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EUROPEAN ATOMIC ENERGY COMMUNITY - EURATOM

POWER SUPPLY FOR ESONE STANDARD PLUG-IN SYSTEM

by

I. DE LOTTO, G. GIANNELLI, L. STANCHI

1962

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The 24 V semi-regulated voltage is obtained controlling two switching transistors with magnetic amplifiers. The regulators use a new circuit and are protected against overloads and short circuits. The analysis of the circuits and the protection system are given.

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CONTENTS

POWER SUPPLY FOR ESONE STANDARD PLUG-IN SYSTEM

SUMMARY

A transistor power supply for two cases according to ESONE standard is described. It consists of a 24 V semi-regulated voltage from which all the regulated voltages required by the standard are derived.

The 24 V semi-regulated voltage is obtained controlling two switching transistors with magnetic amplifiers. The regulators use a new circuit and are protected against overloads and short-circuits. The analysis of the circuits and the protection system are given.

1 - SPECIFICATIONS

The main characteristics of a power supply for the ESONE Standard plug-in system, designed for supplying two cases, are given in tables I and II.

Table 1

	Nominal voltage	Nominal current	Degree of regulation	Max ripple
	V	Amp.	better than :	mV peak to peak
	+ 24	0.5	± 0. 2 %	2.5
	+ 12	0.5	± 1 %	5
	+ 6	1	± 1 %	5
	- 6	2	± 1 %	5
	- 12	2	± 1 %	5
	- 24	0.5	± 0.2 %	2.5
Semi-regulated voltages	- 24 SR	4	± 1 V	500

Table 2

The Characteristics must be maintained with the following simultaneous variations :
a) Load variation from 0 to 100 %
b) Line voltage variation ± 10 %
c) Room temperature variation from 15° C to 40° C

Not all the nominal output currents indicated in table 1 must be simultaneously available but the total regulated power at the outputs must be at least 48 W.

2 - GENERAL BLOCK DIAGRAM OF THE POWER SUPPLY MODEL AL 16

The block diagram of the power supply model AL 16 is given in fig. 1.

The 24 V SR (semi-regulated) has been obtained by means of a switching transistor regulator since it allows a high efficiency and a minimum dissipation in the series power transistor. This type of regulator cannot be used for the other voltages chiefly because of the residual ripple which is consequent to on-off operation. Anyhow taking advantage of the high efficiency, simplicity, easiness of filtering of transistorized high frequency dc dc converters, the power for all the other regulators has been obtained from the 24 V SR through a dc dc converter. The 24 V SR presents lower variations and ripple than a voltage directly rectified and filtered from the line. This allows to have somewhat lower dissipation on the series transistors of the regulators. Moreover the regulated voltages are better isolated against transients from the line. The block diagram shows also the circuits which protect the power supply against overloadings and short circuits.

3 - ON-OFF 24 V REGULATOR

The power regulating systems operating in linear fashion have considerably high losses in the series transistor. Indeed the power dissipation for maximum load and line voltage is nearly equal to the regulated power. Switched operation of power supply regulators is therefore attractive because the power dissipation on the series transistor is low compared to the regulated power.[1, 2, 3] The regulation is obtained by variation of the ratio between the on- and the off-time of the transistor. This variation can be accomplished in three different ways controlling the series transistor by means of rectangular pulses having :

a) fixed rate and variable width

b) variable rate and fixed width

c) suitably variable rate and width.

In fig. 2 the schematic of the 24 V regulator is given. The output current is 9 amp. max. In order to keep into saturation the series transistor also under overload conditions (charging transients on output capacitors, short circuits, etc...) a 2 amp. current must be supplied to its base. This current assures also a sufficient overdrive during the on-time, chiefly during the switching to saturation.

A contral with fixed rate and variable width pulses has been simply obtained by a square wave saturable transformer oscillator and by controlling the series transistor with a magnetic amplifier. The latter is advantageously used in high current power supplies. The circuit has a very low number of components (nearly all of the passive type) and a very simple behaviour so that it is quite stable and reliable.

Transistors Q_4 and Q_5 and transformer T_2 form a 1200 c/s square wave oscillator which drives the two half-wave magnetic amplifiers T_3 and T_4. The output currents of T_3 and T_4 control the power series transistors Q_3 and Q_2 respectively.

The conduction cycle of the magnetic amplifiers is varied by the control current I_c obtained by transistor Q_1 and is a function of the difference between the output voltage and the reference voltage on zener diode Z_1. In the interval between conduction cycles transistors Q_2 and Q_3 are reverse biased by the voltage dividers R_2, R_3, R_4, and D_2. The collector current of the series transistors is limited by inductor L_1. When the series transistors are off, the inductor discharges through the diodes D_1 and transfers to the output the energy stored during the on-time. In this way a very high efficiency is obtained.

The most part of the power dissipation of the series transistors occurs during switchings and can be reduced decreasing the switching duration. Because of inductive load of the series transistors, the dissipation in the switching from on to off condition is particularly high. This transient is speeded up by positive feedback by means of transformer T_5 and capacitors C_1 and C_2. T_5 is a transformer with a low magnetizing inductance and a low coupling coefficient. Stability requirements do not allow to smooth out the ripple on the base of Q_1 which could drive Q_1 at cut off, with an R C filter. It is necessary to keep the ripple sufficiently low directly on the output by the use of a large smoothing capacitor. The high internal impedance generator Q_1 controls the magnetic amplifiers so their response time is a half-period of the 1200 c/s frequency. For load current greater than 3 amp. the current in the inductor does never go to zero. That means that the current at the beginning of each conduction cycle depends on the magnitude of the current in the previous cycles. That is the system inductor - series transistor has a memory, that corresponds to an integration in the transfer function of this system. The transistor duty cycle is consequently independent of the load current and assumes different values only during transients of the load current. That integration lowers the feedback loop stability so the open loop gain of the amplifier must be kept lower; nevertheless the degree of regulation is completely sufficient for the requirements.

This drawback is not present if the current through the on-off transistors is limited by a resistor (fig. 3 b). It is possible to avoid the memory effect also using inductors if sufficient time is allowed to discharge them between conduction cycles. One way to obtain that is shown in the circuit of fig. 3 c in which the transistors conduct during one half period in each cycle and V_{in} is lower than twice V_{out}.

4 - Dc Dc CONVERTER AND REGULATORS

The schematic of the dc dc converter is shown in fig. 4. Its oscillation frequency is 1800 c/s and the output power capability is 80 W. The rectifiers are in the full-wave connection instead of the bridge connection. This system requires a more complex transformer but reduces the voltage drop across the diodes which is not negligible in the case of low rectified voltages and is more economical. A separate winding is provided for each voltage owing to the protection system (fig. 6) that has been used. The schematics of the regulators are shown in the figures 5, 6, 7, 8, 9, 10. They differ from the conventional series type only for the modification analyzed in next paragraph.

The reference voltages are obtained from two temperature compensated reference elements for the + and - 24 volts regulators. The other regulators take the reference voltage from the 24 V regulators.

The operating point of the amplifying transistors of the regulators have been chosen at a rather high current level in order that :

a) the gain be always sufficient for every load condition

b) the transient response towards lower loads be according to the standard requirements

c) the regulators be efficient also for minimum load at maximum working temperature.

5 - THE NEW REGULATOR CIRCUIT

The open loop gain can be expressed as the product of two terms : the gain A_1 of the difference amplifier and the gain A_2 of the series element. For a constant total gain the disturbances injected between the two parts appear at the output greater as A_2 is greater than A_1.

In transistor regulators A_2 is more important than in electronic tubes ones owing to the high gain of the transistors. In the conventional circuit the difference amplifier is supplied either from a very high unregulated supply voltage in order to obtain a very high value of A_1 that neutralizes the disturbances introduced just because the supply voltage is not regulated, or from an auxiliary regulated voltage [4]. Our circuit presents a simple solution that consists in controlling the series element by a high impedance generator (collector of a transistor of complementary type of that of the series one) and this is in turns driven by a high impedance generator (fig. 5 to 10).

6 - PROTECTION ANALYSIS

In a complex system of instruments the power supply is one of the most critical parts because the performances of all the other instruments are dependent on its correct operation. If the power supply is a complex one, i.e.gives many voltages and is designed for supplying a variable number of modular instruments, it is necessary to be guaranteed against overloads because these normally happen. The regulator has then studied so that the following requirements are satisfied :

a) do not damage in any case the instruments it supplies

b) stop operation rather than give voltages different from the nominal voltages

c) supply voltages that with nominal loads do not go out of regulation except for the specified transient times

d) do not give any appreciable increase in voltage in case of internal failure.

The power supply has been designed to be completely safe that is it will not be damaged also in case of wrong use of short circuit or if the fuses are substituted, as it is rather common practice, with fuses for higher currents.

The fuse is a slow device compared to a transistor junction : the short circuit current should be consequently higher than the nominal current of the fuse but lower than the maximum current that the junction can withstand.

The problem of the short circuit current is more critical in transistor regulators than in electronic tube ones because the voltage drop on the series transistor is generally a lower percentage of the output voltage. Therefore transistor power supplies have greater efficiency but also greater short circuit currents.

The most common protection systems are :

6.1 SHORT CIRCUIT CURRENT-LIMITING RESISTOR

The circuit is designed so that the series transistor go into saturation in short circuit condition. The power dissipation on the transistor is consequently low.

The short circuit current is limited to a value less than maximum allowable for the emitter junction by a series resistor. A suitable fuse will blow up in case of permanent short circuit. Because of its simplicity this system is highly sure and practical. It is very suitable for single power supplies. However this system is not free from drawbacks. Overloads cause the output voltage to go under the nominal value; this is often inacceptable specifically in complex power supplies.

The series resistance and the unregulated dc voltage must be so chosen that for maximum load and minimum line voltage, the transistor remains in the active region also for the maxima of the ripple. Because of that the dissipated power is rather high and the efficiency low and this fact is increased if large line variations are taken in account.

6.2 NON-RESISTIVE CURRENT LIMITING SYSTEM AND FUSE

Many systems with more or less sharp threshold which limit the current to a value which is less than the maximum allowable for the transistor junction but higher than the fuse blow up value, can be used. These systems have a higher efficiency than the preceding one but the dissipated power on the series transistor can reach very high values on short circuits. The protection is given by the fuse what presents the already discussed drawbacks. Moreover the output voltage may go out of regulation on overload conditions.

6.3 CURRENT AND TRANSISTOR TEMPERATURE LIMITING SYSTEM

System II may advantageously be coupled to a temperature sensitive device (e.g. thermistor, thermal relay) applied to the series transistor. When the transistor temperature exceeds the prefixed maximum the system opens the supply. This system has the drawbacks of system II and of a very long thermal-time-constant.

When the device is triggered, the regulator will remain inactive, also if the triggering condition disappears, for a time which is defined by this constant. This time is of the order of 10 $\div$ 15 minutes so that the user may be induced to exclude temporarily or permanently the protection system. It is to be noted that the transistor temperature is not only a function of the power dissipation but also of the room temperature therefore the device must be calibrated for the maximum ambient temperature.

The long recovery time can be avoided if an electronic system sensitive to the transistor power dissipation is used.

6.4 THRESHOLD FLIP-FLOP SENSITIVE TO THE OUTPUT-CURRENT

A threshold flip-flop is triggered and opens the supply when the output current exceeds a prefixed value. After that the regulator remains inactive until a manual control turns it on again. The efficiency is very high and the circuit is very fast. In fact it can be so fast as to be triggered by any transient. This drawback could be overcome by introducing an integrating time constant in the trigger but then the series transistor is not protected any more.

7 - THE PROTECTION SYSTEM WHICH HAS BEEN ADOPTED

The chosen system is system II combined with system IV, with a time constant before the circuit. The current is limited by system II to a rather low value so that the maximum power dissipation in the series transistor is sufficiently limited, what allows to use system IV with a long enough time constant. Its value is dependent on the output time constant.

The values of the different critical currents (fig. 11) have been set so that :

a) The maximum nominal current I_n is always delivered in every condition and on all the temperature range. Some overload should be allowed (e.g. 20 %).

b) The threshold current I_t which triggers the discriminator must be greater than I_n (with its overload) and lower than the current I_l for which the limiting circuit comes into operation. In fig. 11 the permitted region for I_t is shown. This takes account of the variations of I_t for temperature variations and for the spread in the characteristics of the components in order to allow mass production using simple circuit solutions.

c) The limit current I_l has permitted region which must never overlap the permitted range of I_t. *

d) The short circuit current I_{sc} does not damage the transistor before

* Current I_l has been calculated taking account of the spread of the characteristics and the effects of the temperature variations which have a great importance because in these circuit the voltage drops on germanium and silicon junctions are compared.

the discriminator fires. This fixes an upper limit for current I_1. The plot of fig. 11 can be obtained with system II alone. In fact the necessity of joining to the type II protection the type IV one arises only when the power dissipated by the series transistors on short circuits is higher than its power ratings. This does not happen for the lower voltages, but system IV has been used also for them because allows to follow the ESONE recommandation that all voltages be cut off when there is a short circuit on one.

To obtain that the discriminator is made to actuate a relay which stops the dc dc converter. Only the 24 V SR. is not controlled by the protection.

8 - SYSTEM SENSITIVE EITHER TO A SHORT CIRCUIT ON OR TO THE ABSENCE OF ONE OUTPUT VOLTAGE

The protection system could be completed by adding a device which cuts off all the regulators when an output voltage fails. The absence of one supply voltage can damage seriously the instruments if they are not designed in order to hold out against such an accident.

While the absence of one voltage at the power supply outputs is a very common event, it is more probable that a supply voltage fails inside the instruments because of bad contacts in the connectors or in the wirings or of a component failure (short circuit in an electrolitic capacitor, opening in a resistor, etc.).

For this reason this supplementary protection has not been adopted apart from economical considerations.

9 - DESCRIPTION OF THE PROTECTION CIRCUIT (fig. 12)

Transistors Q_1 ..... Q_6 amplify the voltages across the series resistors of the regulators. They have a feedback resistor which decreases the influence of emitter junctions reverse currents variations due to the spread of the characteristics and the temperature variations (see appendix). The greatest of the amplified voltages is sent to an R-C integration through a sextuple OR circuit and amplified by transistor Q_7, which has a threshold of 12 V, and finally by transistor Q_8.

The relay stops the dc dc converter by short circuiting one of the transformer windings. This relay is self-locking. It is released by a push-botton control.

A current limiting circuit is provided for each regulator and utilizes the two silicon diodes D_1 D_2 (fig. 5 $\div$ 10) which limit the emitter junction voltage of the series transistor.

10 - PERFORMANCES

The tests made on one prototype have given the following results * :

* No choice of transistor or components has been made in the construction of the prototype.

Table 3 - Actual Output Voltages

Nominal output voltage V	Actual Voltages				Overall variations
	no load	full load	no load	full load	
+ 6	6.007	5.993	6.037	6.022	0.7 %
- 6	6.008	5.996	6.038	6.018	0.7 %
+ 12	12.005	11.995	12.025	12.015	0.25 %
- 12	12.010	11.990	12.040	12.020	0.4 %
+ 24	24.010	23.990	24.000	23.980	0.125 %
- 24	24.010	23.990	24.020	24.000	0.125 %

Table 4 - Transients on the regulated voltages for step variations of the load

Nominal voltage	Nominal current	Transients on the voltage for load variations			
		from 10 % to 100 %		from 10 % to 100 %	
V	A	Amplitude	Duration	Amplitude	Duration
+ 6	1	- 0.7 V	50 μs	+ 0.5 V	30 μs
- 6	2	+ 0.7 V	40 μs	- 0.5 V	70 μs
+ 12	0.5	- 0.3 V	30 μs	** + 0.3 V - 0.1 V	30 μs
- 12	2	** + 1.7 V - 0.3 V	40 μs	- 0.8 V	10 μs
+ 24	0.5	- 50 mV	20 μs	+ 0.4 V	4 μs
- 24	0.5	+ 7 V	4 μs	- 0.5 V	3 μs

** positive and negative peaks of a damped oscillation.

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APPENDIX : Calculation of the input circuit (Fig. 13) of the protection system

V is the voltage across the resistors R_p in series to the regulators (fig. 5 + 10). The equation of the circuit is :

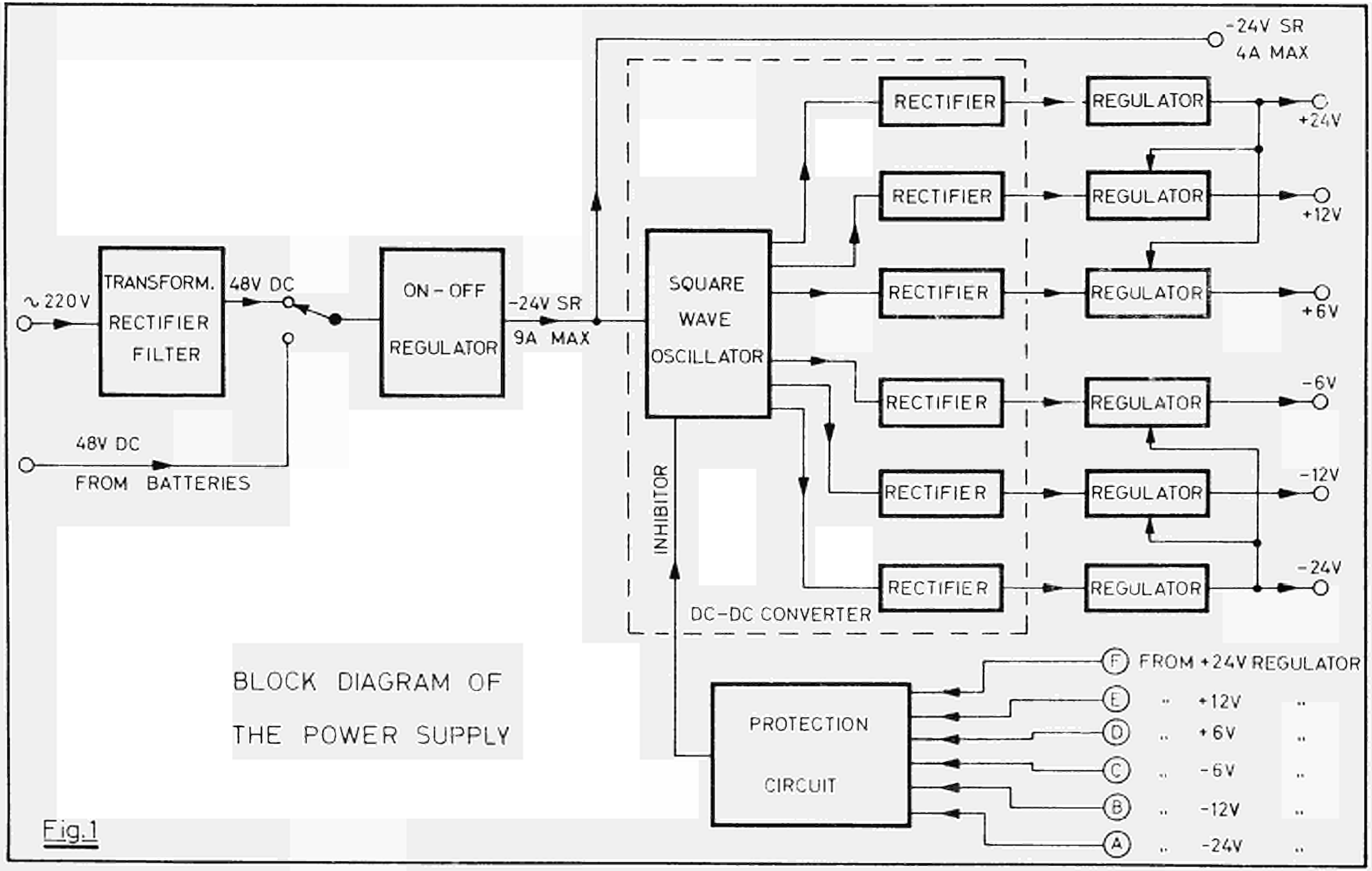
$$v = v_{EB} + v_R = \frac{KT}{q} \ln \frac{i}{I_{ES}} + Ri$$

The only variable quantity is I_{ES}. The spread of I_{ES} (5) at constant temperature is less than a factor of five for the transistors used.

The variation in the temperature range 15° - 40° C is a factor of 16. That gives an absolute variation in V

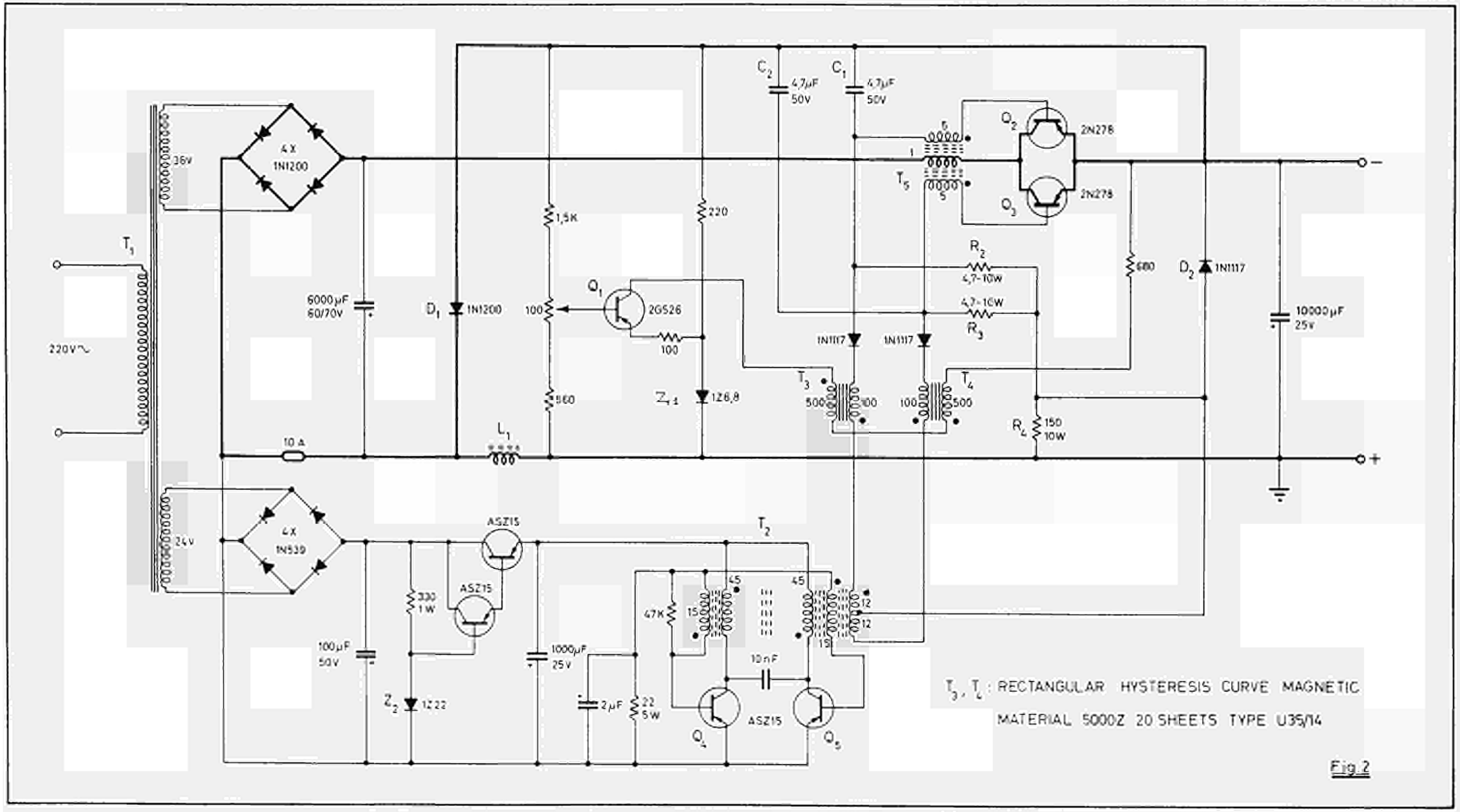
$$v_2 - v_1 = \Delta V = \frac{KT}{q} \ln (5 \times 16) = 110\text{mV}$$

The percentage variation on V can be made as small as desired by making V_R sufficiently high. In fig. 13 are plotted the characteristics of the circuit for normal values of I_{ES} and different R's. It will be noticed that the value of threshold current I_t becomes more sensitive to the variations in the characteristics of the following part of the protection circuit.



BLOCK DIAGRAM OF THE POWER SUPPLY

Fig.1



T3, T4 : RECTANGULAR HYSTERESIS CURVE MAGNETIC MATERIAL 5000Z 20 SHEETS TYPE U35/14

Fig.2

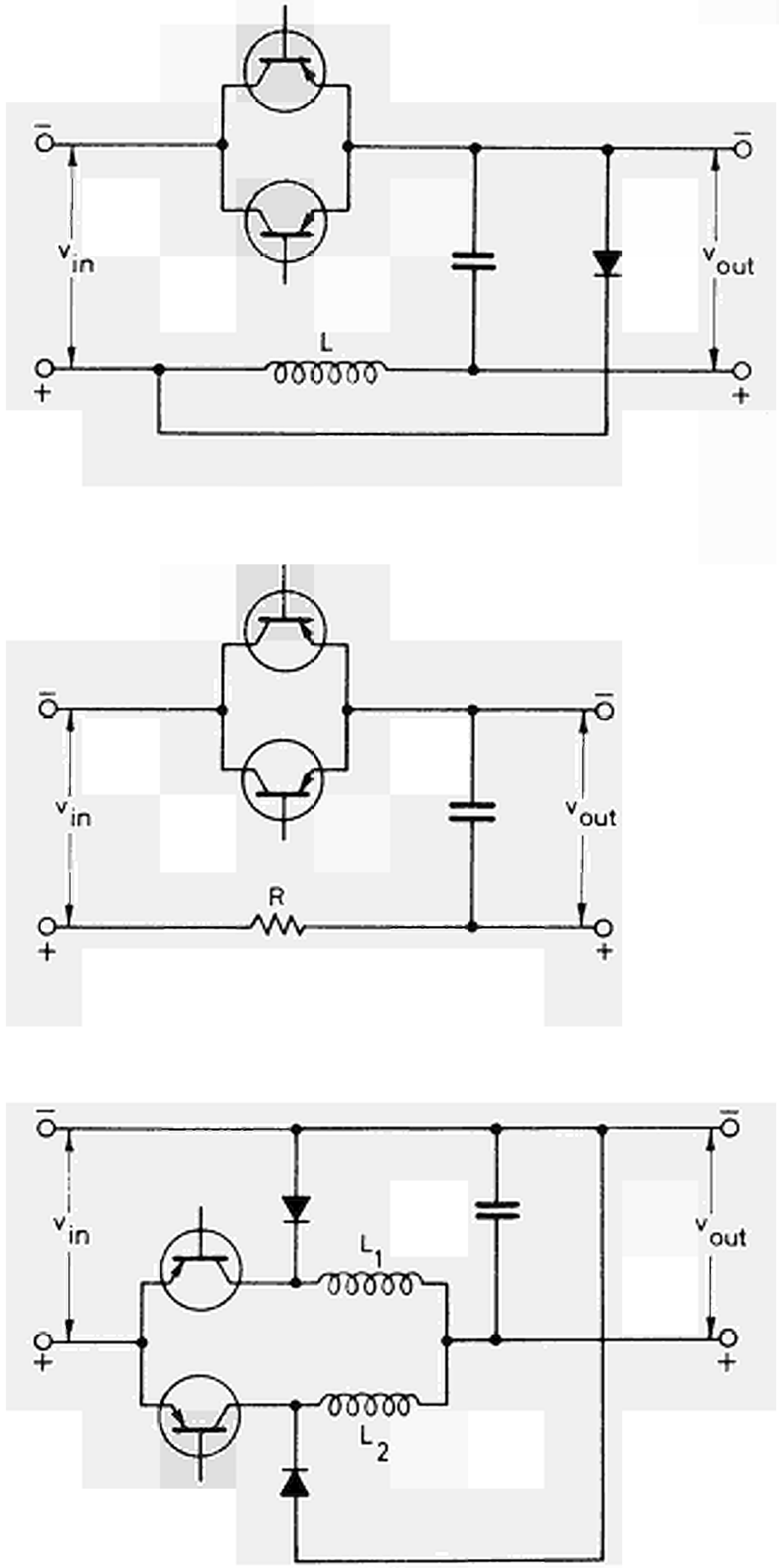
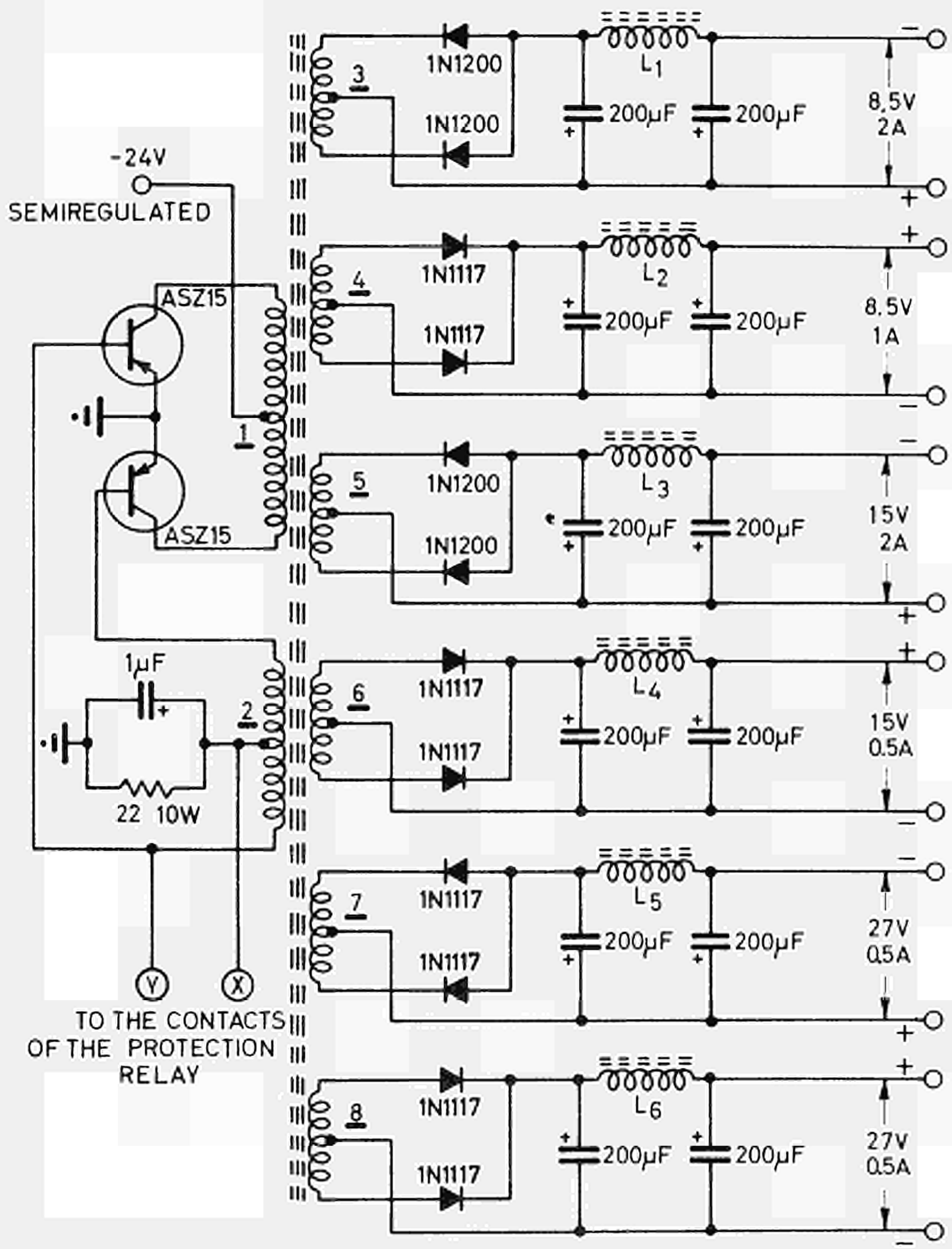


Fig. 3



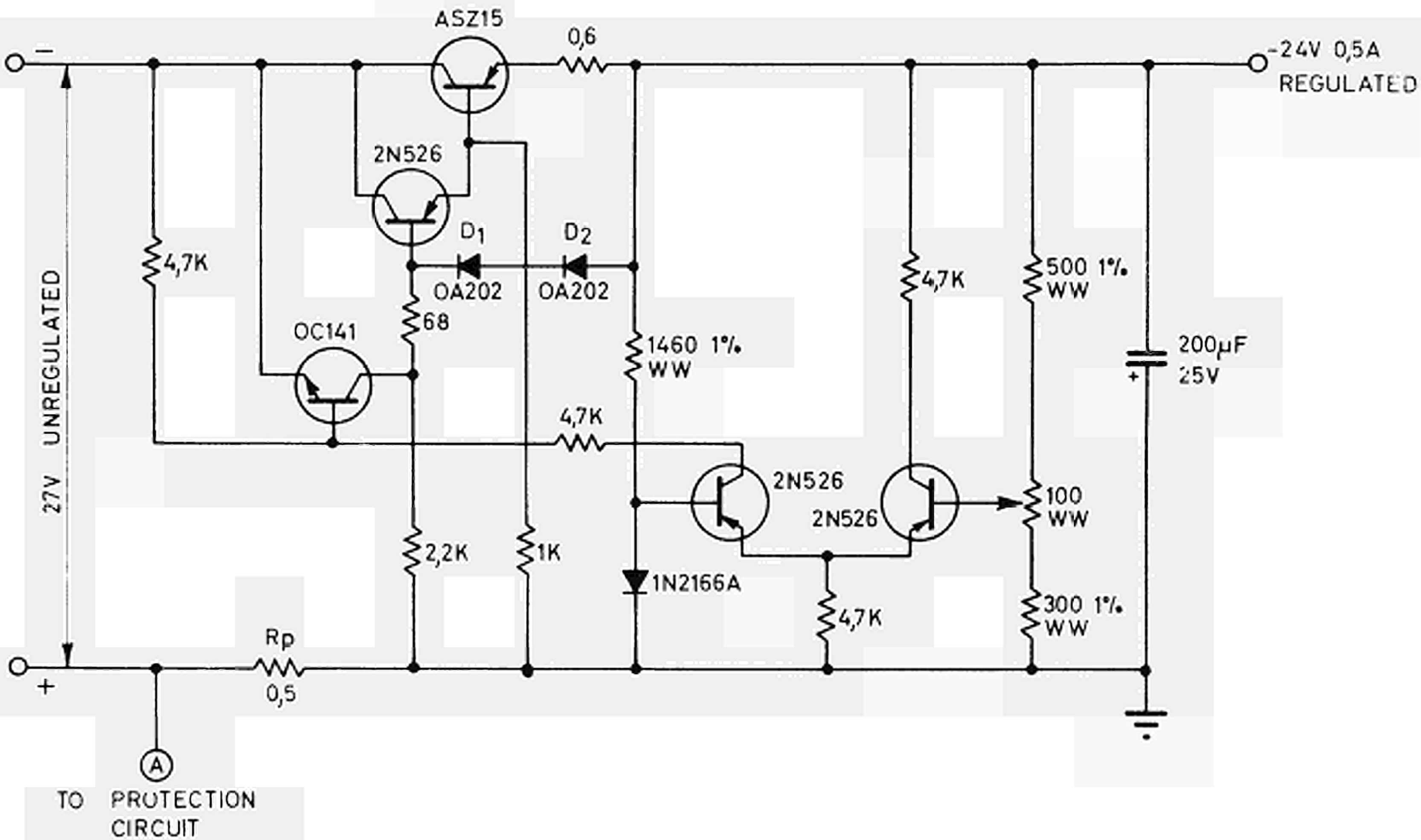
TRANSFORMER: CORE MATERIAL FERROXCUBE PHILIPS M65-K540060-3E1-B-1A

WINDING	Nº 1 = 33+33	TURNS	⌀	1.8	mm
"	" 2 = 12+12	"	"	0.4	"
"	" 3 = 13+13	"	"	1.2	"
"	" 4 = 13+13	"	"	1	"
"	" 5 = 22+22	"	"	1.2	"
"	" 6 = 22+22	"	"	0.5	"
"	" 7 = 39+39	"	"	0.5	"
"	" 8 = 39+39	"	"	0.5	"

L_1-L_2-L_3-L_4-L_5-L_6 = 50μH - 45 TURNS ⌀ 1mm ON FERROXCUBE PHILIPS 4E ⌀ 8 mm LENGTH 30 mm

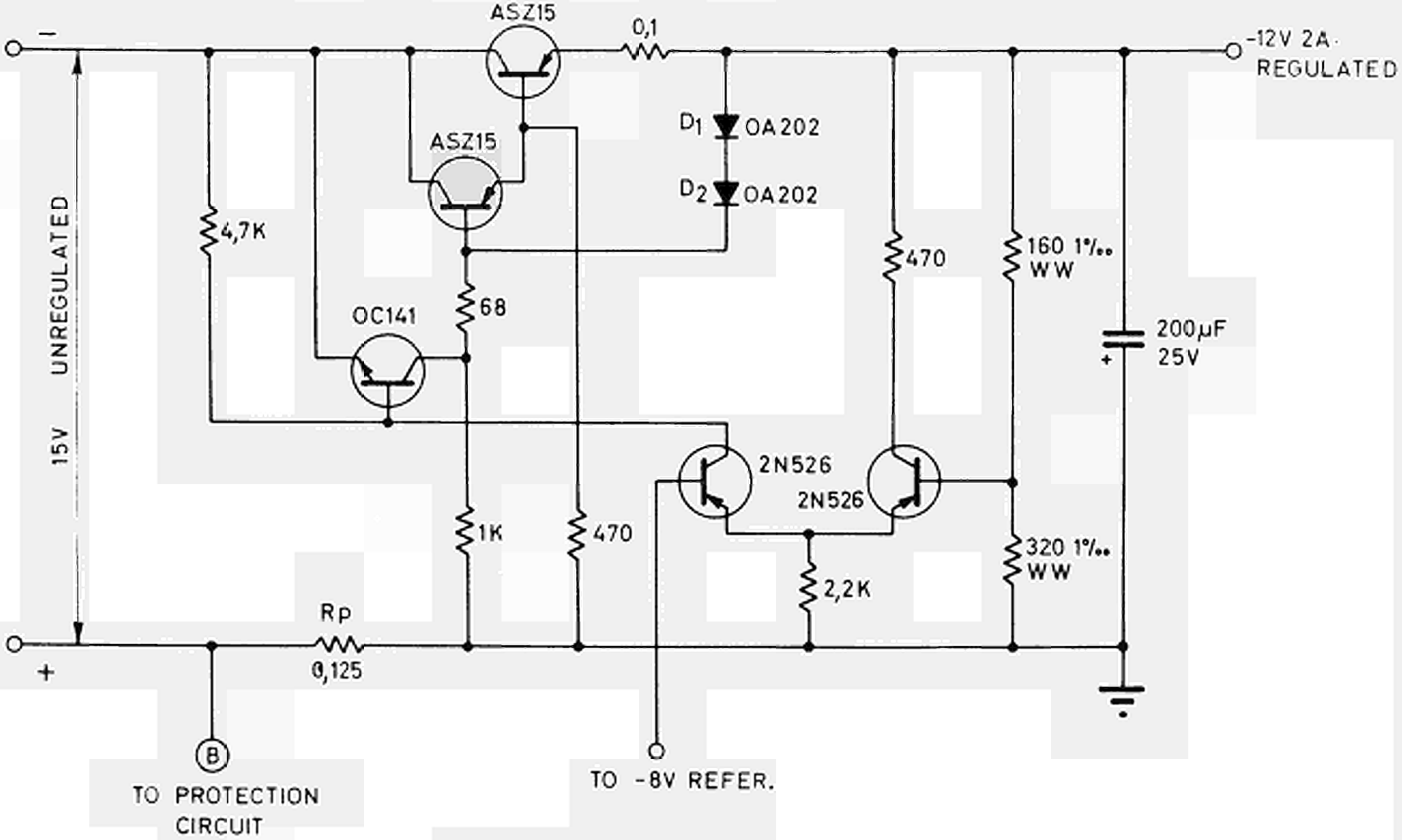
DC DC CONVERTER

Fig.4



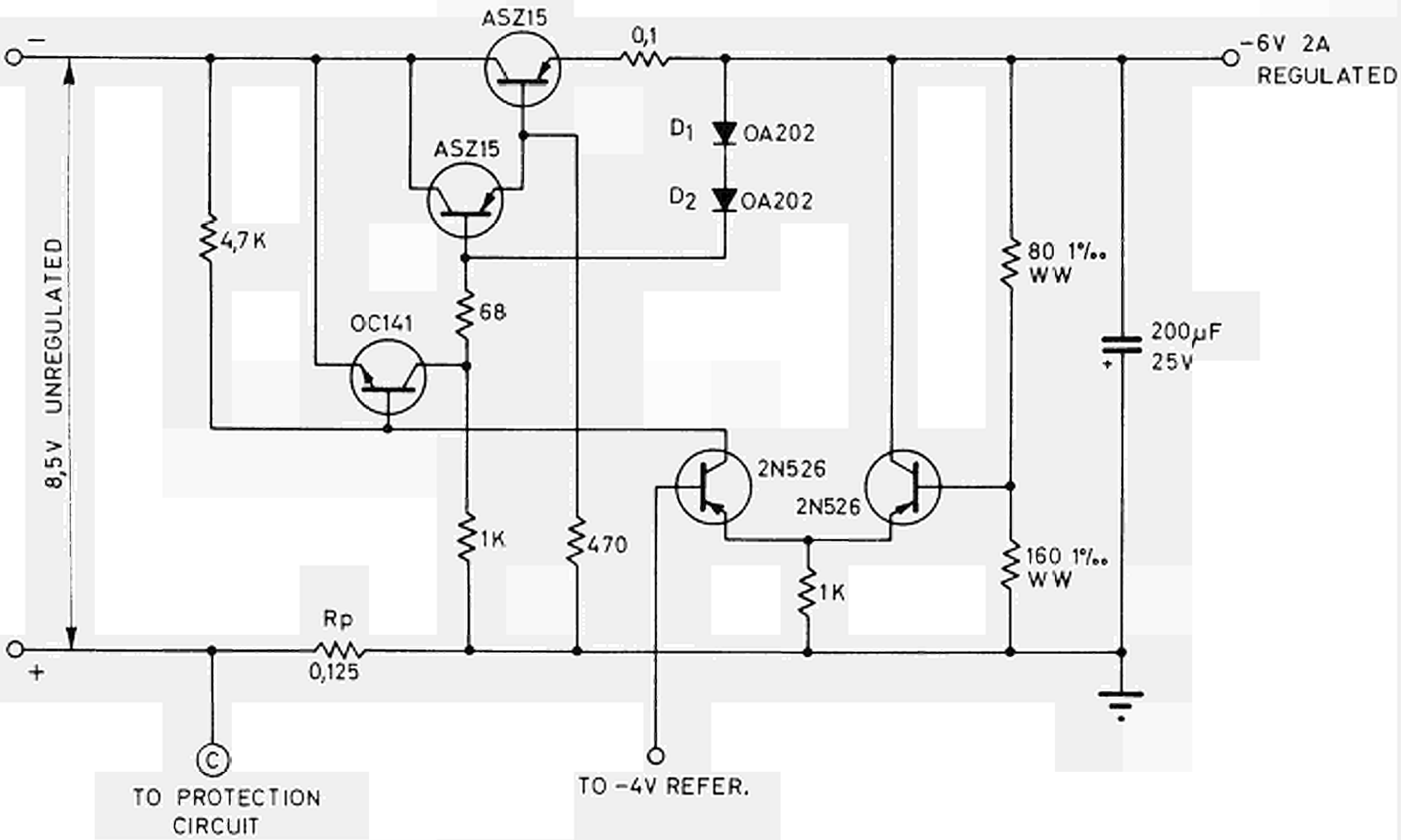
REGULATOR -24V 0,5A

Fig.5



REGULATOR −12V 2A

Fig. 6



REGULATOR -6V 2A

Fig. 7

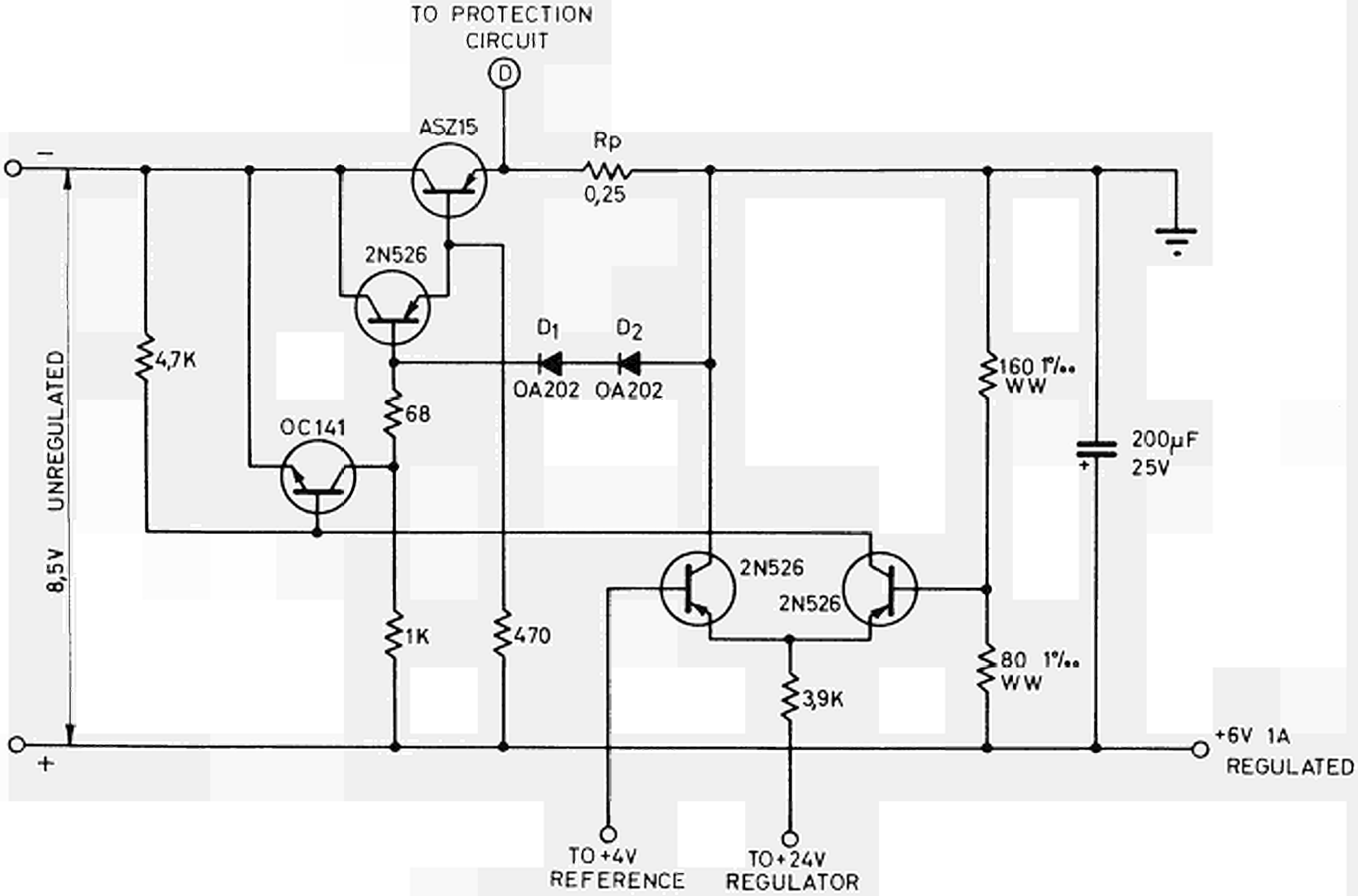


Fig.8

REGULATOR +6V 1A

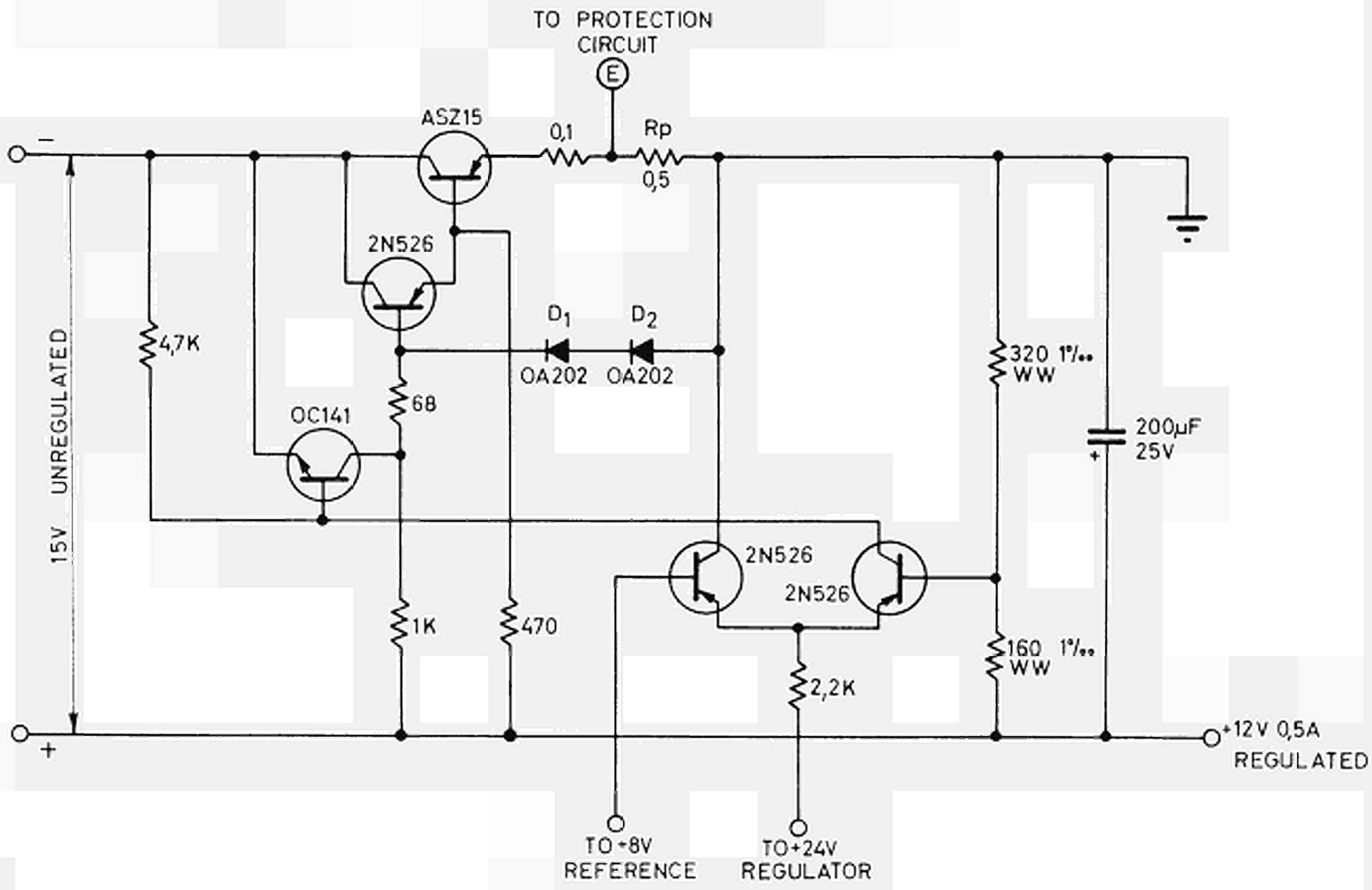
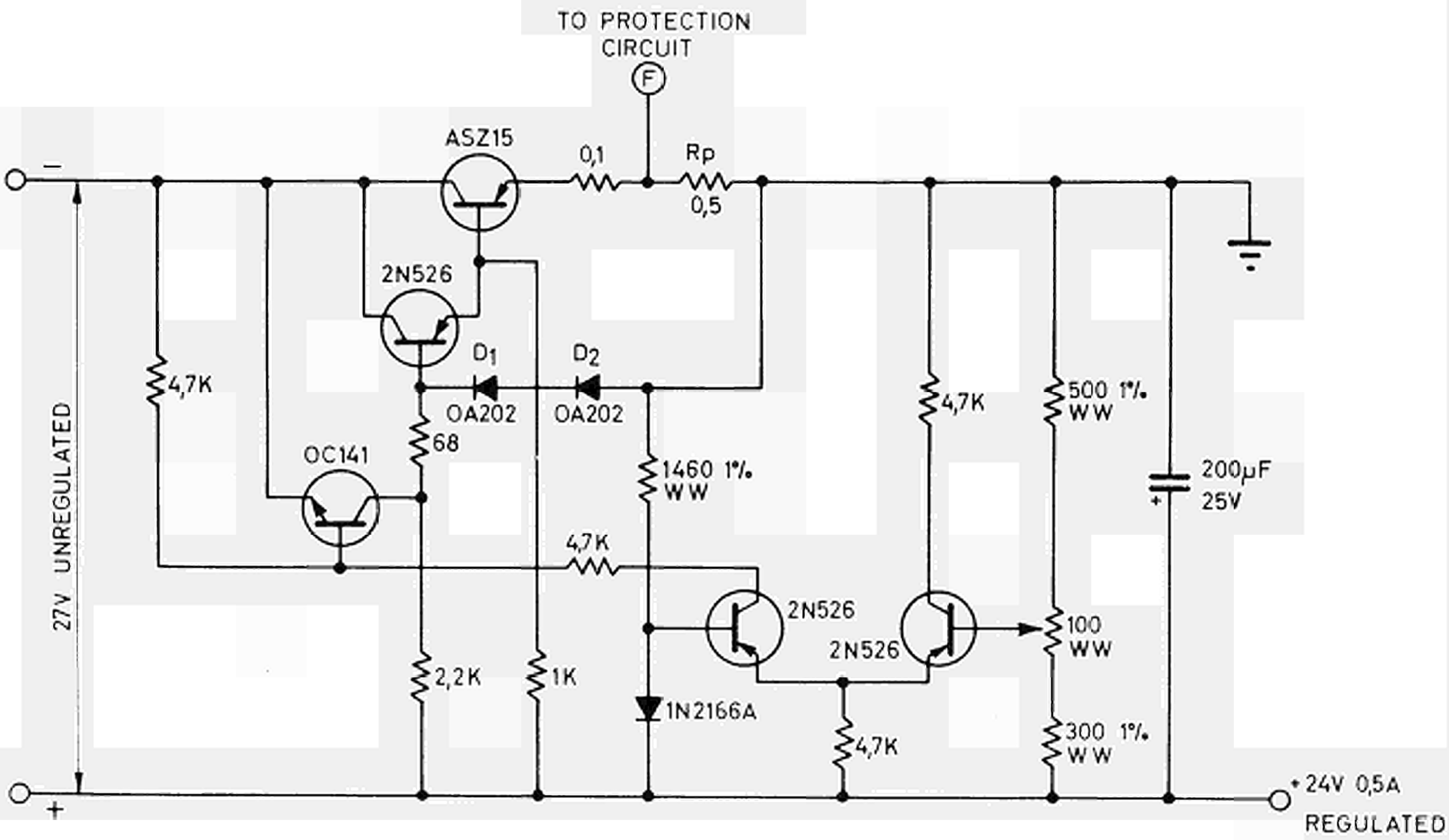


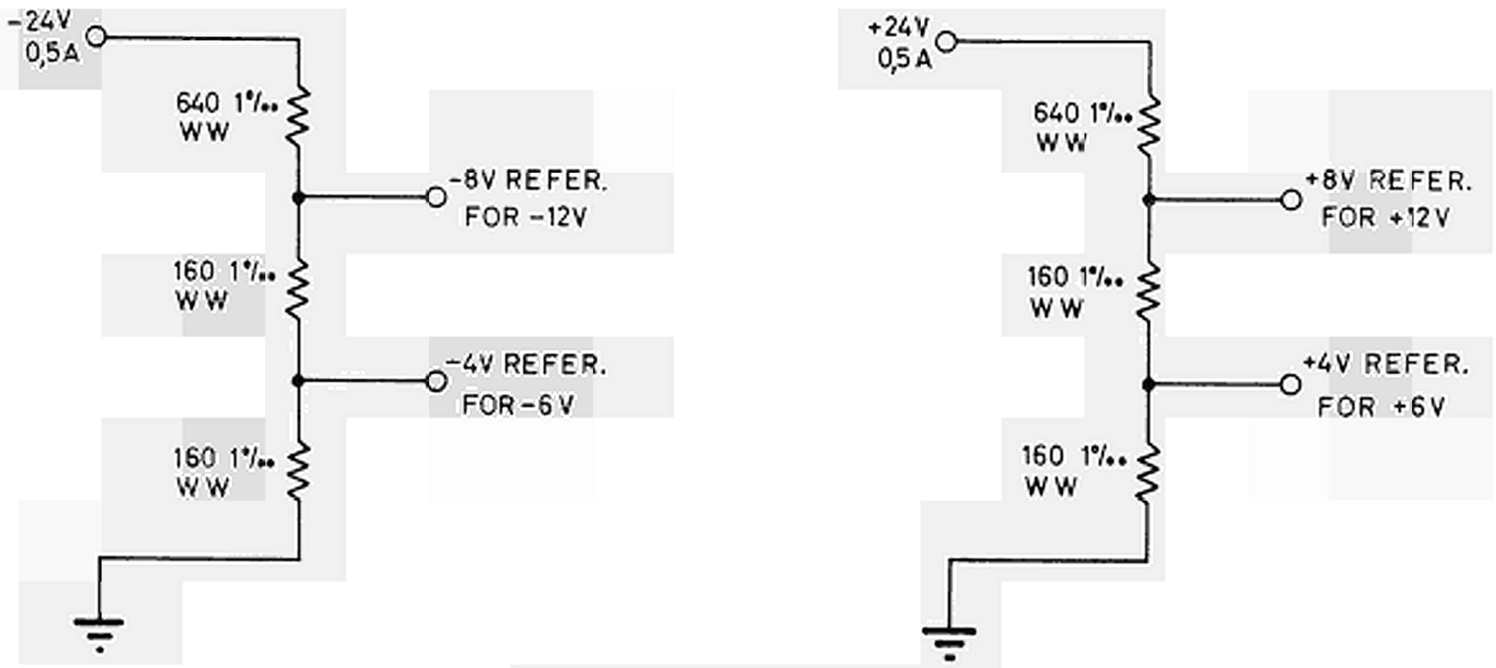
Fig. 9

REGULATOR +12V 0,5A



REGULATOR +24V 0,5A

Fig.10



REFERENCE VOLTAGE

Fig.11

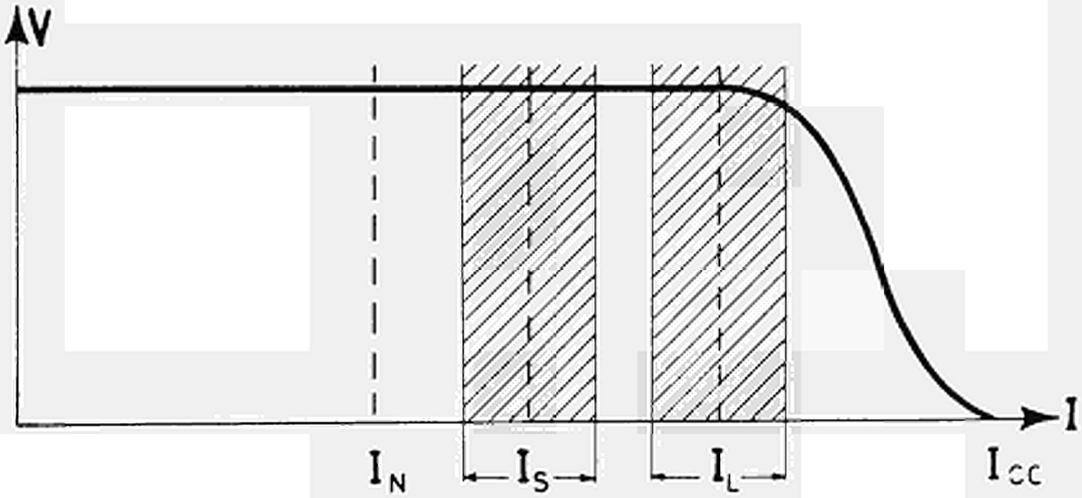
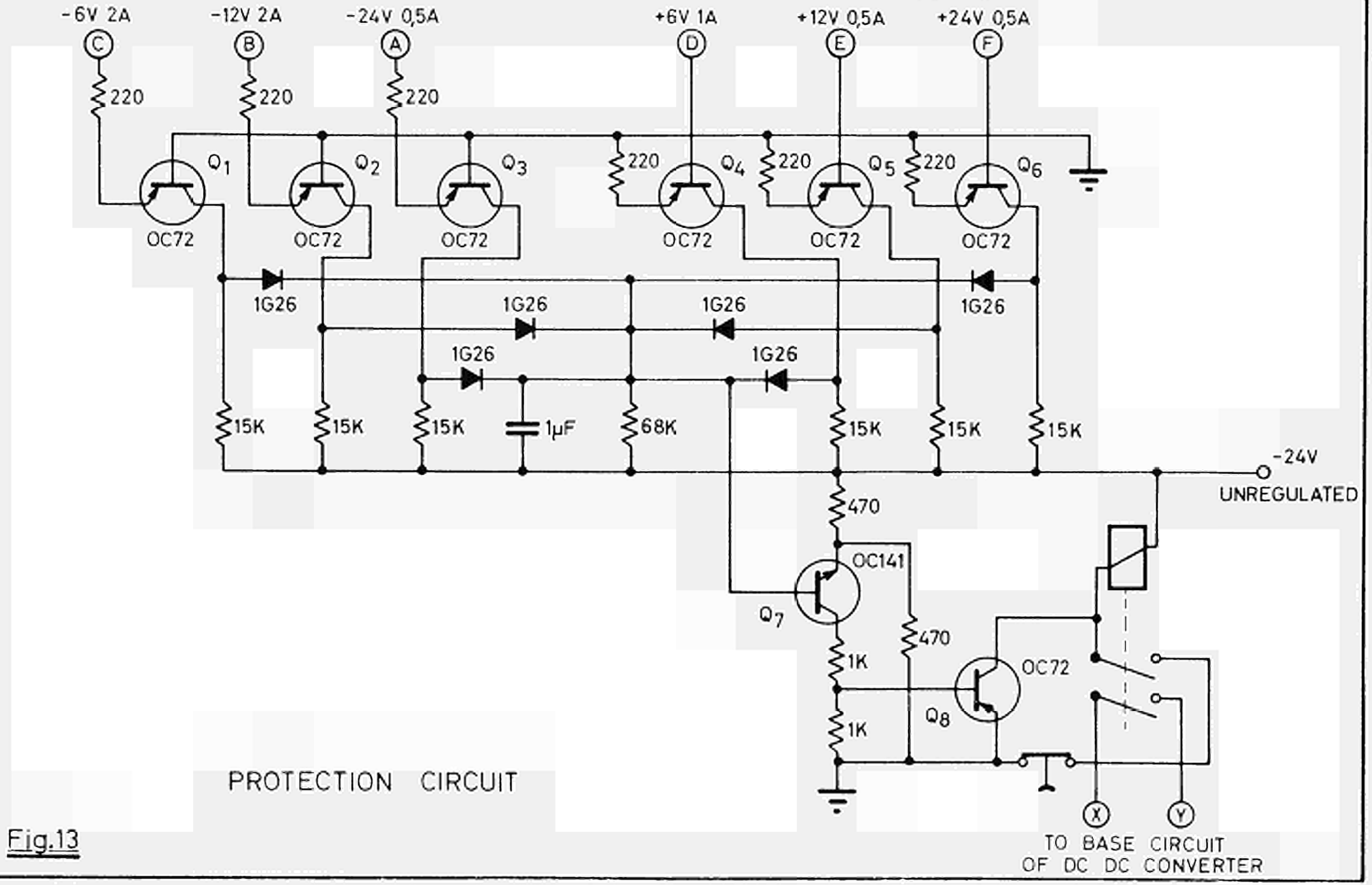
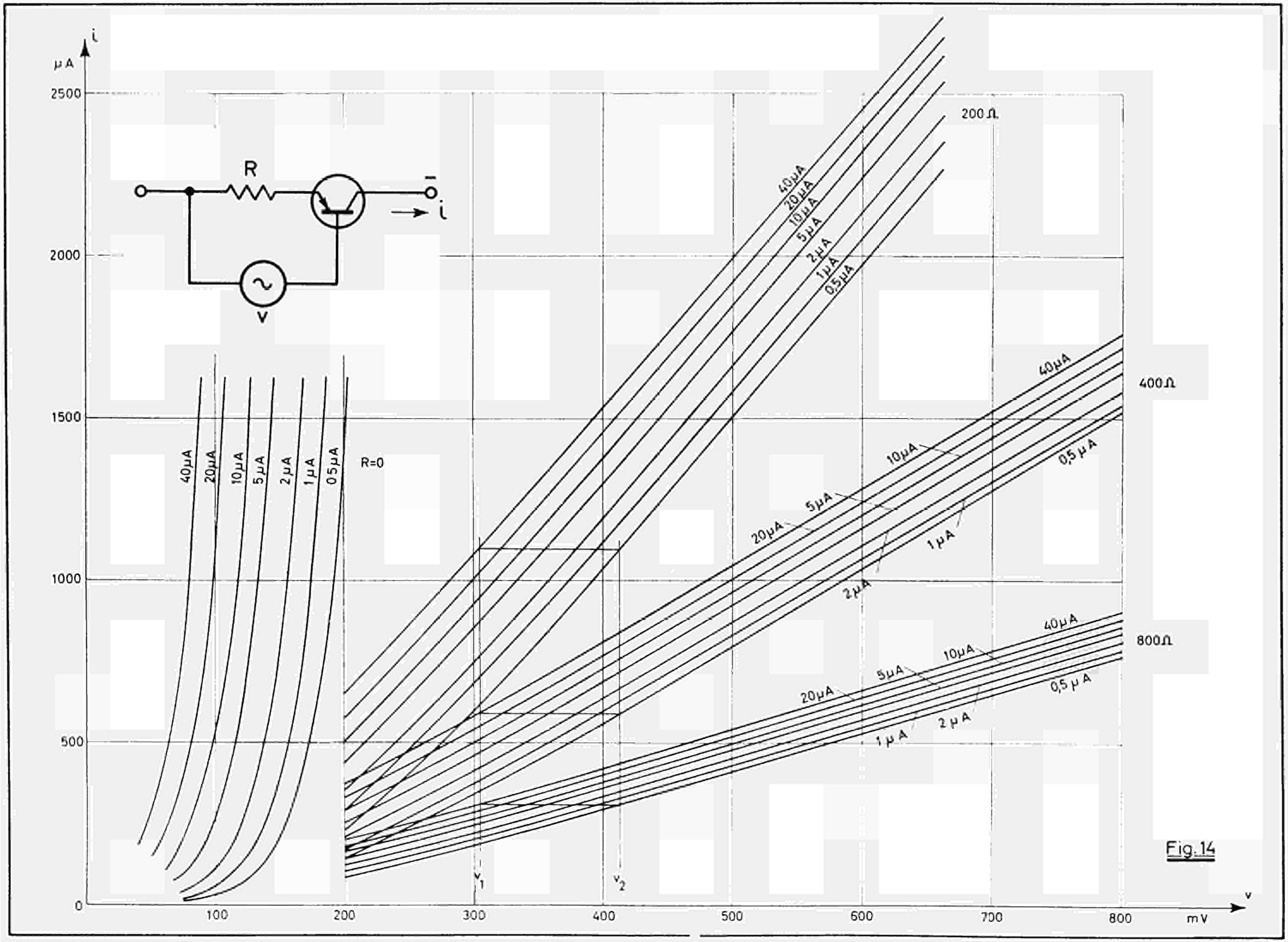


Fig. 12



PROTECTION CIRCUIT

Fig.13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40μA
20μA
10μA
5μA
2μA
1μA
0,5μA
200 Ω
400 Ω
800 Ω
0,5 μA
v_1
v_2

Fig.14