

THE INITIAL COMPARISON AMONG THREE SCHEMES OF PROGRAMMABLE BIPOLAR POWER SUPPLY USED IN THE BOOSTER CORRECTION SYSTEM

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USED IN THE BOOSTER CORRECTION SYSTEM

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The Initial Comparison Among Three Schemes
of Programmable Bipolar Power Supply Used
In Booster Beam Correction System

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(1) Introduction

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There will be about 96 units of Programmable Bipolar Power Supply (PBPS) which offer the 96 magnets that used for correcting the beam in Booster. It is necessary for the PBPS to deliver the correcting magnet a current whose polarity can be changed from one direction to other one and whose amplitude can be controlled by a Standard Analog Voltage Signal coming from the control computer. The current delivered from the PBPS can be changed from minus ten amperes to plus ten amperes. In order to obtain this kind power supply, three schemes, which can offer bipolar current, are discussed here, each of them has individual advantages and weakness. As the conclusion of Comparison among three schemes, two schemes, in which there are obvious advantages, are recommended as the principle testing circuits. The two

diagrams of principle testing circuit are shown here.

## (2) Main Specifications of The Programmable Bipolar Power Supply

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Maximum Current Amplitude	+/- 10	A
Maximum Voltage Amplitude	+/- 50	V
Stability of Current	+/- .1	0/0
Current Regulation Rate	+/- .4	A/MS
Linearity	+/- 1	0/0
Crossover	+/- .1	0/0
Load: Resistor	5	Ohm
Inductance	20	mH

(3) Essential Principle

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In order to obtain a current which flows in a load with different directions, we can naturally consider that two power supplies are used and one power supply delivers plus

direction current and the other one minus direction current. As shown in Figure 1, E1 is plus power and E2 is minus power supply. When the switch connects to 1 the current through road R1 is in plus direction and when the switch connect to 2 the current is in minus direction. Changing E1 or E2 can vary the amplitude of currents. But, the disadvantage of the method is that it requires two power supplies to power the same load and the switching means.

We can save a power supply by using two switches which are shown in figure 2. When the switch connects the contacts of 1, 3 and 4, 6, the current of load is in plus polarity and the current is in minus direction polarity when the contacts of 2, 3 and 5, 6 are connected. The amplitude of current in load can be changed by adjusting the voltage of power supply E. We can also change the amplitude of load current by adjusting the resistance of a adjustable resistor which is connected in series with load and power supply E.

#### (4) Three Schemes For PBPS

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There are many different schemes which can deliver bipolar current, for example , using a relay as the switch, in other words, using contact switch. But , because the time that the relay action need is quite long (30-50 msec) it is not useful for programming current changes during a pulse. And , it is necessary to use other components which control the load current. The three schemes here do not use

contact switches.

(A) Dual P.S. Single Pair Transistors.

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From figure 1, it is found that the semiconductor transistor can be used for not only switching the direction of the load current but also control the amplitude of the load current. Figure 3 shows the diagram of a Dual P.S. single pair transistors PBPS.

110 V AC power charges the capacitors C1 and C2 through transformer T1 and two diodes D1 and D2 to a certain voltage. Transistors Q1 and Q2 are used not only as polarity switches but also as current regulators. The plus analog reference voltage  $V_{in+}$  is input to the plus point of amplifier A1. A1 amplifies the input voltage and drives the transistor Q1, so that plus direction current flows from C1 through Q1, R1 to RL. The voltage across R1,  $V_1$ , is fed back to the amplifier A1 minus end and provides negative feedback. Because of the action of the closed loop circuit, the voltage on R1,  $V_1$  equals the input voltage  $V_{in+}$ :

$$V_1 = V_{in+} \quad (1)$$

or

$$I_{load} = V_1 / R_1 = V_{in+} / R_1 \quad (2)$$

When a minus analog reference voltage  $V_{in-}$  is input to the plus point of amplifier A1, it is amplified and drives the

transistor Q2. So, the minus direction current flows from capacitor C2 through Q2, R2 to RL. The voltage of R1, V1 is fed back to the amplifier A1. The voltage on R1, V1 equals the input voltage Vin-:

$$V1- = Vin- \quad (3)$$

or

$$I_{load} = V1- / R1 = Vin- / R2 \quad (4)$$

Composing (2) and (4) we obtain that

$$I_{load} = Vin / R1 \quad (5)$$

(B) Single P.S., Dual Pairs Transistors.

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From figure 2 we see that two pair transistors can replace the two switches, K1 and K2 and control the load current. Figure 4(A) shows the diagram of a Single P.S. Dual Pairs Transistor PBPS.

110 V AC power charges the capacitor C1 through transformer T1 and diode bridge to its corresponding dc voltage. Transistors Q1 and Q4 conduct the plus direction current and Q2, Q3 conduct minus direction current. When a plus analog reference voltage signal Vin+ is input to the plus end of amplifier A1, it is amplified and drives the transistor Q1 and Q4 through voltage converter VC1. So the

plus direction current which flows from the plus end of C1 through Q1, R2 , load and Q4 to the minus end of C1 is formed. The voltage on R2 , V2 is feedback to the minus end of amplifier A1. Because of the action of the closed loop circuit, the voltage on R2, V2+ equals the input voltage Vin+

$$V2+ = Vin+ \quad (6)$$

or

$$I_{load+} = V2+ / R2 = Vin+ / R2 \quad (7)$$

When a minus analog reference voltage Vin- is input to the plus point of amplifier A1, it amplifies the input the voltage and drivers the transistor Q2 and Q3 through the voltage converter VC2. So the minus direction current flows from the plus end of C1 through Q3, load, R2 and Q2 to the minus end of C1. Because the voltage V1 is feedback to the minus end of A1, through negative feedback, V2- equals the input voltage Vin-

$$V2- = Vin- \quad (8)$$

or

$$I_{load} = V2- / R2 = Vin- / R2 \quad (9)$$

Composing (6) and (8) we obtain that

$$I_{load} = Vin / R2$$

The transistors in figure 4(A) can be changed by a MOSFET Power Module showed in figure 4(B), because the MOSFET module is installed easily and the price of MOSFET module is higher than the price of transistors a little. The driver circuit of MOSFET is simple.

(C) Dual SCR Groups

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An SCR is a good switch. It is found that the switch in figure 1 can be replace by two SCR groups and the SCR groups can control the output voltage by control of their gates or triggering. Figure 5(A) shows the Dual SCR Groups Bipolar Power Supply whose principle is simple. Figure 5(B) shows the control scheme.

When the reference voltage  $V_{in}$  is input to the plus end of A1, A1 amplifies the voltage and transport it to Driver Allotter. When the  $V_{in}$  is larger than zero, the Driver 1 is working and drives the SCR Group 1 and when the  $V_{in}$  is less than zero the Driver 2 is working and drives the SCR Group 2. When the SCRs in Group 1 are triggered the current flows through the load in the plus direction and when the SCRs in Group 2 are triggered the current flowing through the load is in the minus direction. L and C comprise a low pass filter. The direct current transistor (DCCT) provides the negative feedback voltage  $V_1$  to the amplifier A1 minus end. So,

$$V_1 = V_{in}$$

(10)

or

$$I_{load} = K * V_{in} \quad (11)$$

where, K is DCCT coupling coefficient.

A dangerous fault condition is created if the SCR's are erroneously triggered. So in order to prevent this trouble, a Driver Lockout circuit is selected. The state of Driver Lockout unit is determined by the Polarity Inspector circuit. When  $V_{in}$  is larger than zero, only the SCRs in Group 1 may be driven and when  $V_{in}$  is less than zero, the SCRs in Group 2 only may be driven only.

If the SCRs in figure 5(A) are changed by transistor, the trouble triggering is less than SCRs'. The principle of figure 5 (C) is same as figure 5 (A). The power dissipation of transistors used in switch mode may be lower than the power dissipation of SCRs.

(5) Comparison among the schemes.

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Even if the three schemes described above can deliver bipolar current, each of them has identifiable advantages and weaknesses. The advantages and weaknesses are described in the following paragraphs.

Scheme (A): (Fig. 3)

This scheme in principle is simple. Because it uses a pair of transistors, the polarity crossover distortion is small by setting suitable operating state bias of

transistors. The weakness of this scheme is that it needs two rectifiers power supplies and filter capacitors which costs more.

Scheme (B): (Fig. 4)

This scheme can save one P.S. We can use one type transistor. This leads us to conclude that the transistor bridge should be adopted. But the crossover is larger than scheme (A) because one power supply is adopted, and the two transistors have to conduct the current at the same time. In other words, it requires that the four transistors matches each other very well.

Scheme (C): (Fig. 5)

This scheme can deliver high current easily. Because the power dissipation of SCR's or transistors used in switching type is less than the power dissipation on transistors used in linear mode, the efficiency is higher than scheme (A) and (B). But, due to the use of SCR's and their associated method of gate control, the ripple of the load voltage waveform will be larger than scheme (A) and (B), and the crossover is larger too. Because the low pass filter is used, the Current Regulation Rate is limited.

(6) Conclusion

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Scheme (C) is suitable for high current, for example, higher than hundred amperes. Scheme (A) and (B) have individual advantages and weaknesses. Scheme (A) can get

better crossover but it has to use two power supplies of the same power. So the price of scheme (A) is high than that of scheme (B). Scheme (B) has the advantage of using a single P.S. This may lead to a lower price, but the crossover distortion is larger than that of scheme (A). therefore, it is necessary to test the schemes (A) and (B) in order to chose which one gives the finest scheme considering the quality and the price. Initial estimates give the prices of schemes (A) and (B) at around \$1000.00 each.

Figure 6 shows the diagram of a prototype testing circuit of scheme (A), and figure 7 shows the diagram of a prototype principle testing circuit of scheme (B).

Before ending the paper I have to thank Andy Soukas and Jon Sandberg who gave me so much help on the investigation for the PBPS.

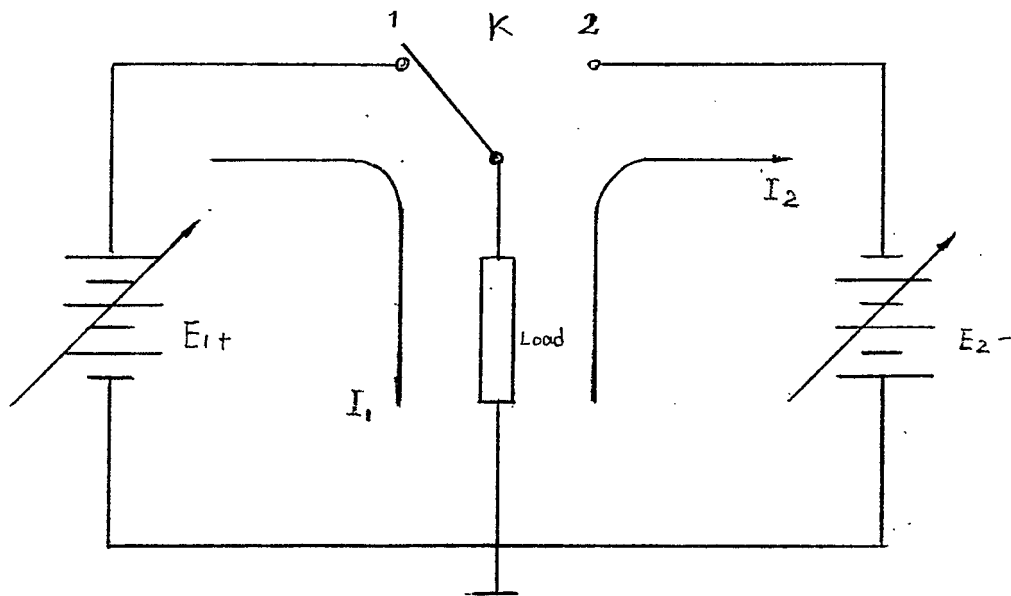


Figure 1, Principle Diagram Of Dual P.S.

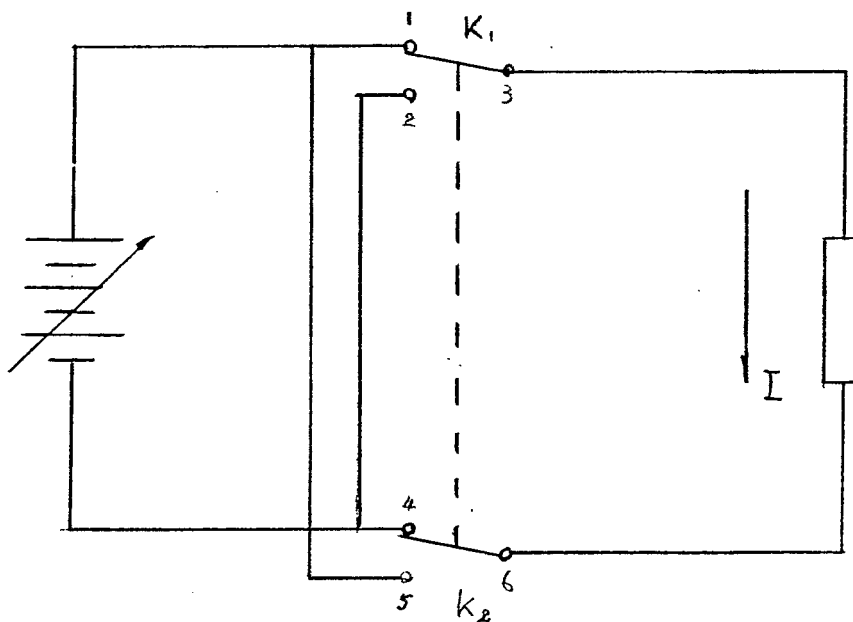


Figure 2, Principle Diagram Of Single P.S.

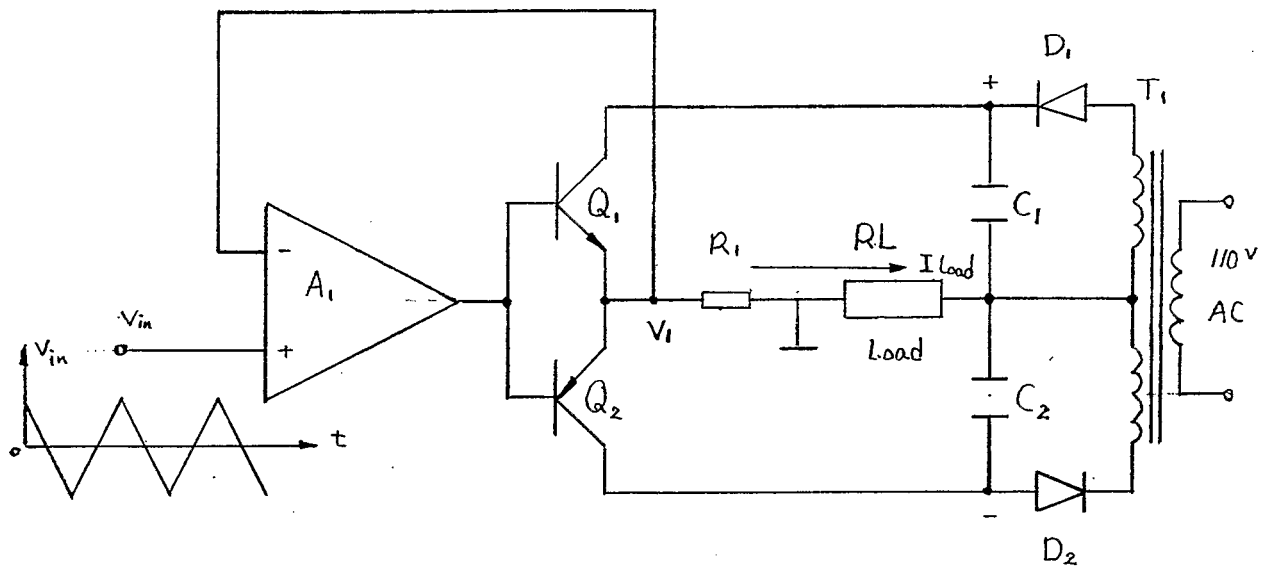


Figure 3, Dual P.S., Single Pair Transistor Scheme Diagram

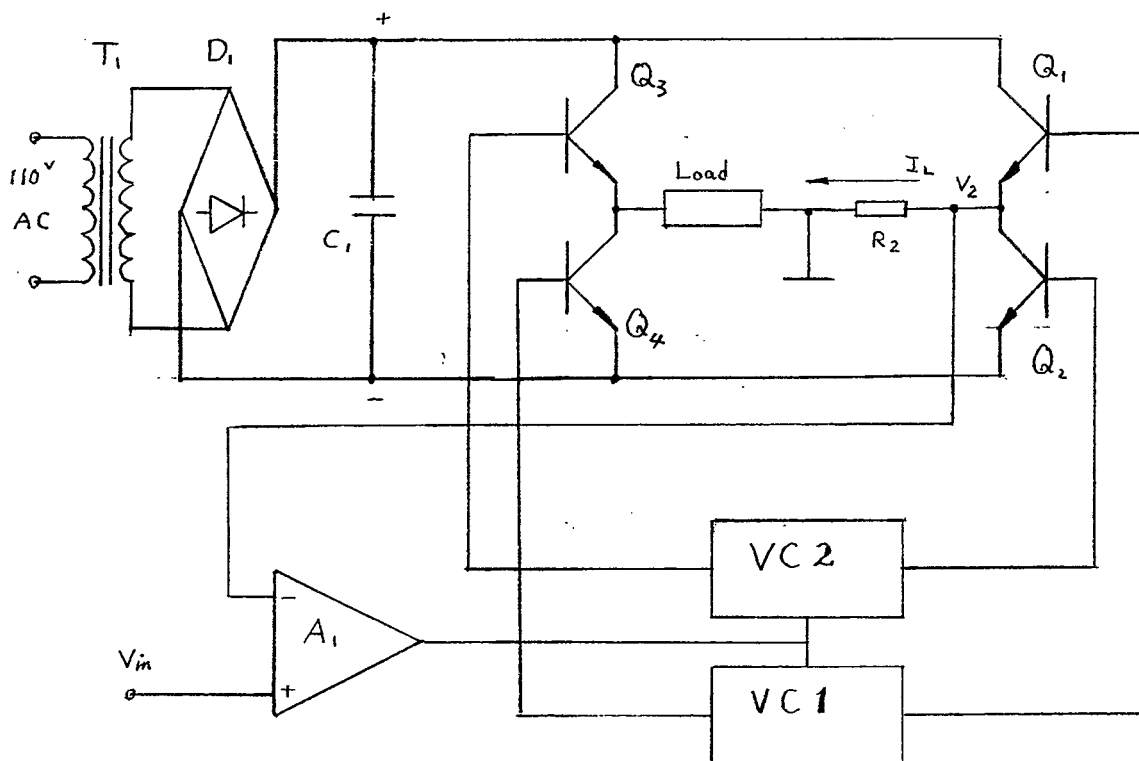


Figure 4(A), Single P.S., Dual Pair Transistor Scheme Diagram

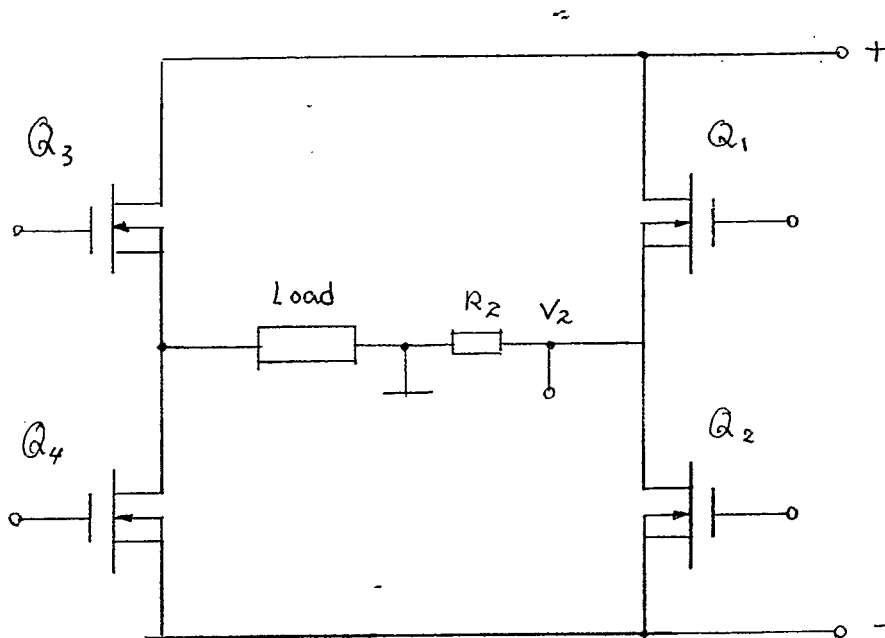


Figure 4(B), Single P.S. MOSFET Bridge Diagram

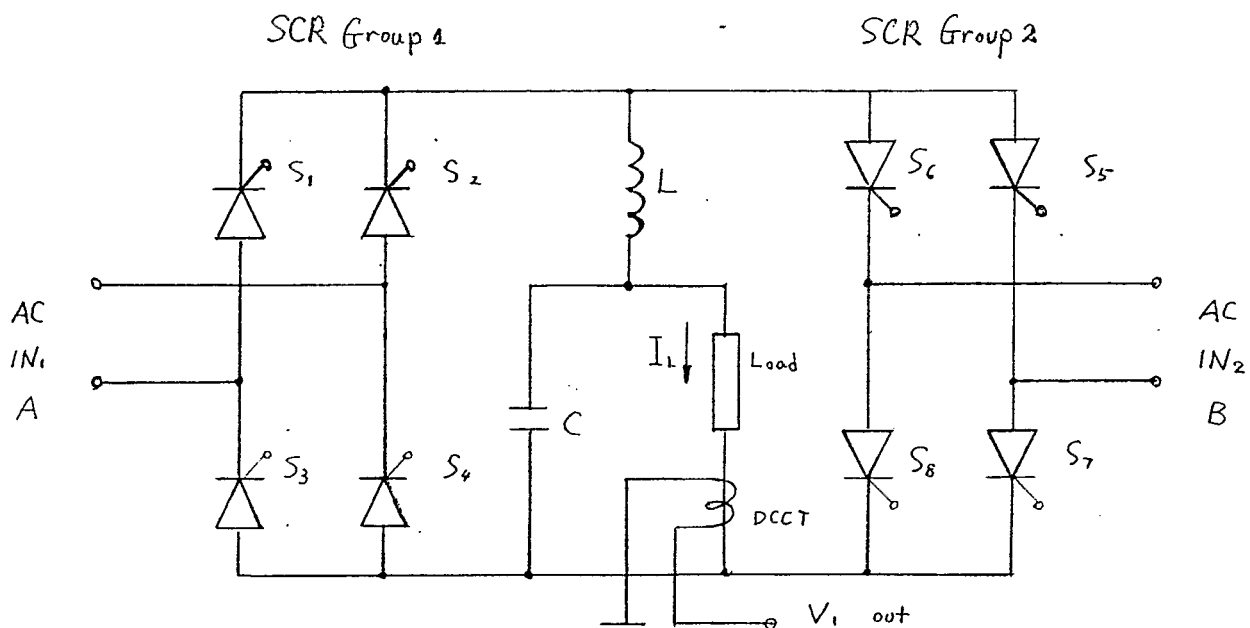


Figure 5(A), Dual SCR Groups Scheme Diagram

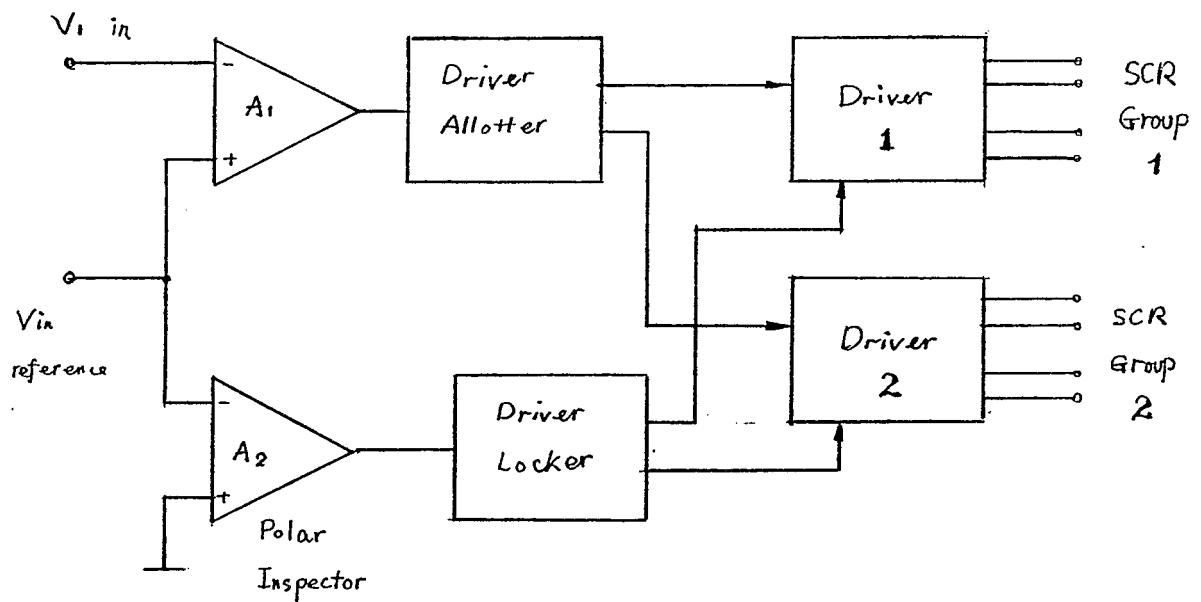


Figure 5(B), Dual SCR Groups Scheme Diagram

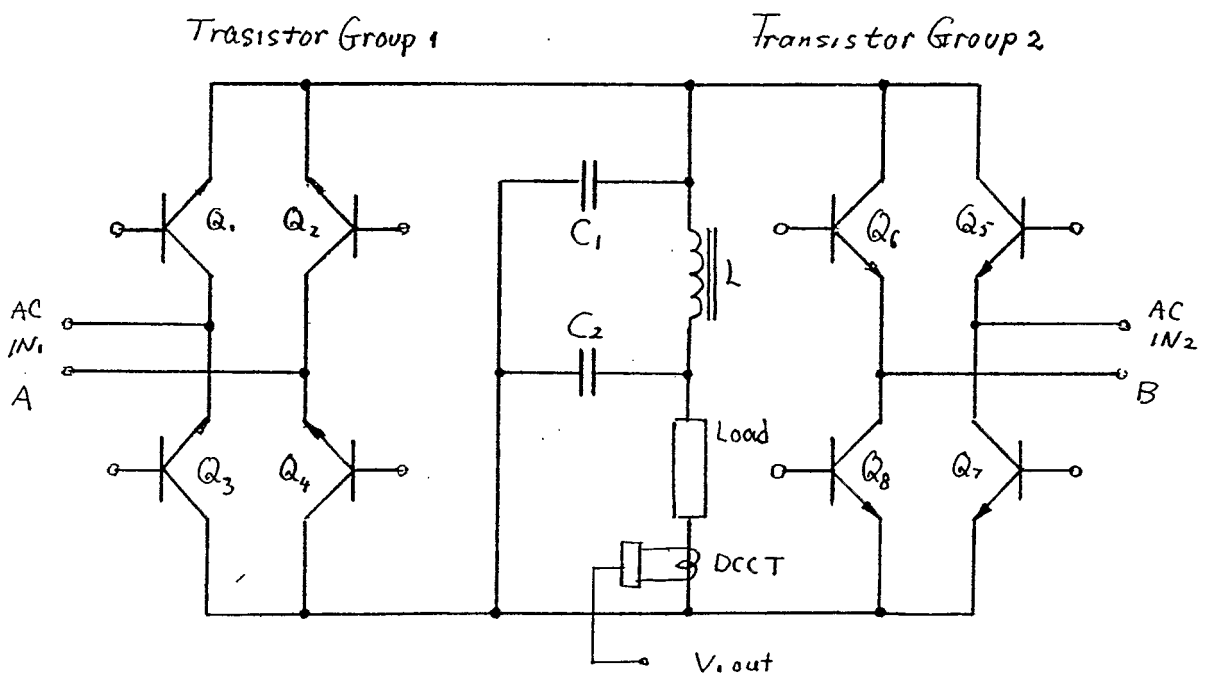


Figure 5(C), Dual Transistor Groups Diagram

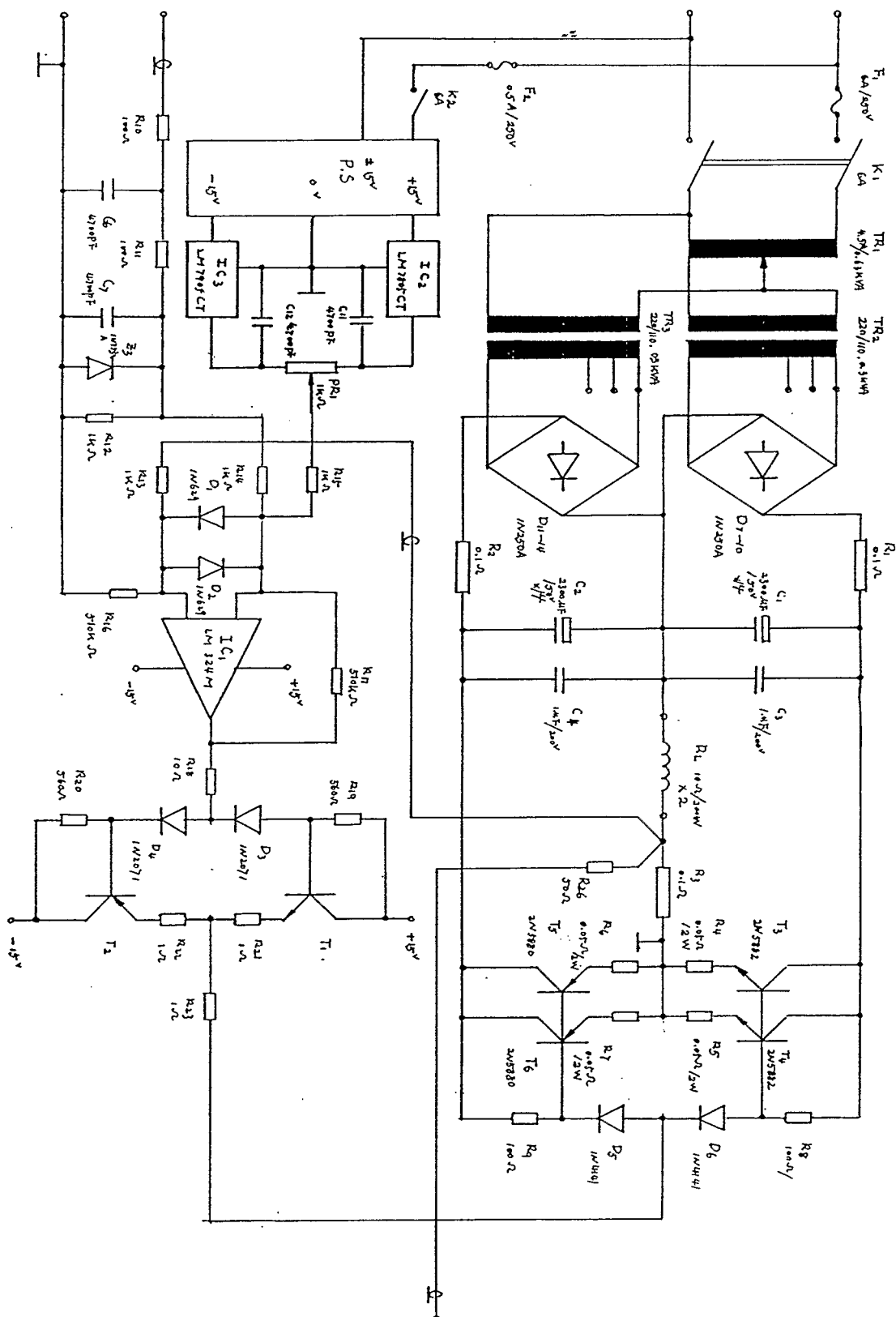


Figure 6, Scheme (A) testing circuit diagram

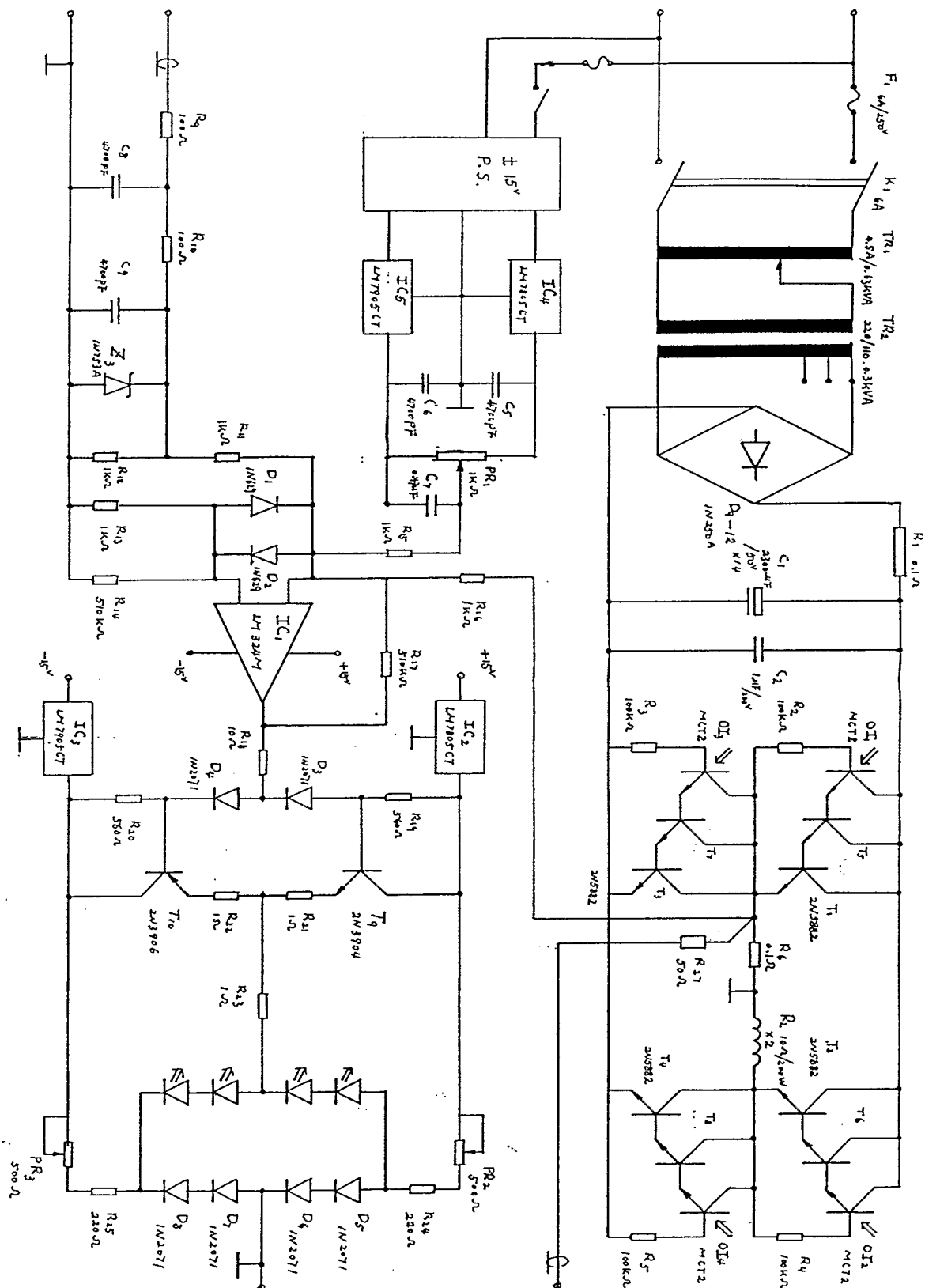


Figure 7, Scheme (B) testing circuit diagram