. 1 Fig. 3 indicates the core flux changes and the current wave forms in some parts of the circuit obtained when inductor A is controlled to fire at some phase angles. It is easy to undersand, with the aid of the photographs of current and flux change wave forms, the performance of half-wave controlled magnetic amplifier, which has already been described. Note that the current required to reset inductor B can flow only during the prefiring interval of the normal gate half cycle for inductor A when

Table 1. Full wave bridge type Magnetic-Amplifier

			Inductor A	Inductor B	Inductor C
Inductor	Core	Material	Sendelta**	Sendelta	Sendelta
		Type	Troid	Troid	Troid
		Size*	0.1×20×60×100	0.1×20×60×100	0.1×10×45×60
	Winding Turns		N_{GA} = 930T	N_{GB} = 930T	N_{L1} = 3000T
			N_C = 230T	N_R = 140T	N_{C1} = 450T
			N_{RC} = 90T		
Rectifier	REC1−4 Germanium; Junction 2GJ2B (JRC) REC−T Germanium; Point conctact 1T22 (Sony)				
Transistor	Germanium; N-P-N Alloy 2T85 (Sony)				

* (tape thickness)×(height)×(inner dia.)×(outer dia.)mm

** Grain-oriented 50% Ni-50% Fe alloy (Tohoku Metal Industries, LTD.)

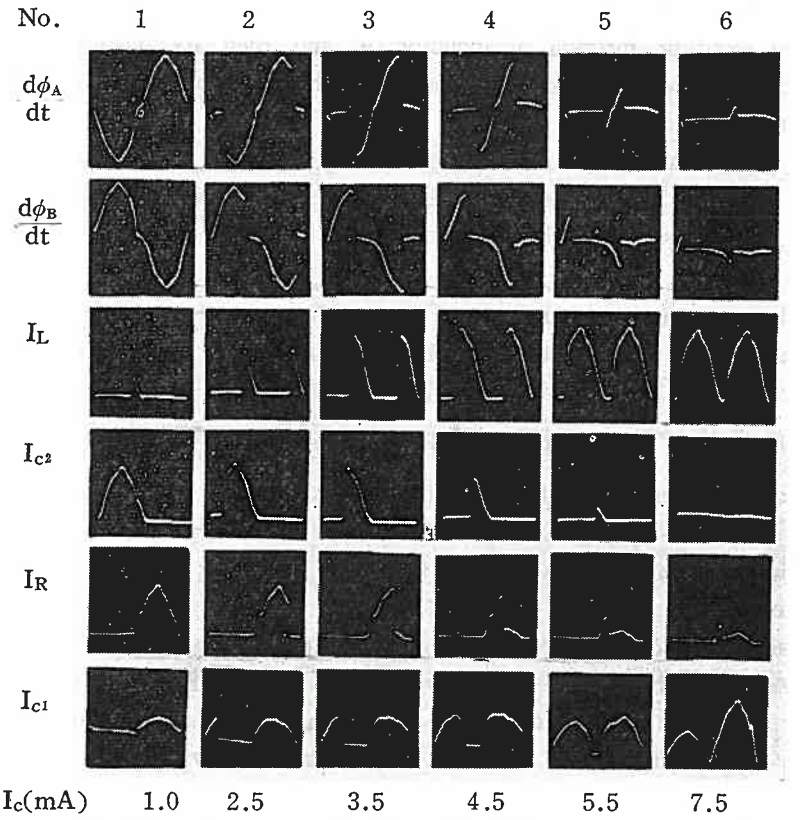


Fig. 3 The core flux changes and the current wave forms in some parts of the circuit. Numbers of oscillograms refer to the points on the control characteristic (Fg. 4) where oscillograms were taken. (Bridge type magnetic amplifier)

the flux level in core A ascends toward saturation, and that the resetting mode of inductor B differs from that of inductor A.

(b) Control Characteristics

The full wave output current taken as ordinate against the half-wave control current of input stage, represented by I_{c1}, as abscissa, is shown in Fig. 4 as the control characteristic for various load resistances. The curreut required to reset inductor A (I_{c2}) is shown also and the way of this current

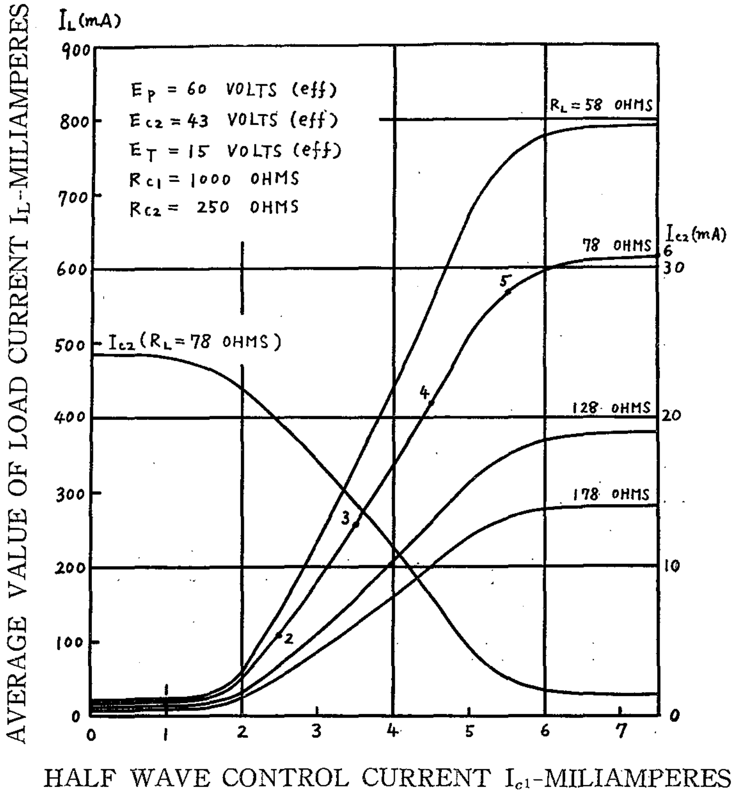


Fig. 4 Measured control characteristic, illustrating effects of variation of load resistance. Numbers on characteristic curve correspond to those of oscillogram (Fig. 3).

change is almost the same for various loads R_L. In this figure the numbers on the curve correspond to those of wave form photographs (Fig. 3). Both gate currents I_{GA} and I_{GB} must be of the same form and equal amount, but it is not to be taken seriously, even if there is a trifling difference between them. Wave forms of load current I_L in Fig. 3 indicate that the right halves are from inductor A and the left halves are from inductor B and the difference between I_{GA} and I_{GB} on the characteristic shown in Fig. 5 is very small. Fig. 6 shows a control characteristic of

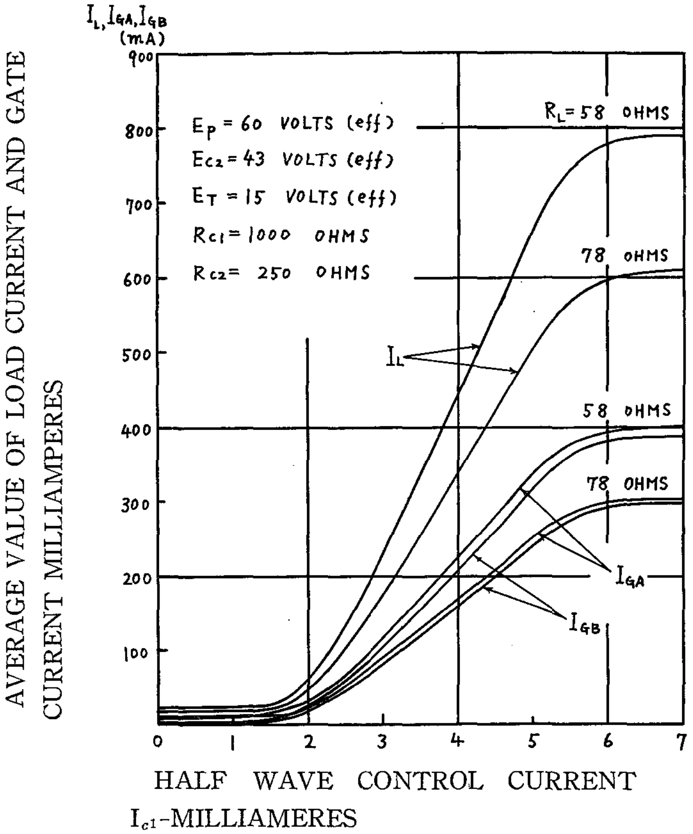


Fig. 5 Gate currents I_{GA}, I_{GB} and load current I_L.

half-wave controlled magnetic amplifier, illustrating effects of variation of supply voltage. This control characteristic keeps the linearity even for the severe voltage variation, and each half-wave form is well-balanced also.

As an example with inductive d. c. load, Fig. 7 shows its charactersitic using a generator field (d. c. shunt generator 5 KW, 110V, 45. 5A; field resistance 90 OHMS; time constant $\tau = 0.15$ sec) as the load.

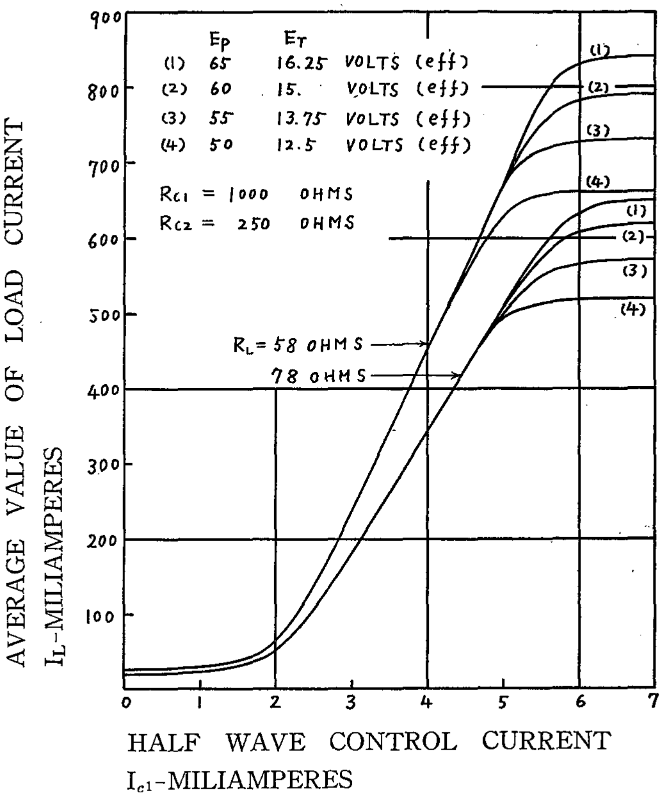


Fig. 6 Measured control characteristic with resistive load, illustrating effects of variation of supply voltage.

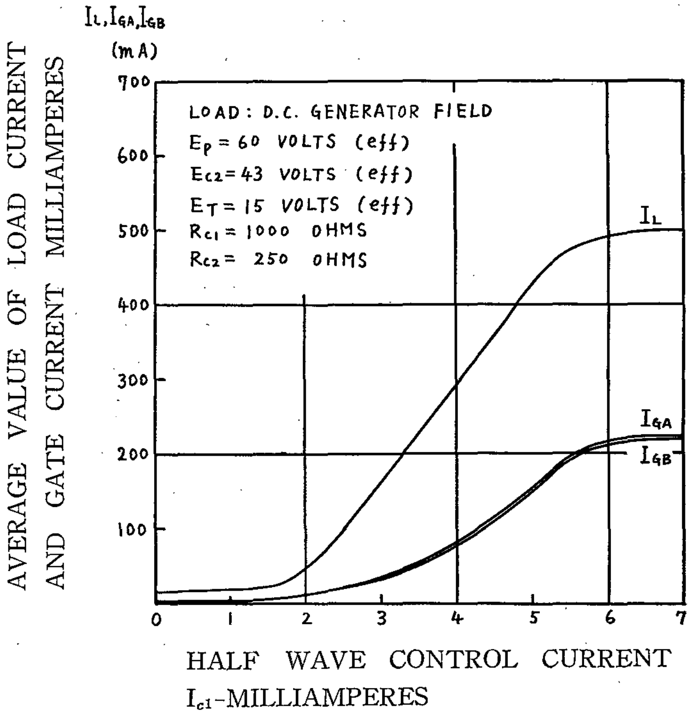


Fig. 7 Control charactristic with the inductive load. D. C. generator field was used as the load.

(c) Comparison with the Ordinary Self-saturting Magnetic Amplifier

It is interesting to compare the characteristic of the author's amplifier circuit with that of the generally used self-saturating magnetic amplifier which is shown in Fig. 8. To make an experiment for the comparison, the author's magnetic amplifier was altered to the ordinary type of circuit whose control winding is equal in number of turns to that of the former inductor A, and the characteristic was obtained as shown in Fig. 9. In this case the input stage magnetic amplifier was

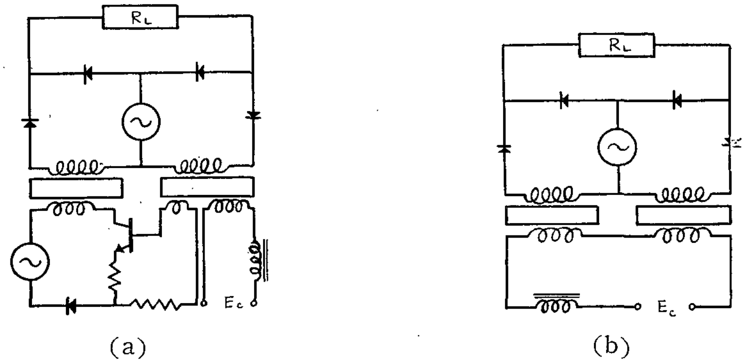


Fig. 8 Circuits for comparison of the control characteristic.
(a) author's magnetic amplifier.
(b) ordinary self-satuating magnetic amplifier.

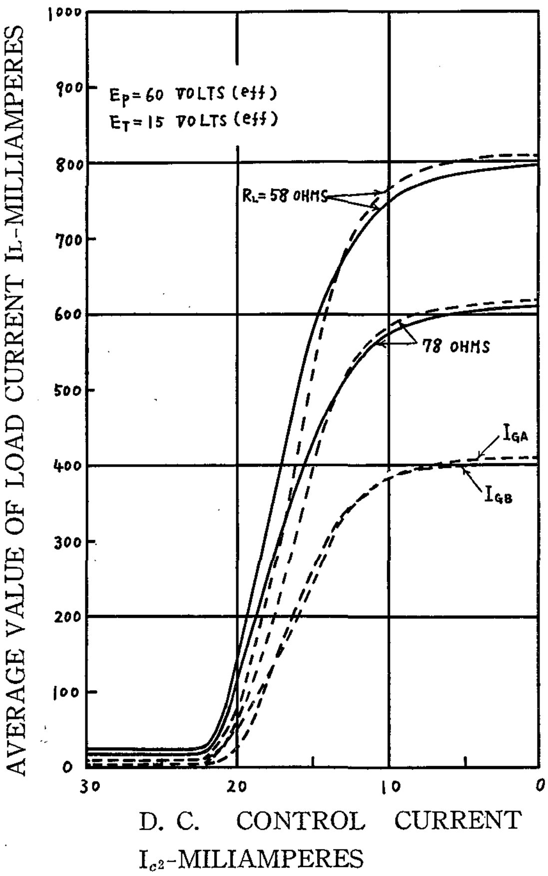


Fig. 9 Compared control characteristic with ordinay self-saturating bridge type magnetic amplifier.
(a) —— for "half wave controlled full wave output magnetic amplifier" (Fig. 1-a).
(b) ----- for "ordinary self-saturating bridge type magnetic amplifier" (Fig. 8).

removed and only both amplifier circuits of output stage were examined. In order to compare the both under the condition of constrained magnetization, the high impedance choke coil (15 HENRYS: 60MA; d. c. resistance 250 OHMS) was inserted in either of the control circuit. The experimental results show no remarkable difference between them.

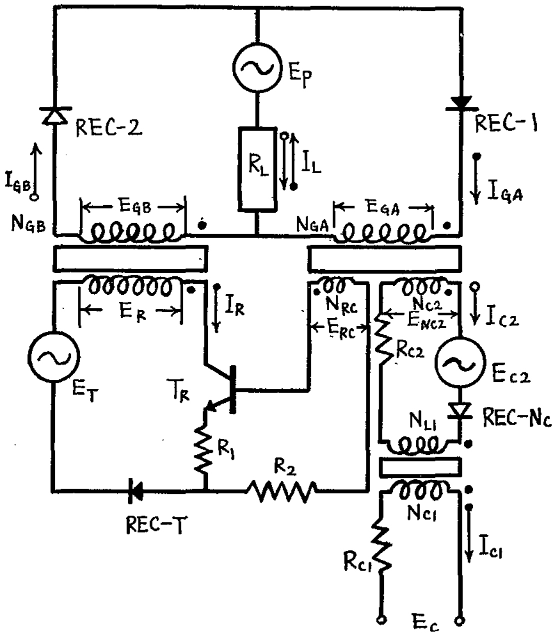


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Fig. 10 Two stage magnetic-amplifier for a-c output with half-wave control signals.

(d) Circuit for a-c Output

Two stage half-wave controlled type of magnetic amplifier for providing an a-c output is shown in Fig.10. For this purpose a part of the connection shown in Fig. 3 is changed. In this case, compared with the voltage for the full-

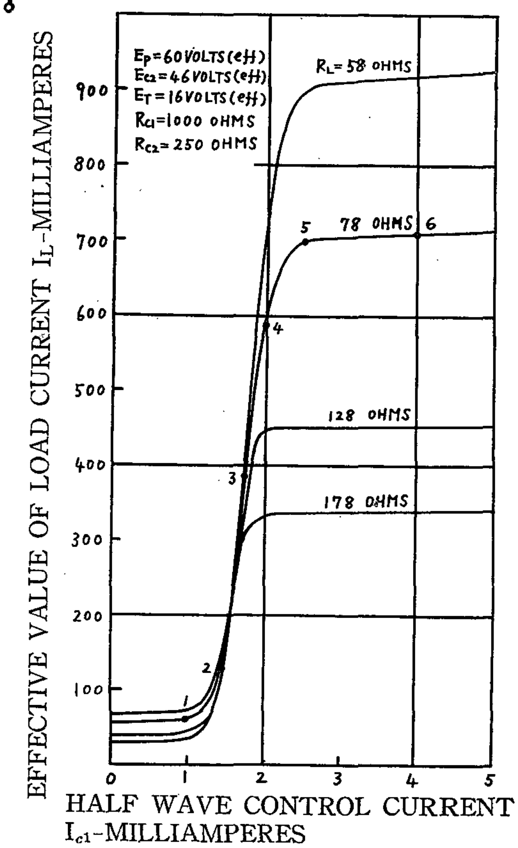


Fig. 11 Measured control characteristic of half wave controlld doubler type magnetic amplifier, illustrating effect of variation of load resistance.

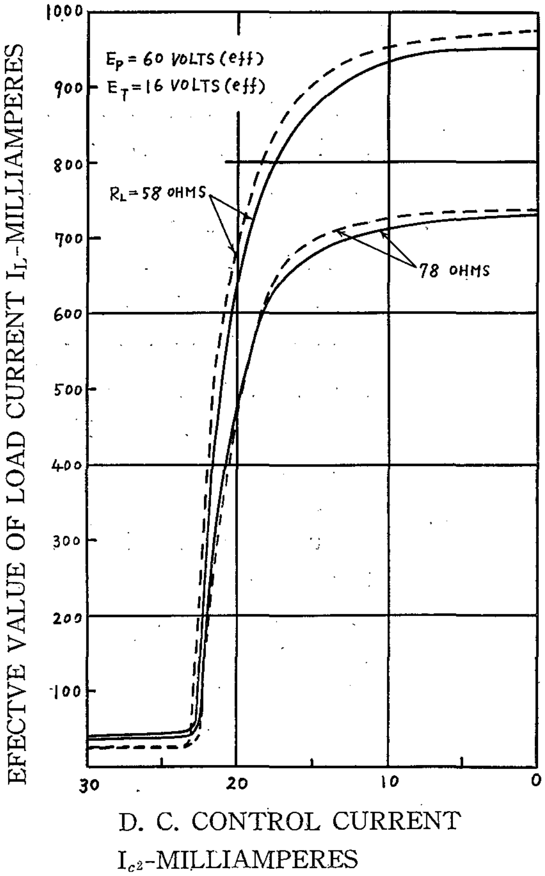


Fig. 12 Comparison of the control characteristic of half wave controlled a-c output amplifier with ordinary self staturating doubler type magnetic amplifier.

(a) —— for "half wave controlled a-c output amplifier.

(b) ---- for "odinary self-saturating doubler type magnetic amplifier.

wave output, the supply voltages of transistor and low power stage are increased by 6.7 per cent, otherwise the magnetic amplifier does not operate well, as the voltages are left as they were. Experimental results on this circuit are shown in Fig. 11, 12, 13.

The obtained static control characteristic (Fig. 11) is superior to that of the half-wave controlled full-wave output magnetic amplifier. But the response time is larger than that of full-wave output bridge type magnetic amplifier. This phenomenon is also observed in the ordinary type of doubler and bridge type magnetic amplifiers.(8)

It may be contributed to the fact that this comes from the rectifier reverse current passing through the gate winding N_{GA} of saturated inductor A during the prefiring interval of inductor B and its being transformed into the control circuit, to produce some positive feed-back.

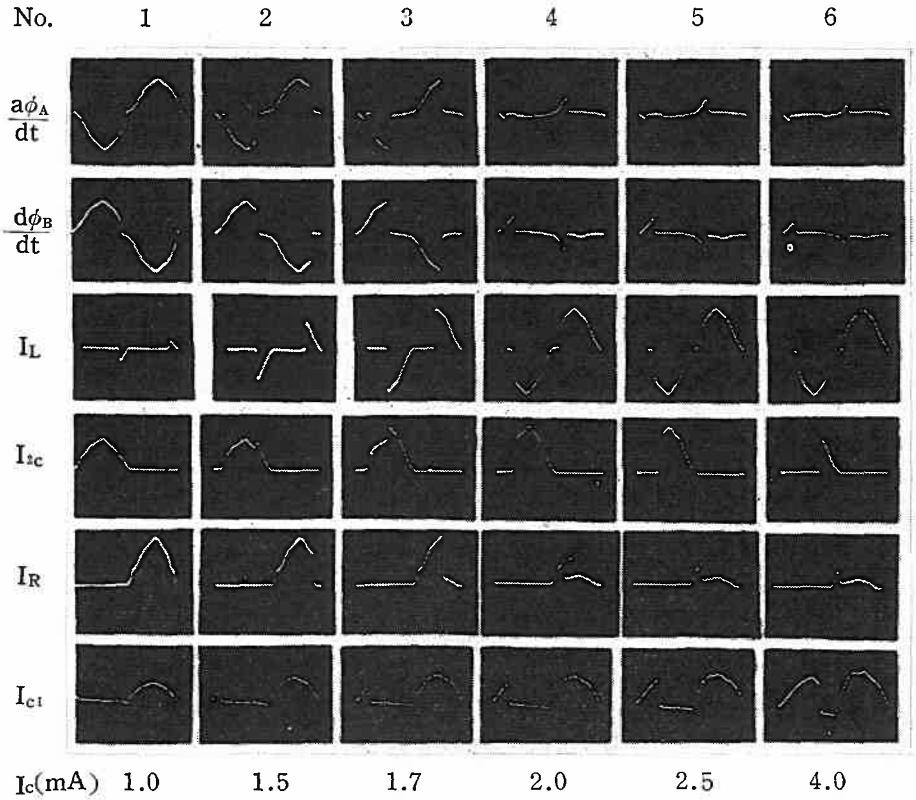


Fig.13. The core flux changes and the current wave forms in some parts of the circuit. Numbers of oscillograms refer to the points on the control characteristic (Fig. 11) where oscillograms were taken. (Doubler type magnetic amplifier)

(e) Transient Response

The results of transient response test of the half-wave controlled magnetic amplifier circuits with various loads are shown in Fig.14 (a) (b) (c). In their oscillograms, the upper trace shows the load current, the middle trace the half-wave resetting signal applied to control inductor A and the lower trace the input stage half-wave control signal.

The effect of gate circuits on the transient response of the half-wave controlled magnetic amplifier may be understood by analogy with the ordinary original self-saturating magnetic amplifier circuits.

However, the transition of the gate current I_{GA} and I_{GB} in the process of controlling is not always similar to each other, even though these currents become the same after all. This fact is resulted from the difference of the inductor A and B in the constitution of reset circuit.

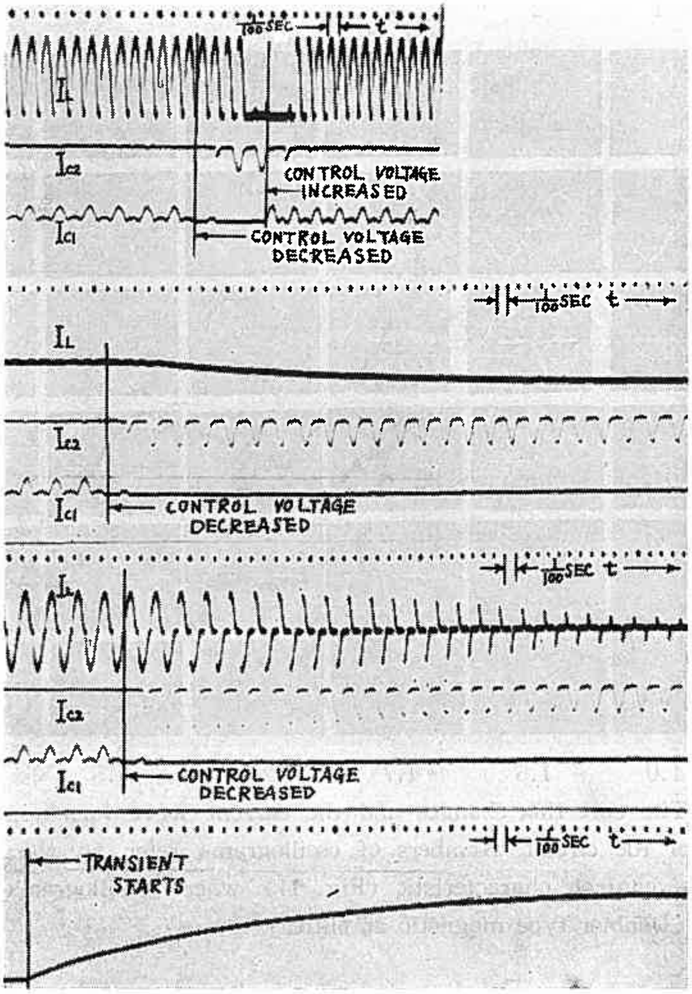
(a)
(b)
(c)
(d)


Fig. 14 Transient response caused by input stage control current-I_{c1} suddenly changed. Oscillograms of load current-I_L, output stage control current-I_{c2}, and input stage control current-I_{c1} are shown,

(a) Full wave output with resistive load (R_L = 78 OHMS).
(b) Full wave output with inductive load (Generator field was used as the inductive load.)
(c) A-c output with resistive load (R_L = 78 OHMS).
(d) Transient response of current through the generator field by d-c voltage suddenly applied,

Conclusion

As pointed out previously, it is certain that the author's half wave controlled magnetic amplifier circuits are useful for the general use of multistage magnetic amplifier. Indeed, there is some fear that the utilization of the transistor might change the control characteristics as a result of fluctuation of ambient temperature, but utilizing the transistor as a means of switching is very much free from such fear in comparison with the normal use of transistor. Perhaps the rectifiers, used also in the ordinary magnetic amplifier, are rather apt to be affected by the amplifier ambient temperature. And consequently it is safe to treat the author's in the same way as the generally used type.

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(3) Magnetic Amplifier Drives Gyro Indicator, **C. C. Voice** Electronics, VOL. 31, Feb. 14, 1958, p. p. 114.

(4) Described in "reference 1." (p. p. 266) and see Fig. 2, 4, 5 (p. p. 266-268).

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(8) "Magnetic Amplifiers" (Book) H. F. Storm, 1955, p. p. 270-271.

Appendix

Half-wave-controlled Magnetic Amplifier with Reset-adjustable-winding

In the preceding explanation of the half-wave controlled magnetic amplifier shown in Fig. 5, a trifling difference between the gate current I_{GA} and I_{GB} has not been taken into the discussion, being negligible in practical use.

If it is required that there should be no difference at all between the gate currents I_{GA} and I_{GB}, an auxiliary winding added on the core B, named "the reset-adjustable-winding" serves to adjust the amount to be reset by the transistor. Thus the circuit shown in Fig. 15 was set up and a satisfactory performance was obtained. Fig. 16 shows a characteristic obtained in this circuit. In this case, since the core B is reset by the transisor collector current in the prefiring interval of inductor A and the adjustment of the core resetting is made in the conducting interval of inductor A, they are not interfered by each other and the core resetting is brought into good condition.

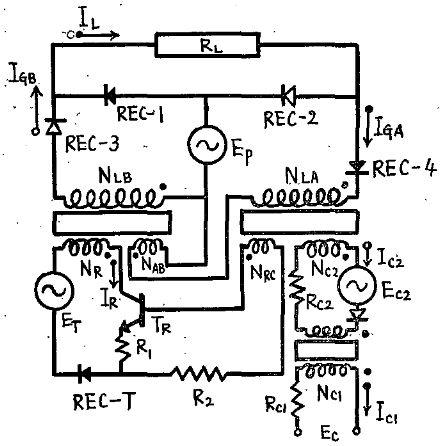

Fig .15 Two stage half-fwave controlld magneitic amplifier provided with the reset-adjustable windng.

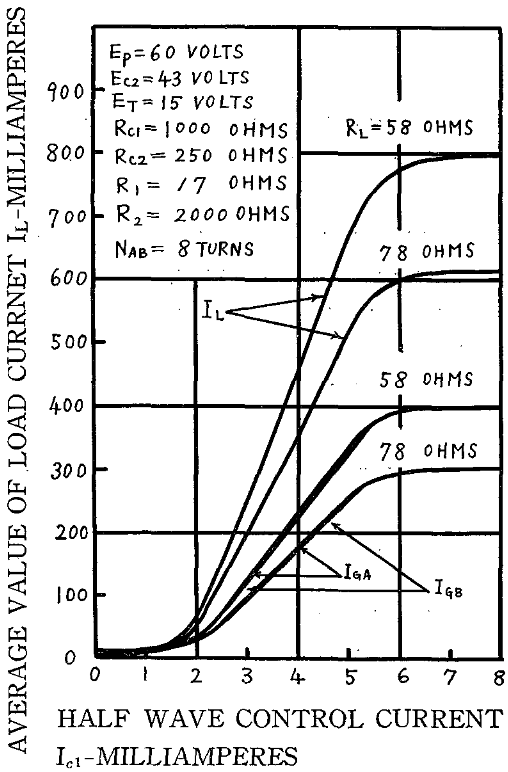

Fig. 16 Measured contvol characteristic of the half wave controlled bridge type Magnetic amplifier provided with the reset-adjustable winding.

NARUSE : Magnetie- Ampliferir Circuits Converting Half-Wave Input into Full-Wave Output with Transistor Switch

半波制御全波出力及び交流出力磁気増巾器

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電気的自動制御装置における磁気増巾器の実用化が進むにつれて，多段磁気増巾器として使用する場合も多くなった。多段磁気増巾器において全波若しくは交流の出力を得るには，初段，中間段，出力段各段共に鉄心を２個づつ用いて増巾を重ねる方法が，従来行われて来たが，初段，中間段においては，各段１個の鉄心を用いて半波増巾を重ね，出力段に至って全波若しくは交流に変換して出力を得るならば，種々の利点がある。即ち，各段毎に２個づつ特性の合った鉄心をえらび出して使用するという煩雑さもなく，回路構成も簡単になり，更に段間結合の容易なこと，過渡応答時間の縮少，初段及び中間段の消費電力の節減等を実現し得る許りでなく，特性も優れたものが得られる。

本稿はこの種の変換型磁気増巾器回路を考案し，その動作原理と共に，実験結果を示したものである。変換動作は，出力段主鉄心のゲートの際の磁束変化によって生ずる誘起電圧により，トランシスタを駆動し，これにより出力段従鉄心のリセット電流の点孤角を制御し，従鉄心にも主鉄心と同等のリセットを行わせて，全波若しくは交流の出力を得るものである。実験はブリッジ型全波出力及びダブラー型交流出力の双方の場合につき，種々の特性を測定し，又主，従両鉄心の磁束変化及び各部電流波形の制御経過中の変化を，特性曲線と対比しつつ，写真によって示し，又，従来の自己饋還型磁気増巾器との特性比較も行ってある。更に，出力電流及び各段制御電流を電磁オシログラフによって撮影し，過渡特性の吟味をも行った。