

June 1968
Capacitor Banks for a Turbulence
Heating Experiment

G. Herppich, A. Knobloch, G. Müller

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Abstract

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A fast main bank for a turbulence heating experiment has already been designed for multipurpose application. This bank was operated at 40 kV. It has now been subdivided into a preionisation bank June 1968

The compression bank stores 3 kJ at 40 kV and delivers 55 kA with a rise time of 570 nsec. The bank is connected by sandwich conductors to a symmetrically double-fed linear coil. The coil length 60 cm is equal to the collector width; the coil diameter is 15.6 cm. Special components of the bank system are the collector system, the pressurised combined start and crowbar spark gaps, and the suppressor units at the collector for reducing line reflections.

One-sixth of the former main bank was sliced off as a theta pinch preionisation bank. The data are 1.6 kJ, 40 kV, 813 kHz. To avoid faulty ignition of the spark gaps by voltage pulses coming from the preionisation bank, suppressors were connected at the spark gaps of the main bank.

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Capacitor Banks for a
Turbulence Heating Experiment
(in English)

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June 1968

Abstract

A fast main bank for a turbulence heating experiment has already been designed for multipurpose application. This bank was operated at 40 kV. It has now been subdivided into a preionisation and a compression bank.

The compression bank stores 8 kJ at 40 kV and delivers 554 kA with a rise time of 570 nsec. The bank is connected by sandwich conductors to a symmetrically double-fed linear coil. The coil length 60 cm is equal to the collector width; the coil diameter is 15.8 cm. Special components of the bank system are the collector system, the pressurised combined start and crowbar spark gaps, and the suppressor units at the collector for reducing line reflections.

One-sixth of the former main bank was sliced off as a theta pinch preionisation bank. The data are 1.6 kJ, 40 kV, 813 kHz. To avoid faulty ignition of the spark gaps by voltage pulses coming from the preionisation bank, suppressors were connected at the spark gaps of the main bank.

The bias field bank feeds a special multiturn coil surrounding the main coil in order to get a special axial distribution of the bias field. In order to avoid high voltages (about 1 MV) which would be induced in the bias field coil, voltage suppressors were developed. For sustained field experiments the bias field bank can also be connected direct to the main coil.

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Figure 2 shows a photograph of the experiment taken after the bank was put into operation. At the left side of the picture, the trigger system and connecting lines can be seen and, at the right side of the picture, a RC capacitor unit for ultraviolet radiation is visible. [3]

1. Introduction

The "Turbulence Heating Experiment" consists of 3 banks: a main bank, a bias field bank, and a theta pinch preionisation bank. The main and theta pinch preionisation banks feed symmetrically into a double-fed linear coil. The bias field bank is connected to a multiturn coil around the theta pinch coil or can be connected by strip lines like the other banks. [1]

2. Bank System

2.1 Arrangement

The dimensions of the lab led to the arrangement sketched in Fig. 1.

The five racks of the main bank are grouped around the collector in a semicircle. Enough room is left between the single racks to allow mounting or repair work.

Behind the five racks of the main bank are four racks of the bias field bank. Two of those racks are placed one above the other. At the left side of the bank are the trigger generators: two Marx generators and the submaster gaps. At the right side are the power supplies, the control and trigger racks, the control desk and a shielded chamber.

The start trigger cables are placed at the top of the five racks of the main bank. The crowbar trigger cables pass under the racks of the bias field bank. (Fig. 3)

Figure 2 shows a photograph of the experiment taken after the bank was put into operation. At the left side of the picture, the vacuum pumps for evacuating the tube can be seen and, at the right side of the collector, a 120 kV capacitor unit for ultraviolet preionisation. [2]

2.2 Data

The following table lists the most important data of the main bank, theta pinch bank, and bias field bank.

Main bank:

Charging voltage	2 x 40 kV
Capacitance	2 x 5 μ F
Stored energy	2 x 4 kJ
Peak current	554 kA
Discharge frequency	440 kHz
Peak flux density	11.6 kG
Peak voltage at the load	2 x 28.2 kV
Initial rise of current	1.53 $\frac{\text{MA}}{\mu\text{s}}$
Initial rise of flux density	32.1 $\frac{\text{kG}}{\mu\text{s}}$
Coil length	60 cm
Coil diameter	15.8 cm

Theta pinch preionisation:

Charging voltage	2 x 40 kV
Capacitance	2 x 1 μ F
Stored energy	2 x 0.8 kJ
Discharge frequency	813 kHz
Peak current	204 kA
Peak flux density	4.27 kG

Bias field bank:

Charging voltage	12 kV
Stored energy	41.7 kJ
Capacitance	580 μ F
Multiturn coil diameter	40 cm
Mirror ratio	1:1 or 2:1
Peak current	87 kA
Discharge frequency	1870 Hz
Peak flux density	9.6 kG

2.3 Description of the single banks

2.3.1 Main bank

The two parts of the series-connected main bank are placed one above the other in order to provide easy access to the coil and make the storage block compact.

The main bank consists of five double racks, each consisting of twelve tiers. Each tier represents 180 J with two 40 kV, 0.1 μ F capacitors. The single capacitors are enveloped in foils in the wooden tiers of the rack.

The complete bank consists of 60 capacitor units, each of them having its own pressurised combined start and ferrite-decoupled crowbar spark gap connected to the capacitors by a broad busbar strip. Each spark gap is connected to the collector by four strip lines. The strip lines are 1.6 m long. In order to compensate the lengths of the strip lines, they run in an S-curved form to the vertical precollector plates.

The charging resistors, decoupling inductances, and shorters are at the rear of the rack (Fig. 3).

The triggering of the start gaps is performed in 3 stages. A pulse coming from a 14 kV thyatron trigger set is stepped up by a 2:1 transformer to trigger a master gap. The pulse from the master gap triggers four submaster gaps. Each submaster gap triggers 15 start spark gaps by means of shorted delay cables of equal length. The clamping circuit has its own trigger circuit. One master gap triggers two Marx generators. These two Marx generators have to trigger, each by way of 30 cables, 60 ferrite-decoupled crowbar spark gaps.

All ground connections converge at a central point in the middle of the experiment.

2.3.2 Theta pinch preionisation

One-sixth of the former main bank was sliced off as a theta pinch preionisation bank. These 2 x 5 capacitor units have their own trigger system, power supply, and control system. The spark gaps were connected to a compressed air supply of their own. To avoid faulty triggering of the spark gaps by voltage pulses coming from the preionisation bank, suppressors shall be connected later at the spark gaps of the main bank. For the present, ensuring uninterrupted bank operation, the pressure in the spark gaps has been increased.

2.3.3 Bias field bank

Behind the main and preionisation banks are four racks of the bias field bank. The bias field bank consists of twenty 29 μ F / 15 kV capacitors, five to a rack. The start and crowbar switches are ignitrons triggered by multi-channel thyatron trigger sets. All capacitor units are discharged on a busbar strip which is connected by two strip lines to a multiturn coil at the collector. There is also the possibility of connecting the two parts of the bias field bank direct to the theta pinch coil by strip lines and feeding the coil symmetrically like the main and preionisation banks.

3. Development of Components

The electrical data of the bank system were calculated and determined with the aid of analogue models. The following components were subjected to fatigue tests:

- a) 1 capacitor unit (spark gap, capacitor, strip line)
- b) 2 capacitor units (in series, in parallel)
- c) collector insulation
- d) crowbar trigger cables (voltage tests)
- e) shorters (voltage test, mechanical test)

The components a) - d) with the higher density were tested in about 10^4 discharges.

3.1 Main and theta pinch preionisation banks

3.1.1 Spark gaps (G. Müller)

To switch the main bank a pressurised switch unit was designed, for switching the main bank. Its outer dimensions are 200 x 140 x 100 mm, and it can easily be handled together with the closely connected capacitor unit of $2 \times 0.1 \mu\text{F}$, 40 kV. Sixty of these units were installed to serve as the main and theta pinch preionisation banks of the experiment.

The switch unit is fully described in [3] and [4]. A start spark gap and a ferrite-decoupled crowbar gap are mounted together in an epoxy resin pressure chamber (Fig. 5) with a perspex cover. The unit is of the strip line type and is located between the capacitor and the energy transmission lines. One part of the strip line forms the bottom of the pressure case and is embedded in the resin. This plate also supports the connector flange for the outer part of the coaxial ferrite tube, which should be mounted parallel to the strip line. The strip line parts are made of aluminium and insulated by foils. The necessary bushings for the trigger and pressure connections are of the same material because of the better bonding to epoxy resin.

The epoxy resin is of the two-component type and filled with quartz. The fresh mixtures are degassed with a large surface at 1 torr and cast in the prepared aluminium mould at 40 torr. The final process is finished after a moulding time of 12 h and an ageing time of 7 days at 60° C. This procedure results in satisfactory dielectrical and mechanical properties.

The start spark gap has cylindrical electrodes 30 mm in diameter and a parallel-rod trigger electrode 8 mm in diameter, these being made of aluminium owing to the low work function and low current of the gap. An irradiating gap formed by tungsten pins is situated inside the hollow trigger electrode and irradiates the switching gaps through holes 3 mm in diameter. The trigger electrode operates like a swinging cascade gap [5] and is controlled by an ohmic divider at four-tenths of the working voltage. The dynamic behaviour is determined by a capacitance to ground. The trigger electrode receives a pulse voltage of 50 kV, 100 nsec rise time from the trigger system as described in detail below. (Fig. 5)

The crowbar spark gap is of the ferrite-decoupled type, a principle first mentioned by Früngel and subsequently treated at length in the literature [3, 4, 6, 7, 8, 9, 10, 11, 12]. The crowbar spark gap is arranged at right angles to the start spark gap, formed by an extension of the grounded spherical start gap electrode (40 mm in diameter) and the decoupled cylindrical crowbar electrode (30 mm in diameter), which also receives the crowbar trigger pulse from the spherical pulse sharpening electrode (20 mm in diameter). The coaxial ferrite cores lie outside the pressure chamber and form a coaxial tube about 300 mm long and 10 - 60 mm in diameter.

The pressure chamber operates with a clean, dry (-50° C dew point) mixture of 80 % N₂ and 20 % O₂, so-called artificial air, which is stocked in bottles and commercially available. Constant quality is necessary to prevent uncontrolled humidity from causing erosion, premature triggering, and decreased life.

Changing the switch range is achieved by changing the pressure so that the breakdown voltage of all gaps will be changed almost in proportion. With the chosen gap spacings the pressure-dependent data of the switching unit are as follows:

Gap spacing,	DC breakdown voltage (kV) at pressure (ATM)					
	1 ATM	2 ATM	3 ATM	4 ATM	5 ATM	6 ATM
Auxiliary gap 3 mm	11	16.5	22	27.5	33	38
Auxiliary gap 2 mm	8	13	18	22.5	27	32
Main gap 5 mm trigger el. mounted	14,5	25.5	37	48	60	70
Irradiating gap 1 mm	3	4.5	6	7.5	9	10.5
Crowbar gap 3.5 mm	12.5	20.5	28.5	37	45	53
Pulse sharpen- ing gap 5.5 mm	17	30	43	56	68	81
Min. working voltage kV, jitter less than 6 nsec abs.	10	15	20	25	30	35
Proposed max. working voltage kV	12	20	30	39	48	56

Breakdown values within $\pm 5\%$ for both polarities.

Improved by controlling the trigger electrode more perfectly with a suitable capacitive divider.

The switching unit is mounted together with 2 capacitors of 0.1 μ F each.

The data of this assembly are as follows:

Charging voltage	40 kV
Outer hold-off voltage (assembly)	50 kV
Inner hold-off voltage (switch unit)	80 kV
Stored and switched energy	160 kJ
Max. discharge current at 1.4 MHz , 40 kV	70 kA
Operational discharge current at 440 kHz, 40kV	22 kA
Inductance of the assembly	65 nH
Inductance of start spark gap ^{x)}	35 nH
Inductance of crowbar gap ^{x)} with saturated ferrite tube	185 nH
Resistance of the assembly	85 m Ω
Resistance of the start spark gap ^{x)}	15 m Ω

^{x)} in between strip line connections

During development, three units were tested up to 10^4 and $0.5 \cdot 10^4$ discharges under bank operational conditions, the parameters remaining nearly unchanged. The erosion products of the aluminium electrodes are a nonconducting white coloured powder. The premature ignition rate seems to be very low. It could not be decided whether breakdowns are caused by the switching unit itself or by the trigger circuits.

When operated with the theta pinch preionisation discharge the main bank start spark gap must have a certain stability to transient voltages. This is achieved for the present by increasing the pressure, possible with respect to the reported minimum working voltage. The stability could be further improved by controlling the trigger electrode more perfectly with a suitable capacitive divider.

3.1.2 Capacitors

For energy storage a commercial type of capacitor available in quantity was used. These capacitors have a welded steel case with 2 x 3 ceramic terminal stems.

Capacitance	0.1, μF \pm 10 %
Charging voltage	40 kV reversal 85 %
Stored energy	80 joules
Inductance	61 nH
Self-resonant frequency	2.04 MHz
Case dimensions	200 x 225 x 64 mm
Case at half potential	

3.1.3 Strip lines

In order to get a simple connection design at the spark gaps as well as at the collector, strip lines were chosen for the connecting the bank and the load. The main bank and preionisation bank have 240 strip lines altogether.

Electrical data:

Mechanical data:

$$C = 0.5 \text{ nF/m}$$

$$\text{Copper width} = 37.5 \text{ mm}$$

$$L = 70 \text{ nH/m}$$

$$\text{Copper thickness} = 1 \text{ mm}$$

$$Z = 12 \Omega$$

$$\text{Width with insulation} = 40 \text{ mm}$$

$$\text{Delay time} = 6 \text{ ns}$$

$$\text{Length} = 1.6 \text{ m}$$

For symmetrical double feed into the main coil, the bias field bank can also be provided with strip line connections.

For the bias field windings, a copper bar 10 mm in diameter was used. The windings are supported by nylon segments, these are also serving as support structure for the end and mirror windings as well as for the voltage suppressors.

3.1.4 Collector system

The collector system consists of two series-connected low-inductance collectors of the type shown in Fig. 6. The upper and lower parts each contain 10 collector sandwiches, each of which can carry the currents of 14 strip lines: 12 for the main and theta pinch preionisation banks and 2 for direct connection of the bias field bank. Each collector sandwich has its own suppressor unit designed to match 12 strip lines. The sandwiches consist of 2 mm half-hard copper plate and are stacked with backing-up layers composed of PVC and "phenolic" according to the electric field stress. The coil feed zone is fitted with special lead-through connectors (see Fig. 14) for the bias field windings and is backed up by a non-ferromagnetic steel structure. At the holes for the lead-through connectors the current connecting copper plate has been especially contacted to the steel structure in order to allow the bias field flux to slip through the holes without sparking.

The electromechanical forces, which are comparatively low here, are held by pressing screws in the stacked region as well as in the coil feed zone. The coil consists of two non-magnetic steel shells with 2 mm copper plate for current conduction and is subdivided into 4 axial sections. Since both the sandwich conductor ends as well as the coils are axially subdivided, the coil feed region is fitted all the way through with copper plates to ensure smooth current distribution in the coil even when the banks are operated at partial energy.

For the bias field windings, a copper bar 10 mm in diameter was used. The windings are supported by nylon segments, these are also serving as support structure for the end and mirror windings as well as for the voltage suppressors.

Collector conductance for main bank 2 x 4 nH
for theta pinch preionisation bank 2 x 4.25 nH

Collector capacitance 2 x 42 nF

As insulation 1.2 mm stacked mylar foil is used.

3.1.5 RC suppressor unit

In trying to suppress transient voltages [14] at the end of the strip lines and at the collector, it was found with the aid of the low-voltage analogue system that an economic RC unit limits the peak voltage to $\frac{U}{U_c} = 1.3$

U = peak voltage

U_c = charging voltage

The number of precollector sandwiches requires 20 RC units.

The data for one unit are:

R	=	2.67 Ω
C	=	10 nF
L	=	3 nH

The capacitor and the resistor are in a plexiglas case soaked with oil (Fig. 8) [15]. The unit is connected to the collector by parallel busbars. Figure 7 shows the 20 RC units at the top and bottom of the collector. The space available for the experiment led to a new capacitor design, which is described in [15].

3.1.6 Trigger system (G. Müller)

Fig 9 shows the trigger system of the main bank, consisting of 2 master gaps, 4 submaster gaps, 2 Marx generators and the relevant transmission material. The trigger system of

the theta pinch preionisation bank is similar (not seen in the figure).

The chronological sequence of triggering is as follows:

Two delay setups generate pulse voltages of + 100 V peak, with a rise time of 15 nsec and time delays in keeping with the auxiliary banks of the experiment. These pulses are for triggering the start and the crowbar gaps of the main bank. First they ignite 12 kV thyatron units, which are spending high voltage pulses of 35 kV, 50 nsec rise time and 5 nsec time jitter at the secondary connections of the 2:1 pulse transformers, which will then trigger the master gaps. The exchange of the transformer wires supplies both polarities, which is important for several combinations of bank polarities. The start and crowbar trigger master gaps then short-circuit the connected and charged cables (RG 8U/50 ohm), which produce pulse voltages of opposite polarity to the charging voltage in order to trigger 4 submaster gaps and 2 Marx generators. With this arrangement it is possible to supply master and submaster gaps by the one high-voltage supply only.

The start trigger system itself consists of 60 charged cables, connected in batches of 15 to to 4 submaster gaps. If the cables are short-circuited by triggering, they deliver a trigger pulse, again of opposite polarity to their charging voltage, to the start trigger connector of the switch unit. The delay time counted from the delay setup is 650 nsec, the time variation of the 60 pulses delivered is within the range of 10 nsec and the peak voltage would be 50 kV at 30 kV charging voltage of the cables. The DC trigger cable voltage is separated from the trigger electrode by a blocking capacitor of 2×2000 pF.

The master and submaster gaps are coaxial four-electrode spark gaps working at atmospheric conditions and in the swinging cascade gap mode. [5]

The static breakdown voltages of these gaps are adjusted to 33 kV.

Operational charging voltages of connected cables are 25 kV for the submaster gaps and 22 kV for the master gaps.

The trigger cables are polyethylene insulated cables RG 8U / 50 ohm, 13 m long, and have the following data 11 :

$C = 98.5 \text{ pF/m}$; $L = 0.266 \text{ } \mu\text{H/m}$; $Z = 52 \text{ ohm}$

DC breakdown voltage 225 kV, AC breakdown voltage (50 Hz) 53 kV_{eff} 3 min.

In order to trigger the crowbar gaps two 2-stage Marx generators receive a pulse voltage from the master gap via 2:1 pulse transformers, which are also necessary for independent selection of the crowbar trigger pulse polarity. If charged with 35 kV, 2 x 30 voltage pulses of about 100 kV maximum height and 150 nsec rise time are delivered to the connector of the pulse sharpening electrode at the switch unit. The delay counted from the delay setup is 550 nsec, and the time variation of 60 pulses is within 10 nsec.

During the rise time of the pulse, the ferrite cores are premagnetized to ϕ_S so that the peak value of the very fast voltage rise of the crowbar electrode is determined approximately by:

$$U_C \text{ max} = 2 \cdot \phi_S \cdot S$$

ϕ_S saturation flux kV · nsec

S steepness of U_C kV/nsec

To trigger the crowbar gap, the breakdown voltage of the gap must be less than $U_C \text{ max}$, otherwise the voltage of the crowbar electrode would fail owing to the low impedance of the saturated ferrite cores. At correct operation this is done by the coil current.

The crowbar trigger cables are polyethylene insulated cables [13], 11 m in length and with the following data:

$c = 102 \text{ pF/m}$; $L = 0.278 \text{ } \mu\text{H/m}$; $Z = 52 \text{ ohm}$

DC breakdown voltage more than 250 kV ; AC breakdown voltage 50 Hz 80 kV_{eff} 10 sec ; 72 kV_{eff} more than 90 min.

The cable head is made by a special polyethylene insulation only 150 mm in length.

3.1.7 Power supply and control system

The "Turbulence Heating Experiment" has 5 high-voltage power supplies.

Main bank	40 kV	1.2 kVA
Theta pinch preionisation	50 kV	1.0 kVA
Bias field bank	15 kV	4.5 kVA
Marx generator	50 kV	3.0 kVA
Trigger cables	40 kV	0.8 kVA

The charging circuit of the main bank is subdivided over 10 charging resistors. In order to have only one shorter for five capacitor units, the single units belonging to the same group are dynamically decoupled by inductances (Fig. 10).

The control and monitoring system is designed to provide adequate flexibility for checking and operating all or small portions of the system. It incorporates the electrical and personnel safety features for ensuring reliable and safe operation of the system.

The important control and monitoring elements are centrally located in a control desk. After the current programme has been chosen, the complete charge and discharge cycle operates

automatically. The restoration of the pressure in the spark gaps gives the minimum repetition rate because after each discharge about 30% of the air in the spark gaps will be renewed, i.e. about 1 shot/minute.

In case of emergency, the bank can be shorted at once by single shorters. This occurs even on line failure.

The following table gives different possibilities of discharges for reversing the polarity of the power supplies.

<u>Bank</u>	<u>Polarity</u>	<u>Mode of operation</u>
Main bank	+ -	reversing
Main bank	+ -	crowbar
Main bank	+ -	diverting
Preionisation bank	+ -	reversing
Bias field bank	+	crowbar

3.1.8 Ground system

Between the collector and capacitor racks there is a central ground bar. All ground connections run to this point. All components with high voltage potential are grounded by inductances. This means that all components are grounded statically, whereas they are decoupled dynamically. A peculiar detail is the earth potential line for the coil. For optimum magnetic field symmetry it has to be a closed loop which is linked theoretically with the total return flux (Fig. 4).

All components of the experiment which can be touched by the operators, such as control desk, control rack, trigger rack, and screened chamber, are connected direct to a separate ground. The whole control system is powered by an insulating transformer (Fig. 12).

3.2 Bias field bank

3.2.1 Multiturn coils

The bias field bank can be connected by 20 strip lines direct to the theta pinch coil and can feed the coil symmetrically from the two sides, or else it can be connected via a busbar strip to a multiturn coil around the theta pinch coil.

The bias field coil consists of 8 windings through the collector plates and of mirror coils. The coils are connected in two symmetrical branches, and so the bias field frequency can be varied in certain steps between 0.8 and 2.7 kHz at flux densities between 5 and 10 kG. The mirror coils can be connected with a mirror ratio 1:1 and 2:1 (Fig. 21).

Figure 13 shows the bias field coils without the mirror coils. The windings are held by nylon pins. An important detail of the collector is the lead-through connection of the windings through the collector plates. Figure 14 shows a cross section of a model.

The main problem for the design of the bias field coils were high voltages induced into the outer multiturn coil by the inner theta pinch coil. A solution was provided by a 1:2 scaled collector model. [16, 17] Suppressor resistors were connected across the coils as shown in Figs. 15 to 20.

The resistors with the higher current density are electrolytic resistors, the others are pulse carbon types.

3.2.2 Bank

The bias field bank (Fig. 3) consists of 20 capacitor units in 4 racks. Two racks are placed one above the other. One unit consists of a commercial energy storage capacitor $C = 29, \mu\text{F}/15 \text{ kV}$, one start and two crowbar ignitrons.

The rated charging voltage is 12 kV. In order to get less crowbar ripple and better reproducibility, the clamp circuit consists of two ignitrons. One ignitron clamps the capacitor, the other one clamps the load side (Fig. 22). Voltages coming from the main bank drop at decoupling inductances in each circuit.

Operating with 2 x 1 or 2 x 2 capacitor racks and connecting the load coil branches in series or in parallel, one obtains the following discharge data (charging voltage 12 kV):

The authors wish to acknowledge the collaboration of the following colleagues, whose names do not appear in this presentation: W. Jakobus, H. Lohmert, H. Schichen.

Mirror ratio 1:1			Mirror ratio 2:1		
J/kA	B/kG	f/Hz	J/kA	B/kG	f/Hz
41	9.1	925	36	8.35	790
29	6.4	1320	24	5.6	1110
59	6.5	2640	49	5.7	2100
87	9.6	1870	69	8.0	1580

4. Operating Data and Experience

The experiment has been in operation since March 1967 at a charging voltage of 35 kV. In February 1968 the 20 RC suppressors were connected to the collector, and from then on the main bank was operated at 40 kV. Up to now about 2000 discharges have been recorded without major trouble. Figure 23 shows some oscillograms.

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Report 4/30 1966 IPP Garching | A. Knobloch
J. Mantel
H. Schlageter
G. Roos
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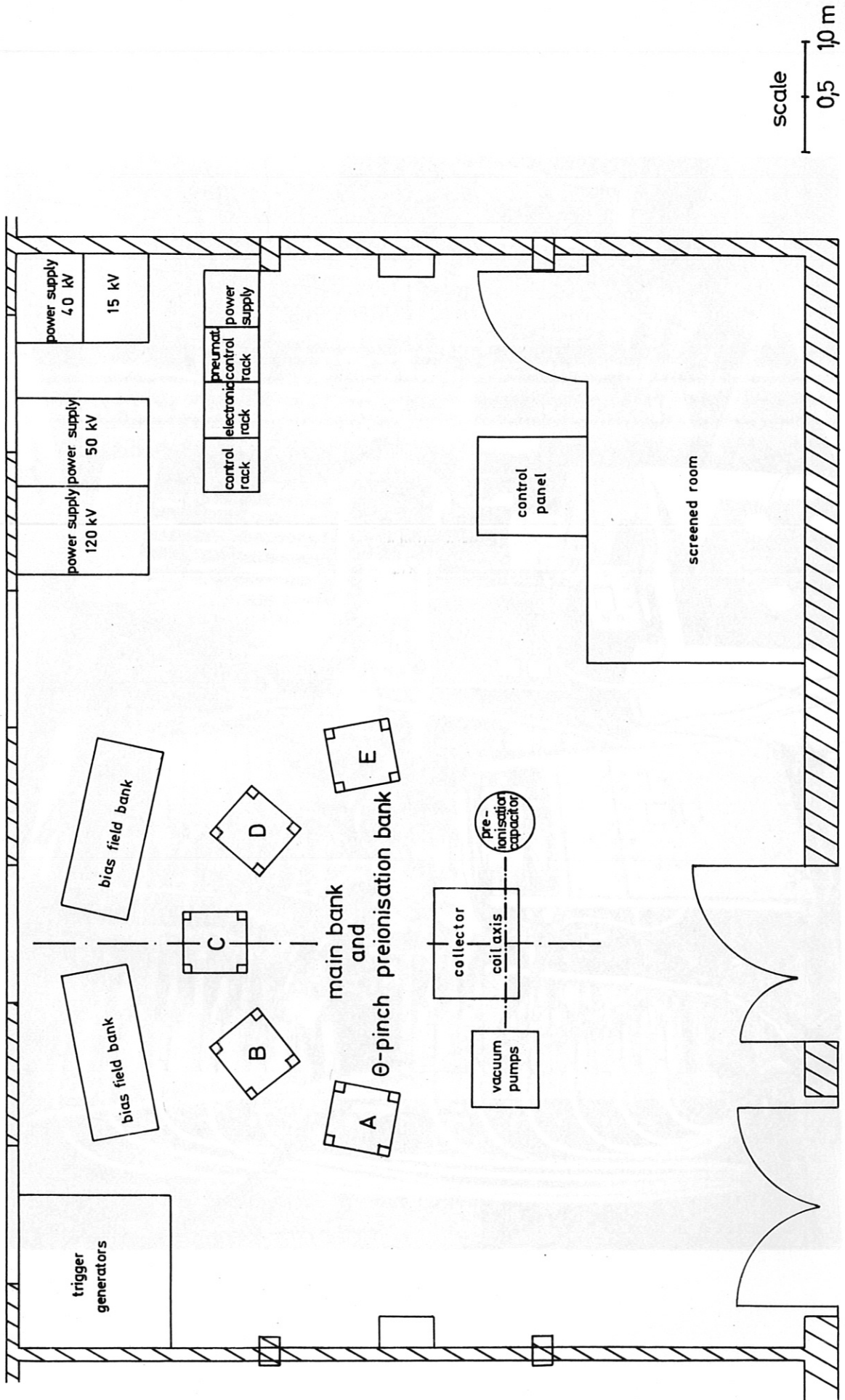


Fig.1 Plan View Fig.2 Turbulence Heating Experiment P.109

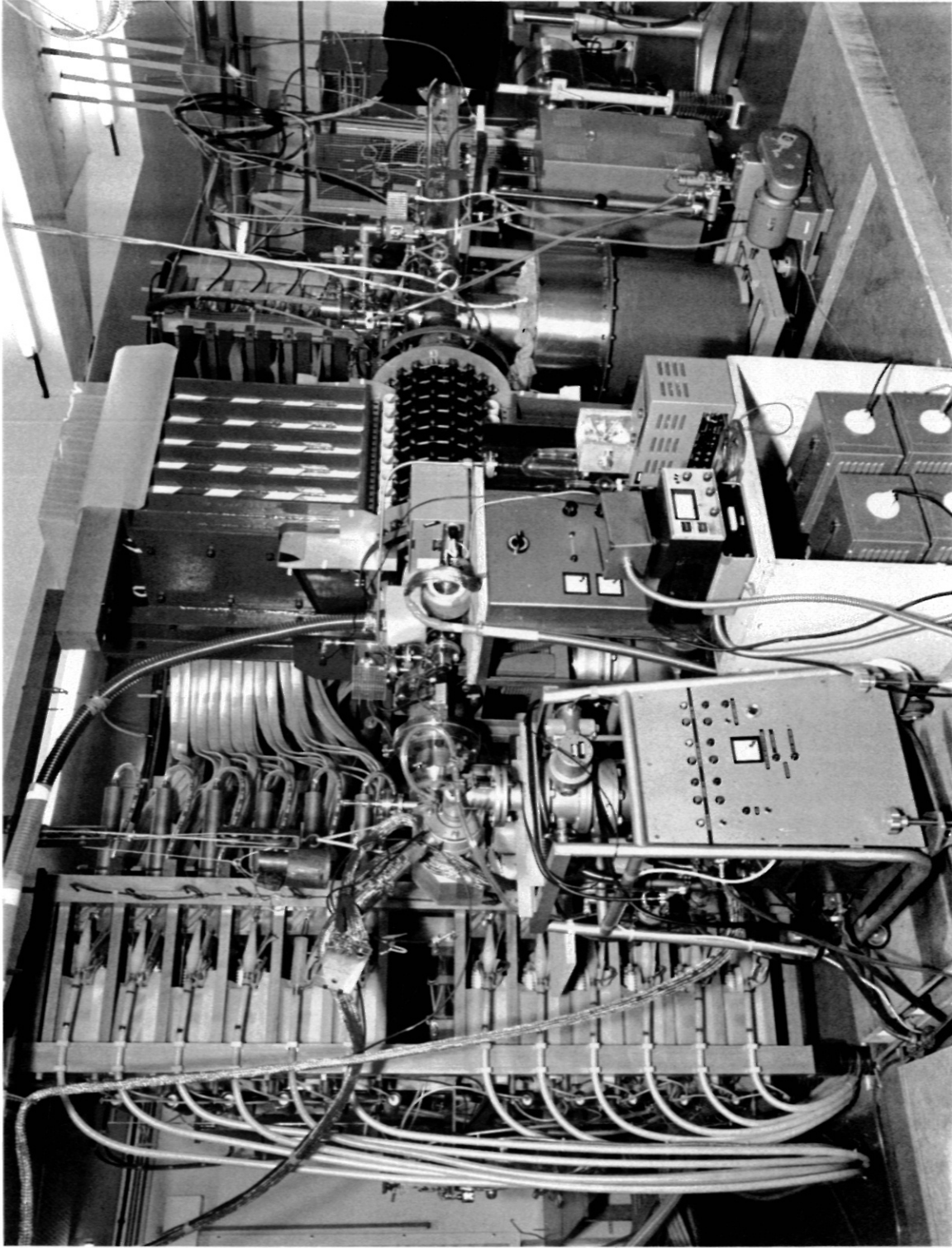


Fig.2 Turbulence Heating Experiment

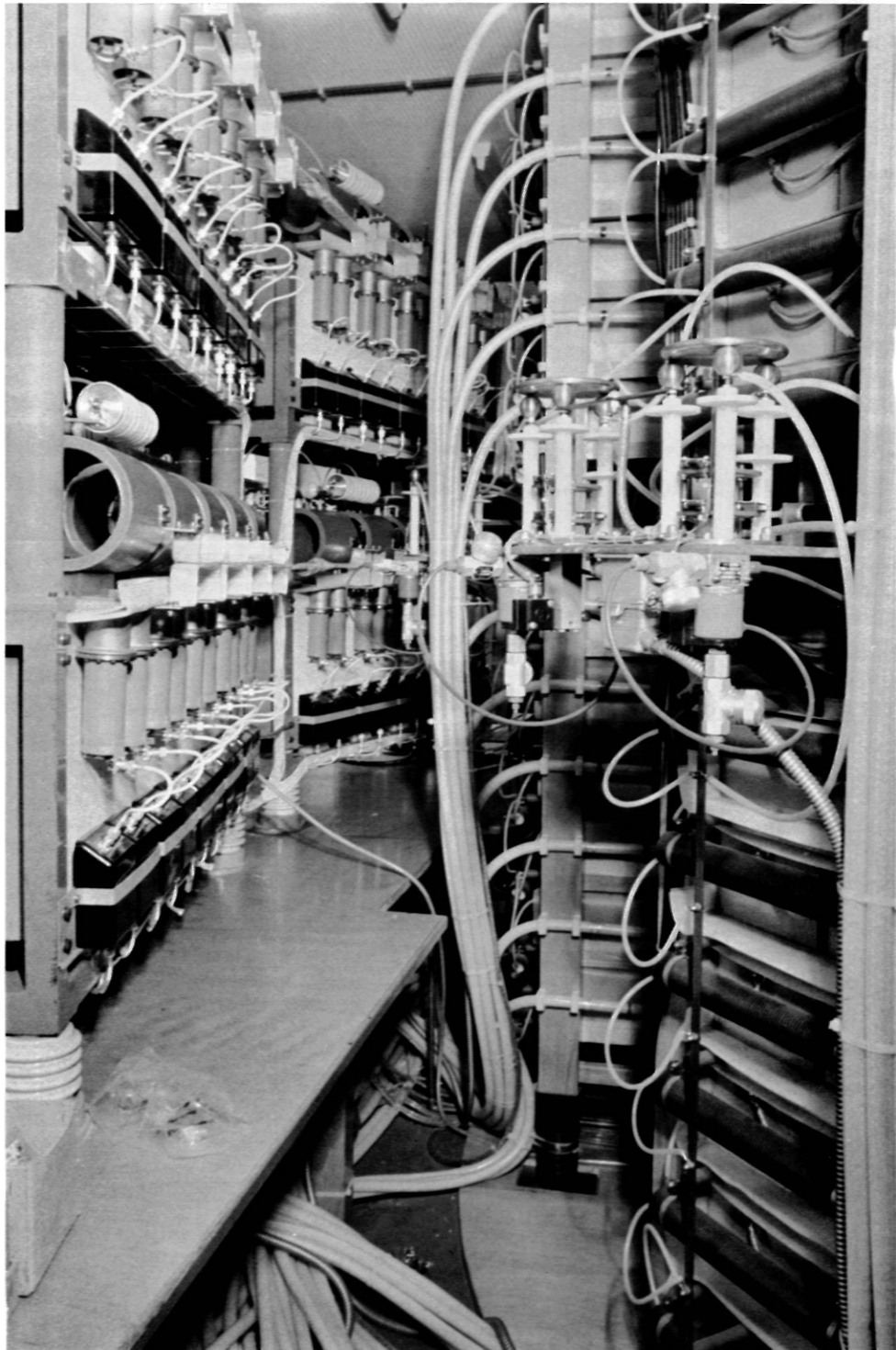


Fig.3 Biasfield bank at the rear
of the main bank

P 104

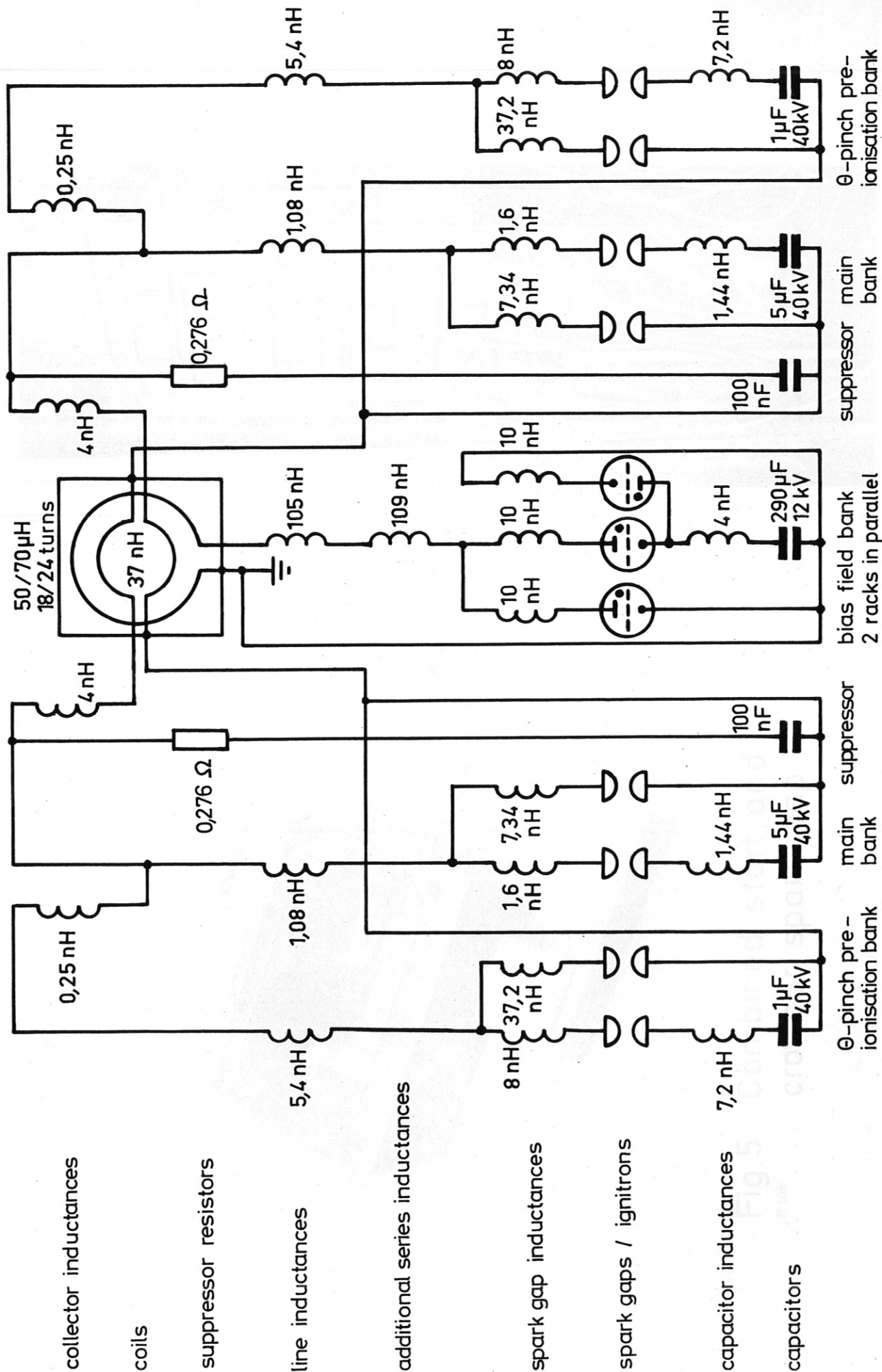


Fig. 4

Turbulence Heating Experiment

Circuit Diagram

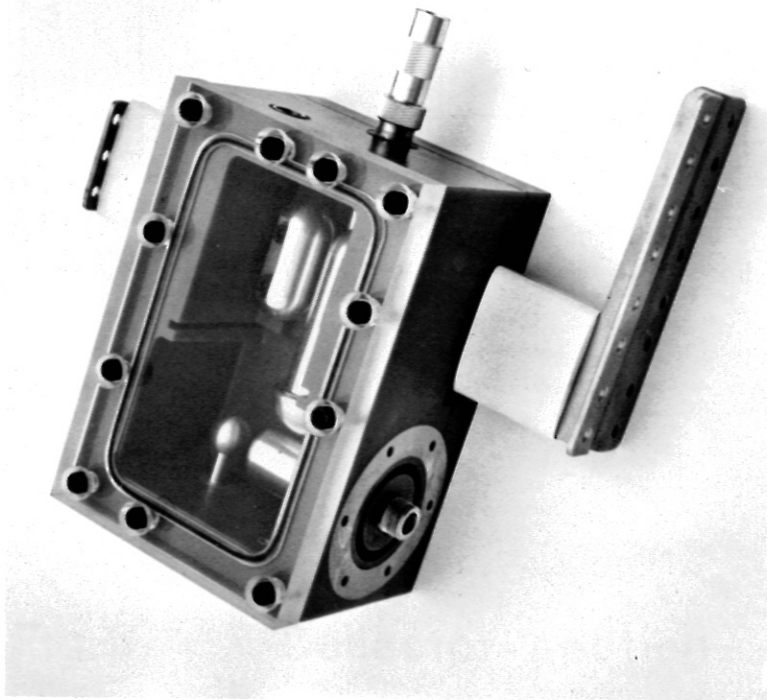


Fig.5 Combined start and
crowbar spark gap
P 108

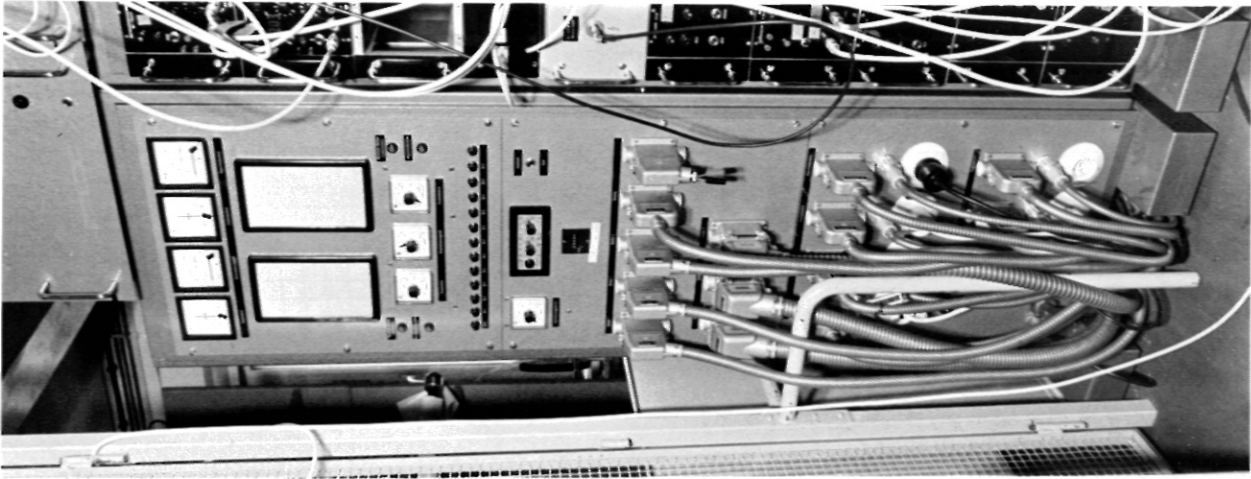


Fig.11 Control rack
P 107

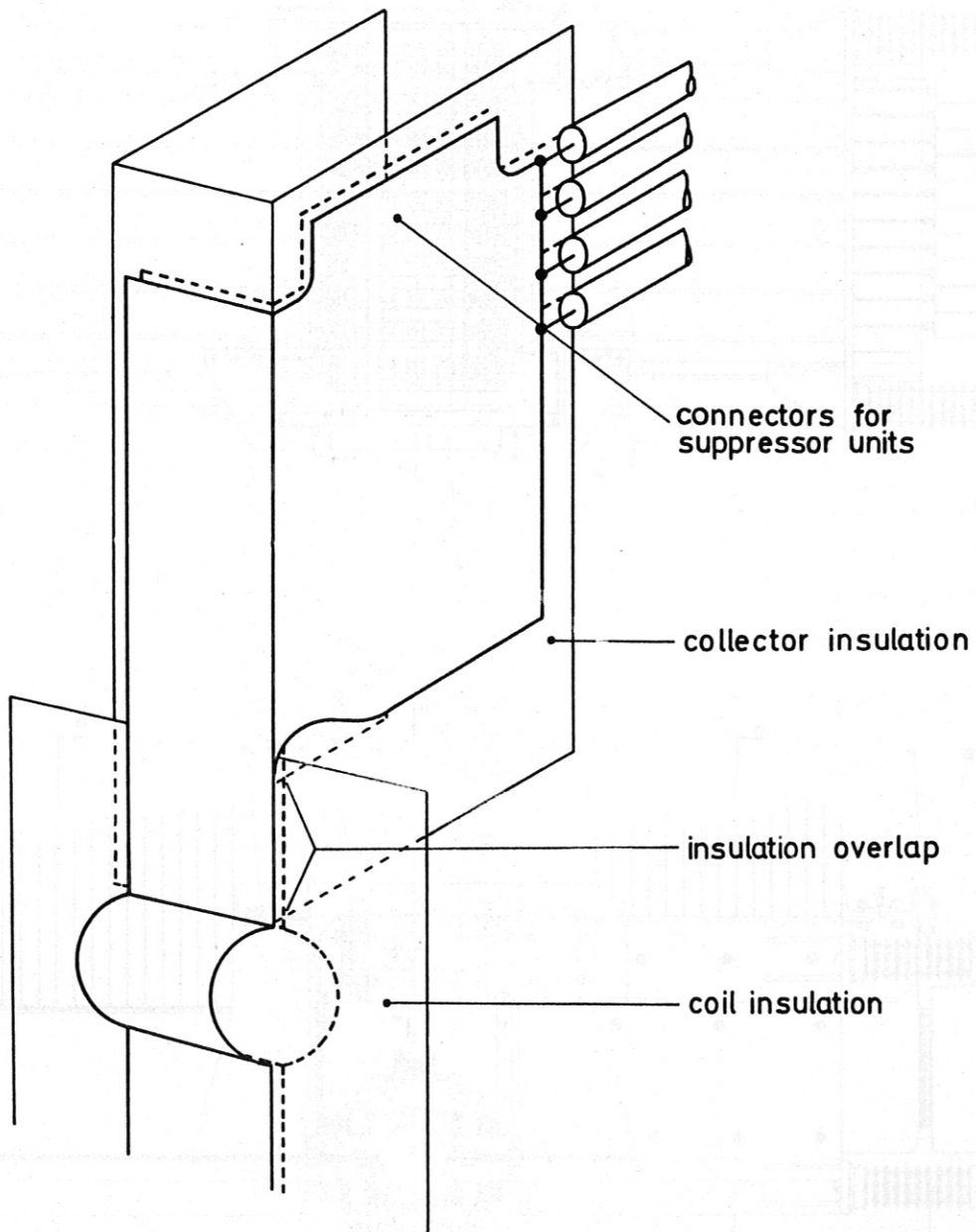


Fig. 6
P 111

Collector section

Fig 7 Collector system

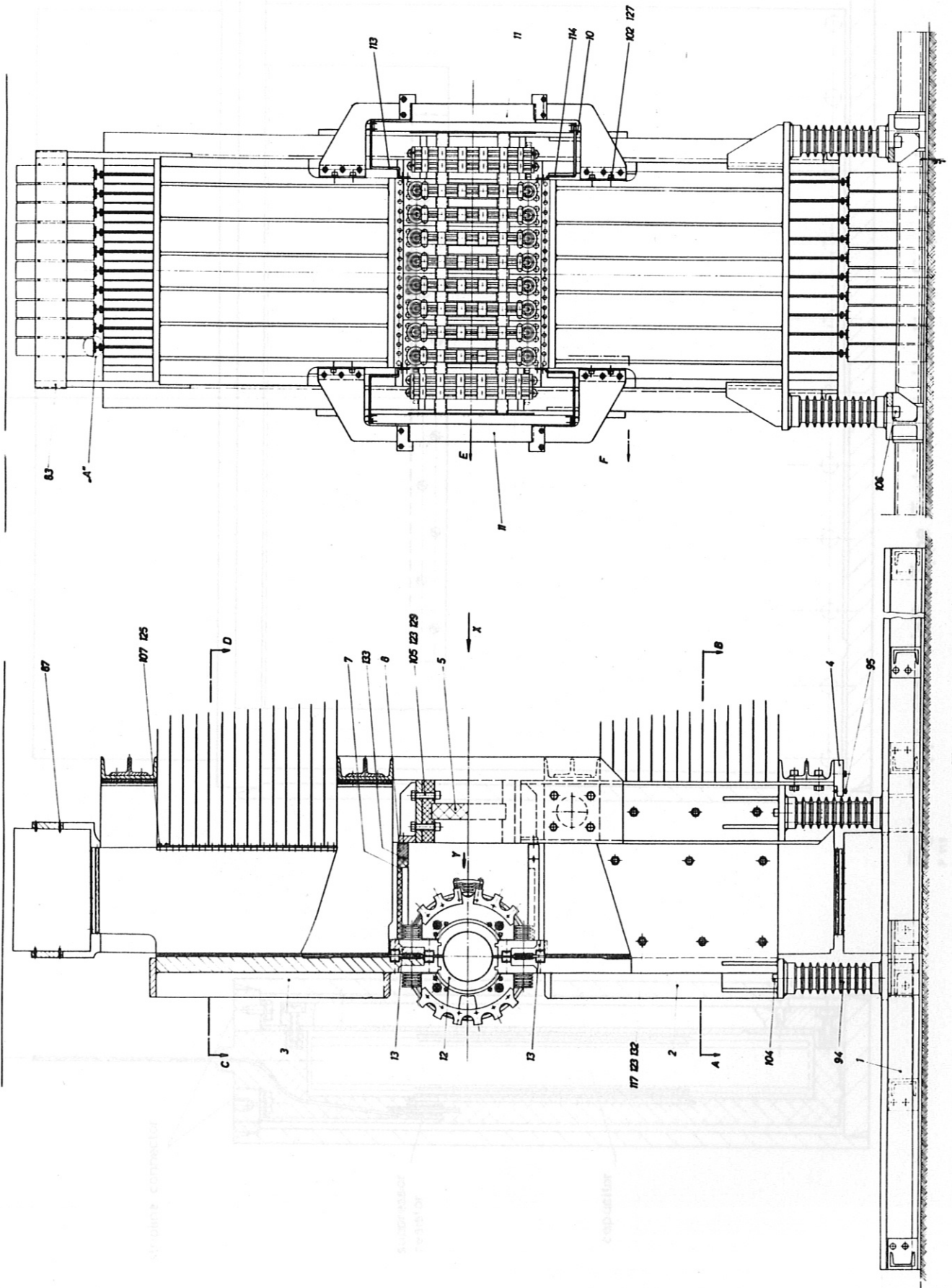


Fig. 7 Collector system

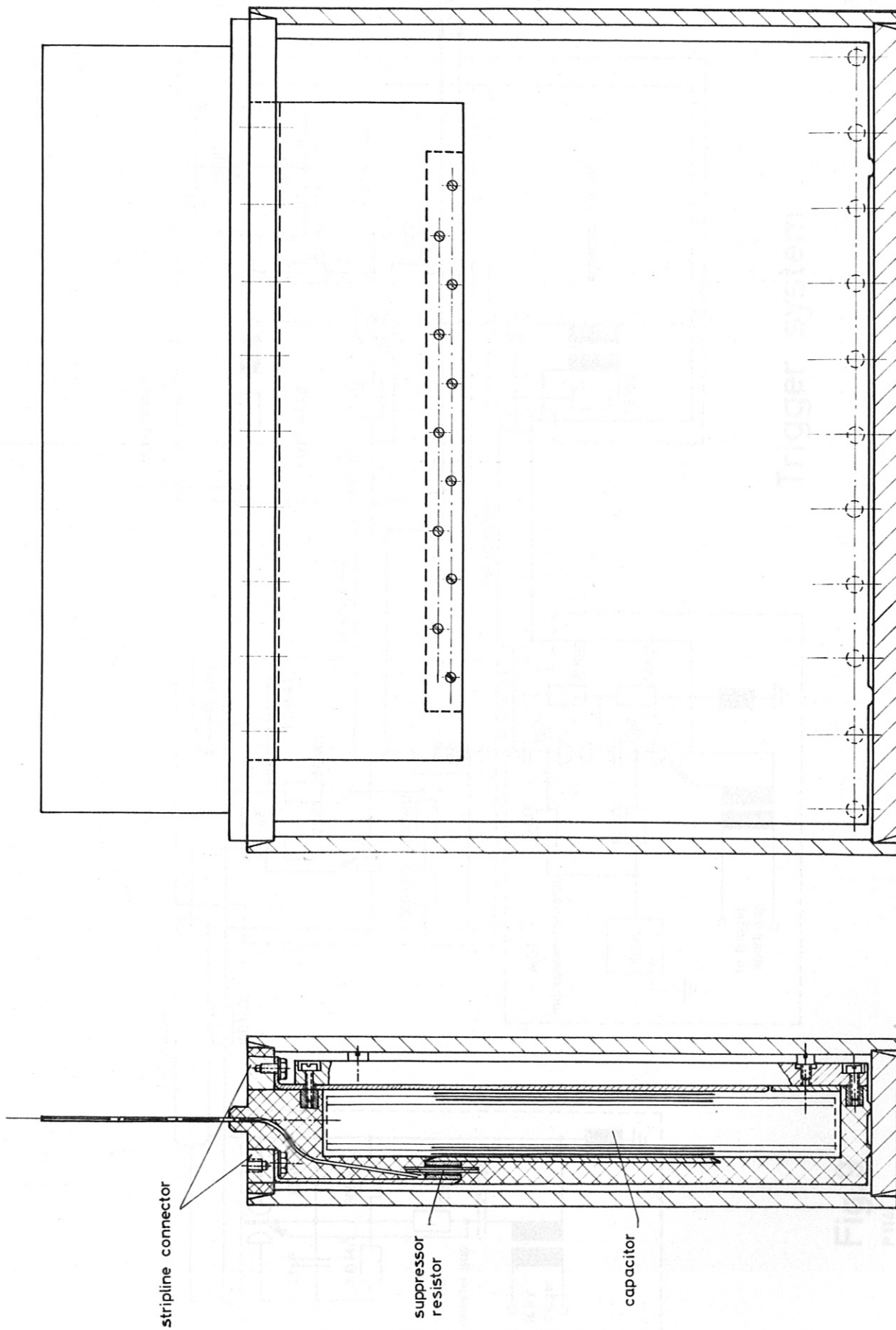
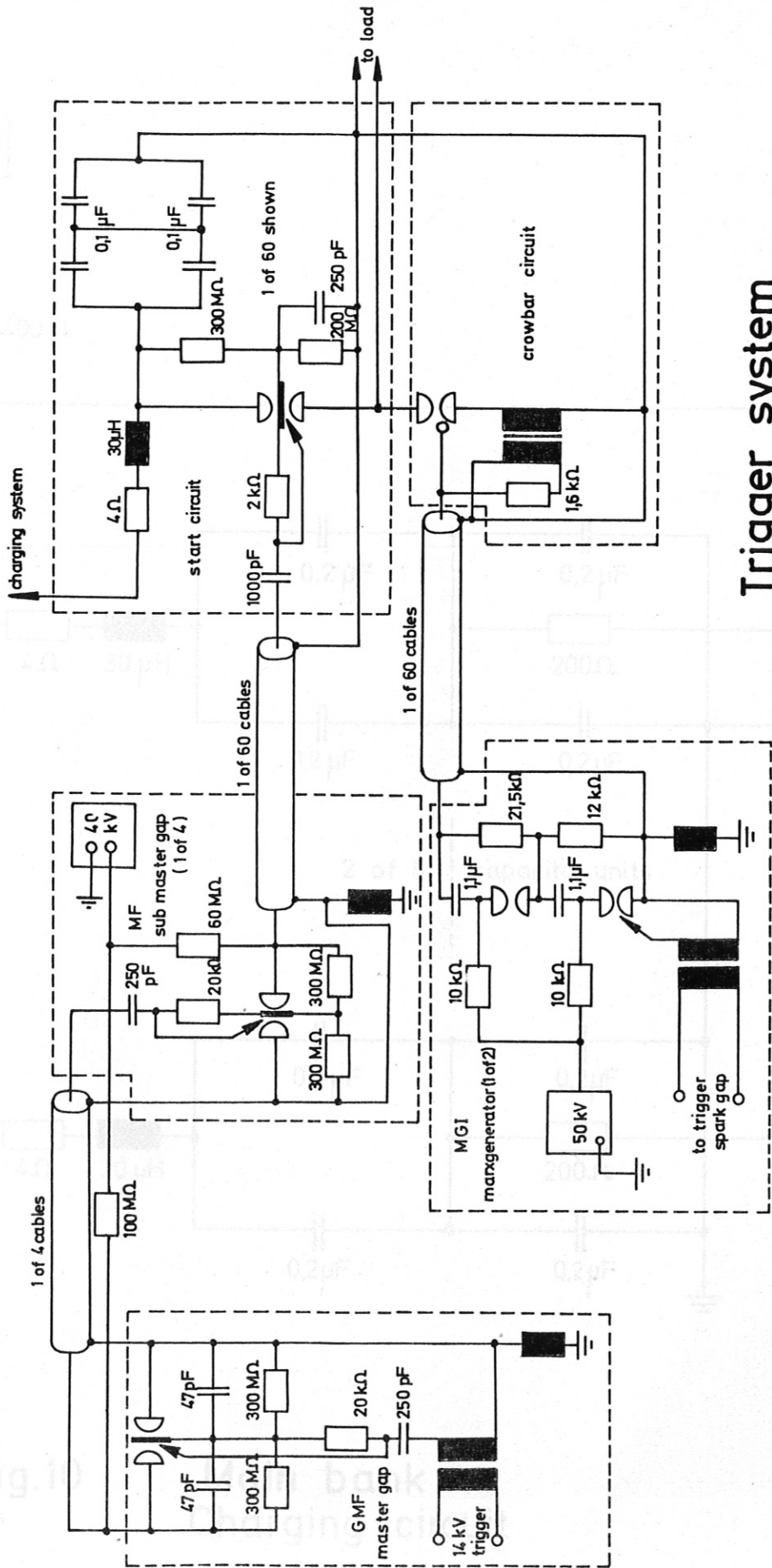


Fig.8 Suppressor Unit Type Turbulence Heating Experiment



Trigger system

Fig. 9
P114

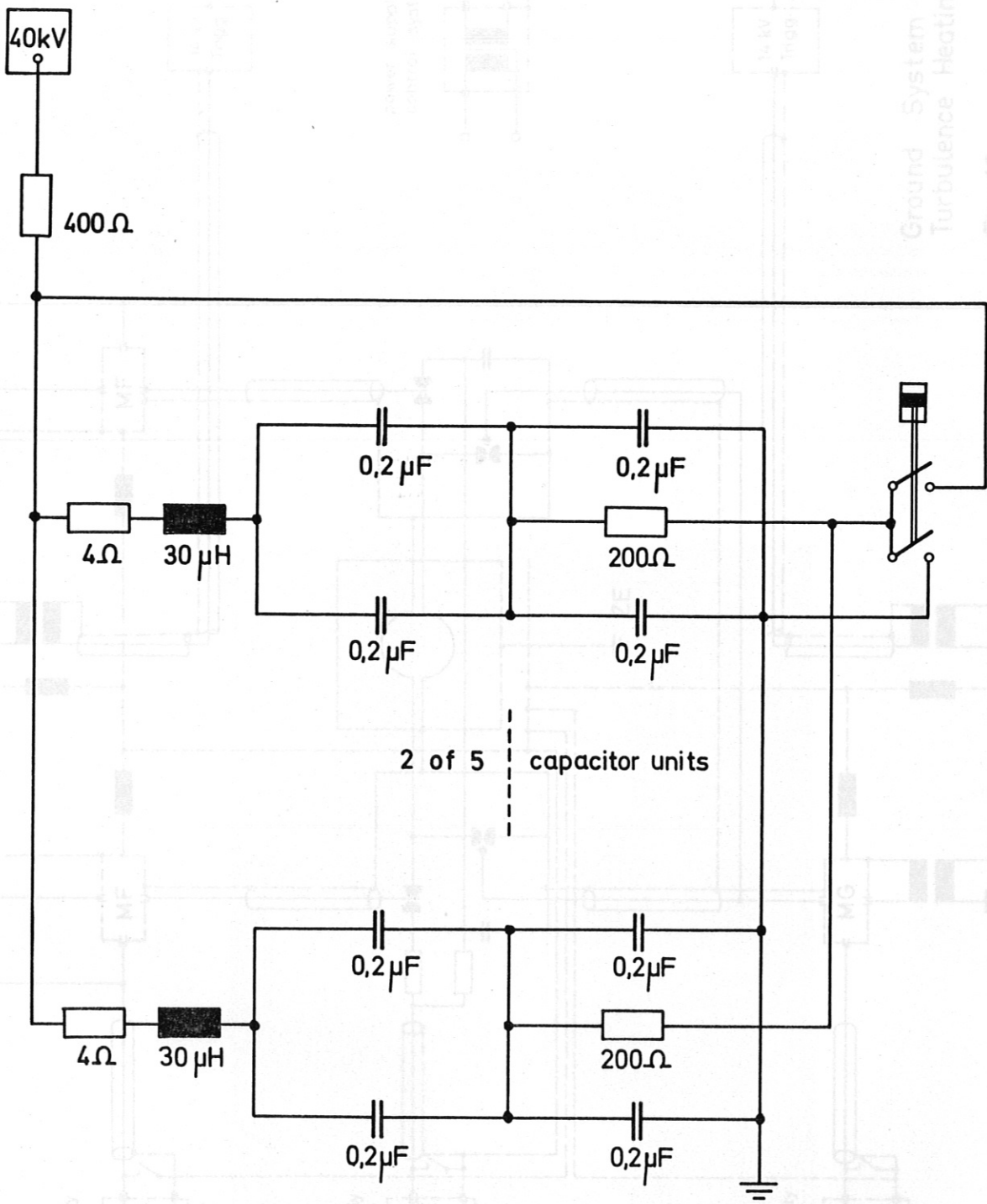
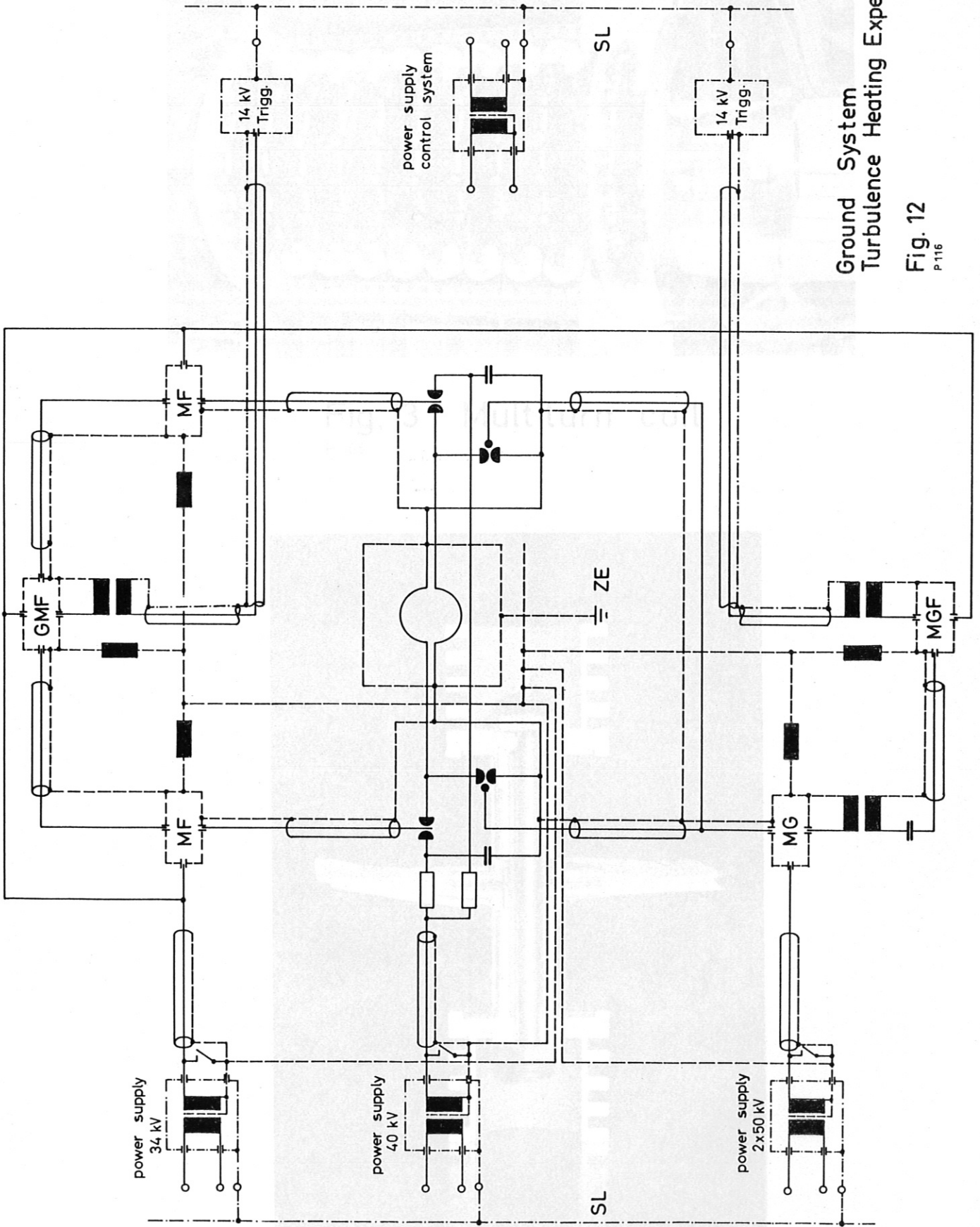


Fig.10
P 115

Main bank
Charging circuit



Ground System
Turbulence Heating Experiment

Fig. 12
P.116

Fig. 4 Lead-through connection

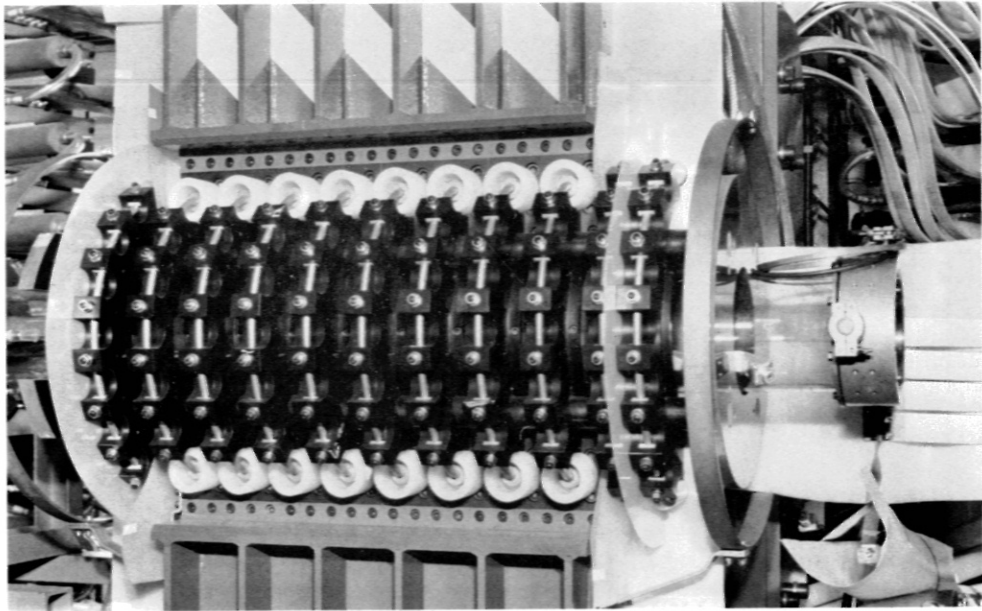


Fig.13 Multiturn coil

P 105

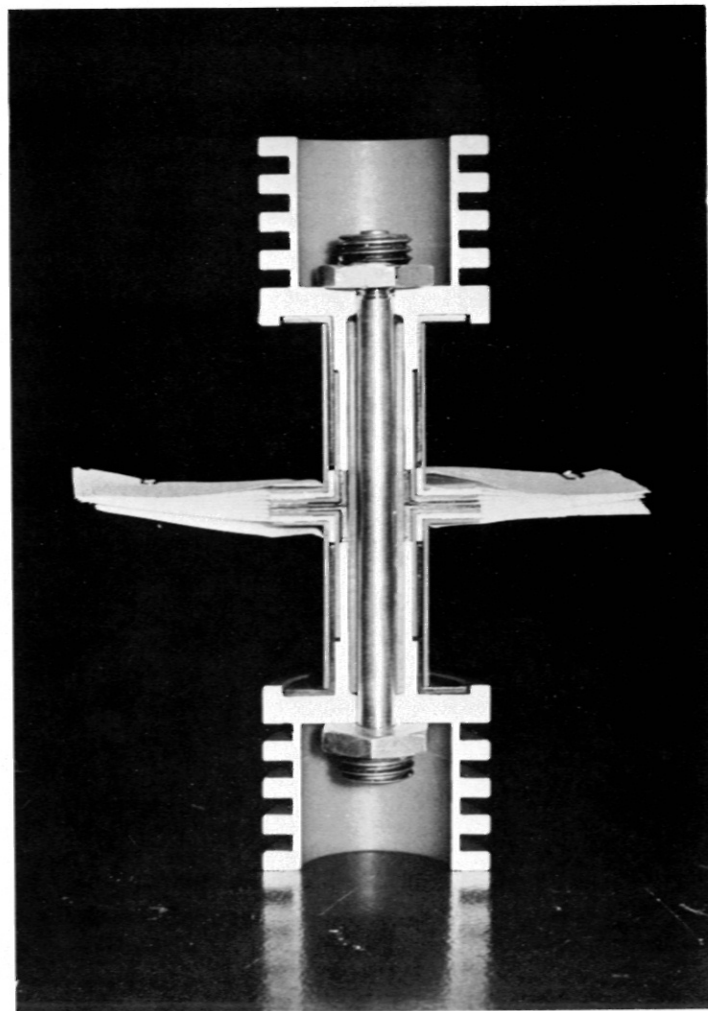


Fig.14 Lead-through connection

P 106

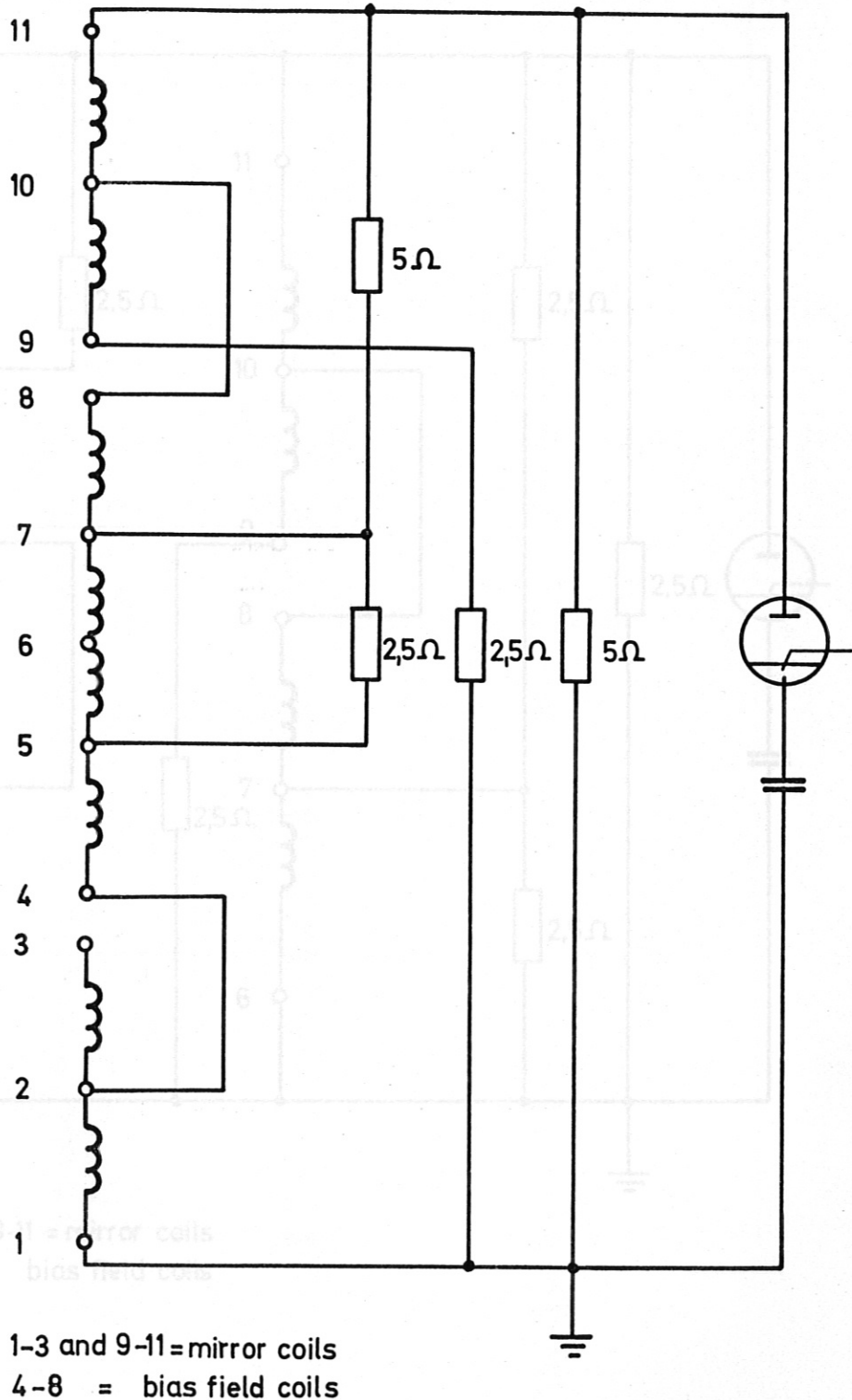
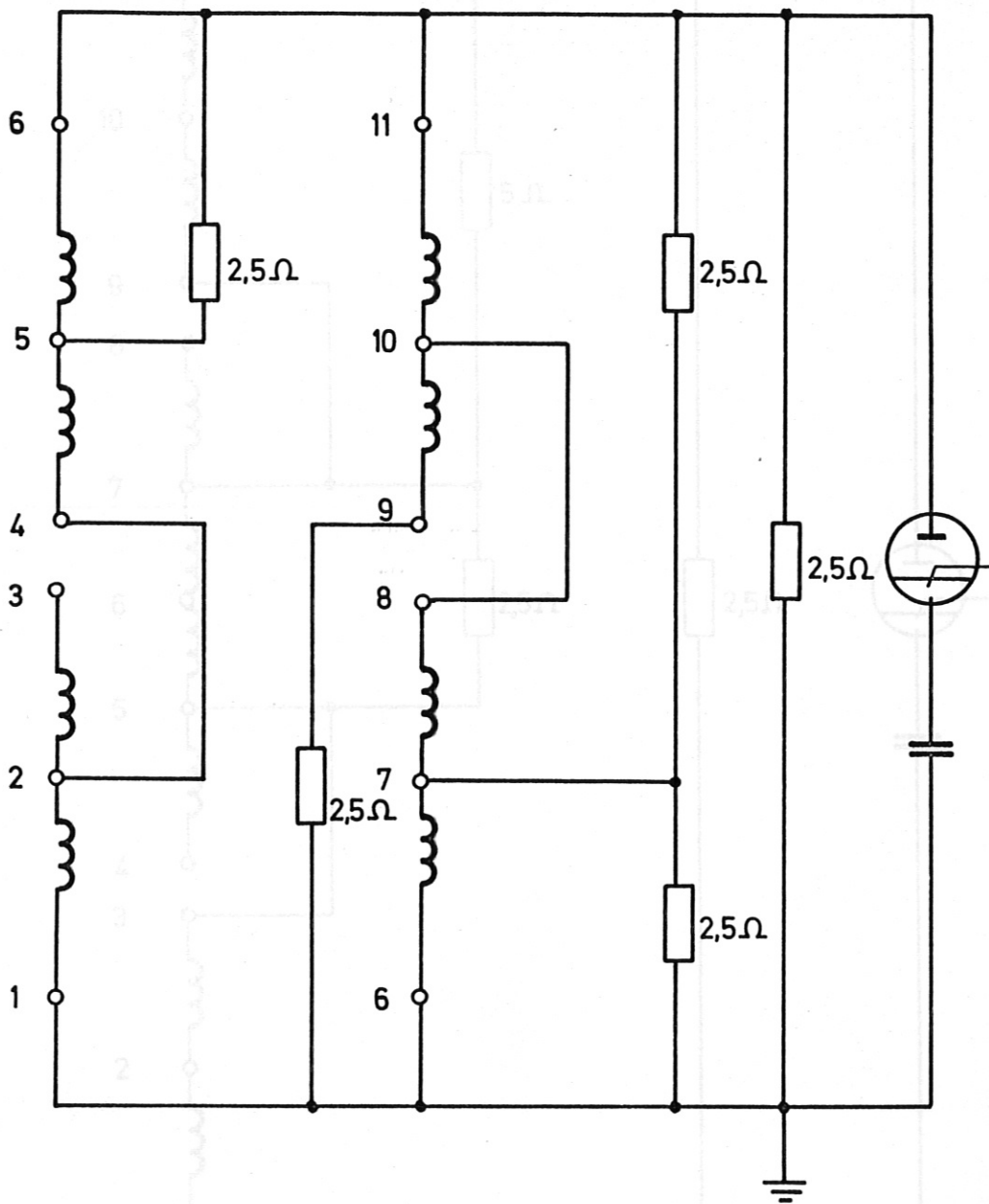


Fig.16
P116

Fig.15 Bias field coils in series mirror ratio 1:1

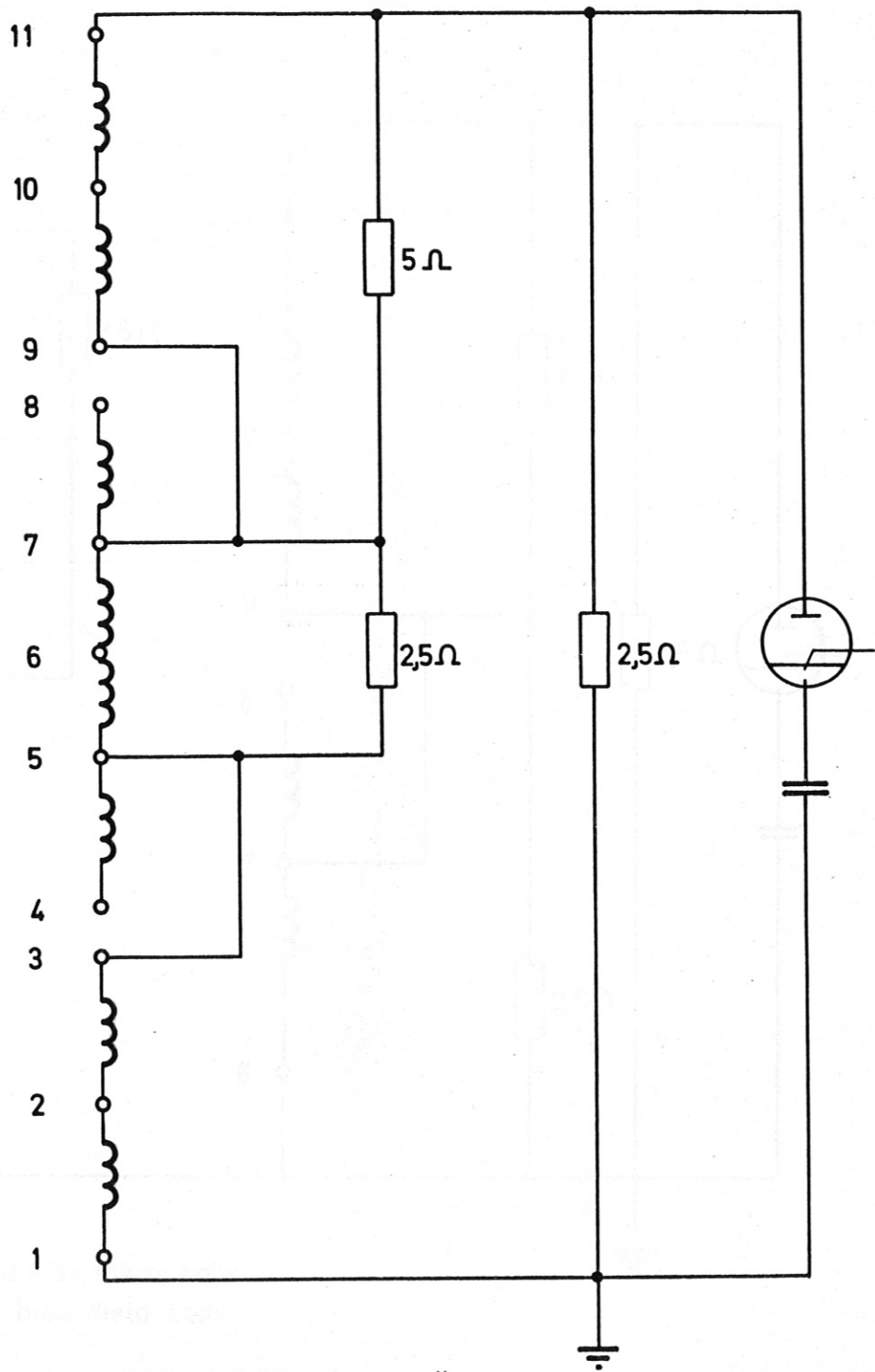


1-3 and 9-11 = mirror coils
 4-8 = bias field coils

Fig. 16

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Bias field coils in parallel mirror ratio 1:1

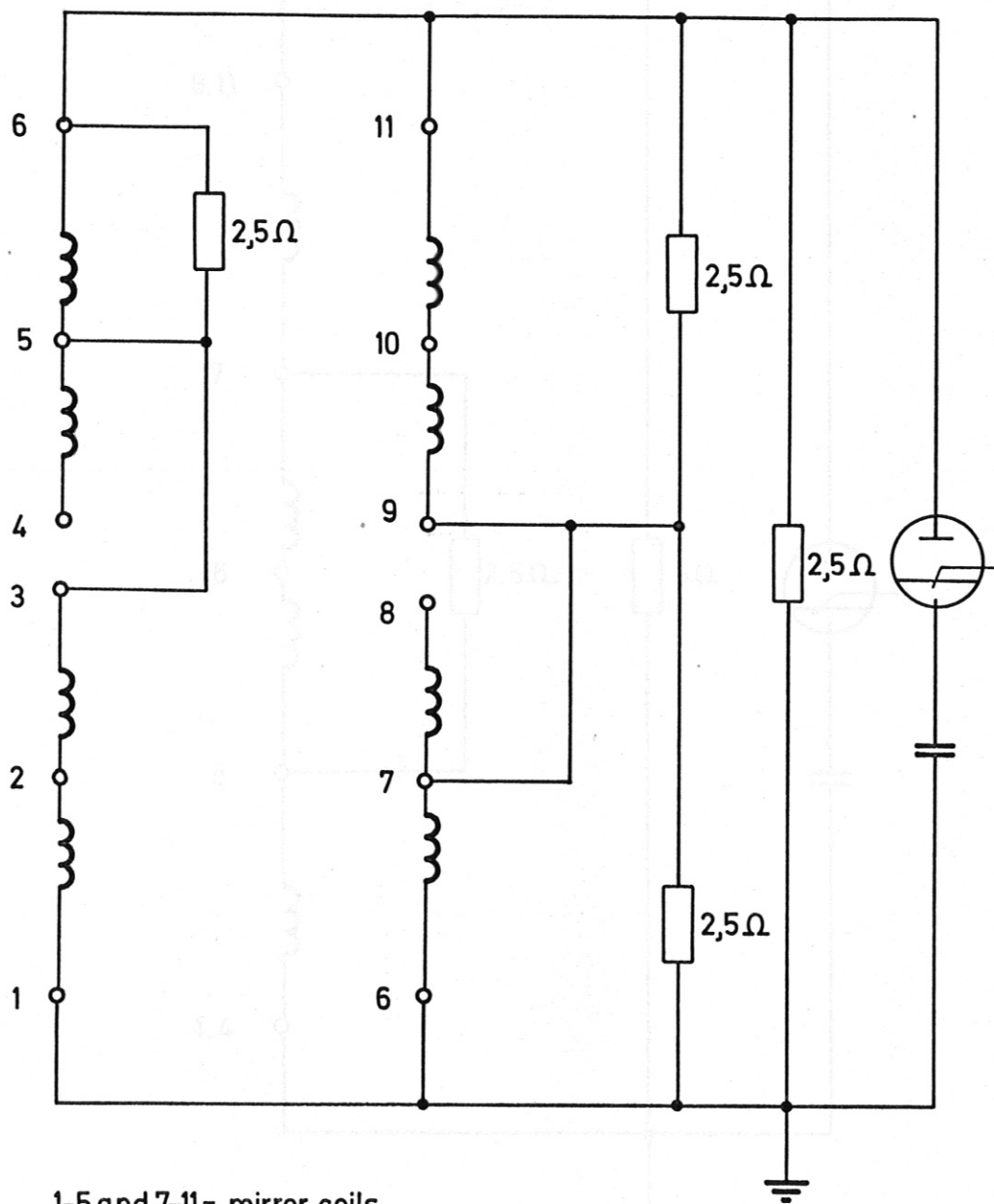


1-5 and 7-11 = mirror coils
 5-7 = bias field coils

Fig.17
 P 147

Bias field coils in series mirror ratio 2:1

Fig.18 Bias field coils in parallel mirror ratio 2:1

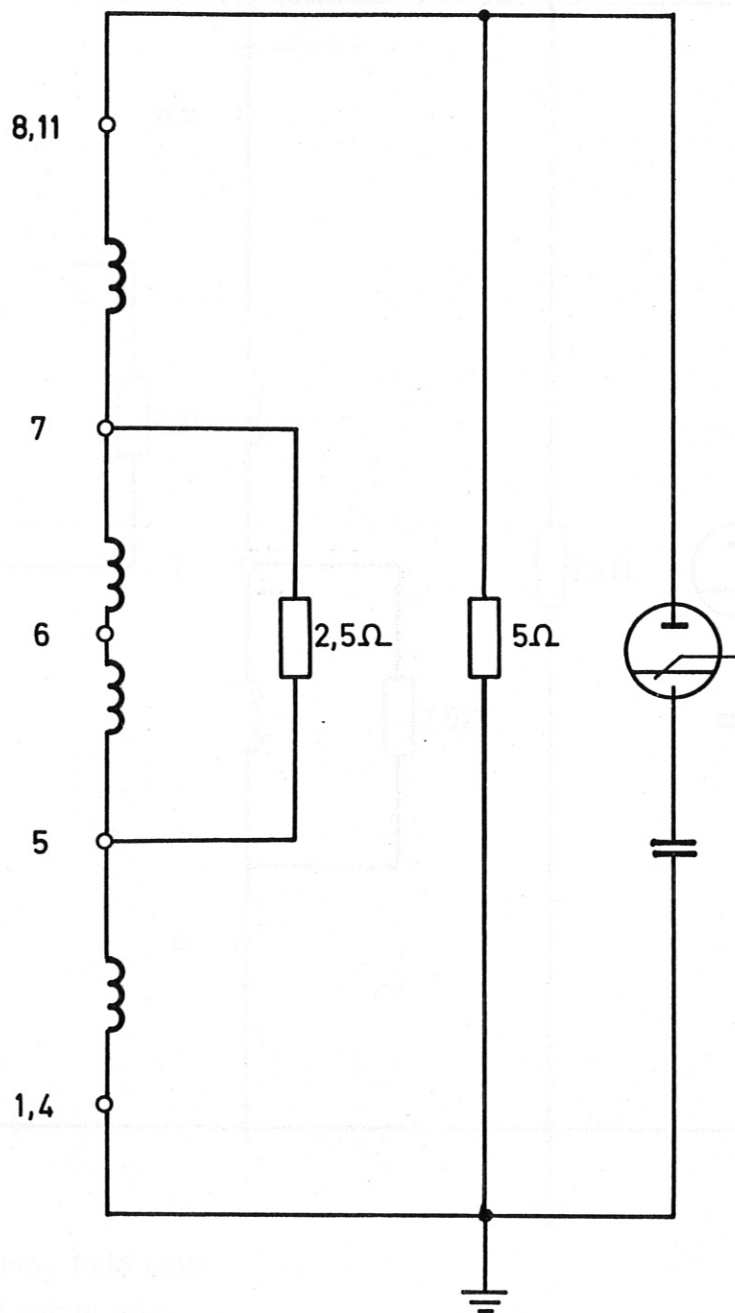


1-5 and 7-11= mirror coils
 5-7= bias field coils

Fig.18
 P 148

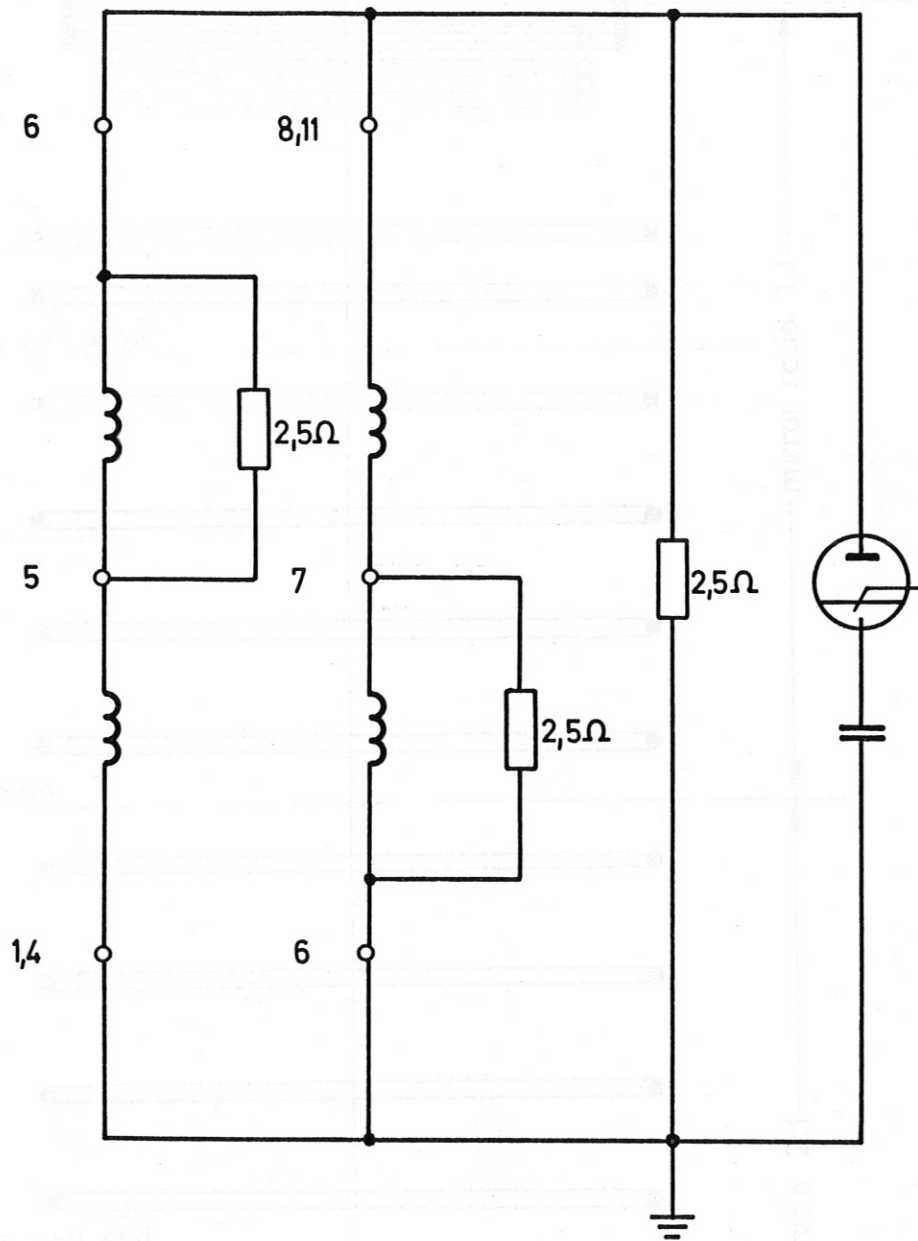
Bias field coils in parallel mirror ratio 2:1

Fig.19 Bias field coils in series



1-11 = bias field coils
without mirror coils

Fig.19 Bias field coils in series



1-11 = bias field coils
without mirror coils

Fig.20 Bias field coils in parallel

P 150

Fig.21 Bias field coils

P 151

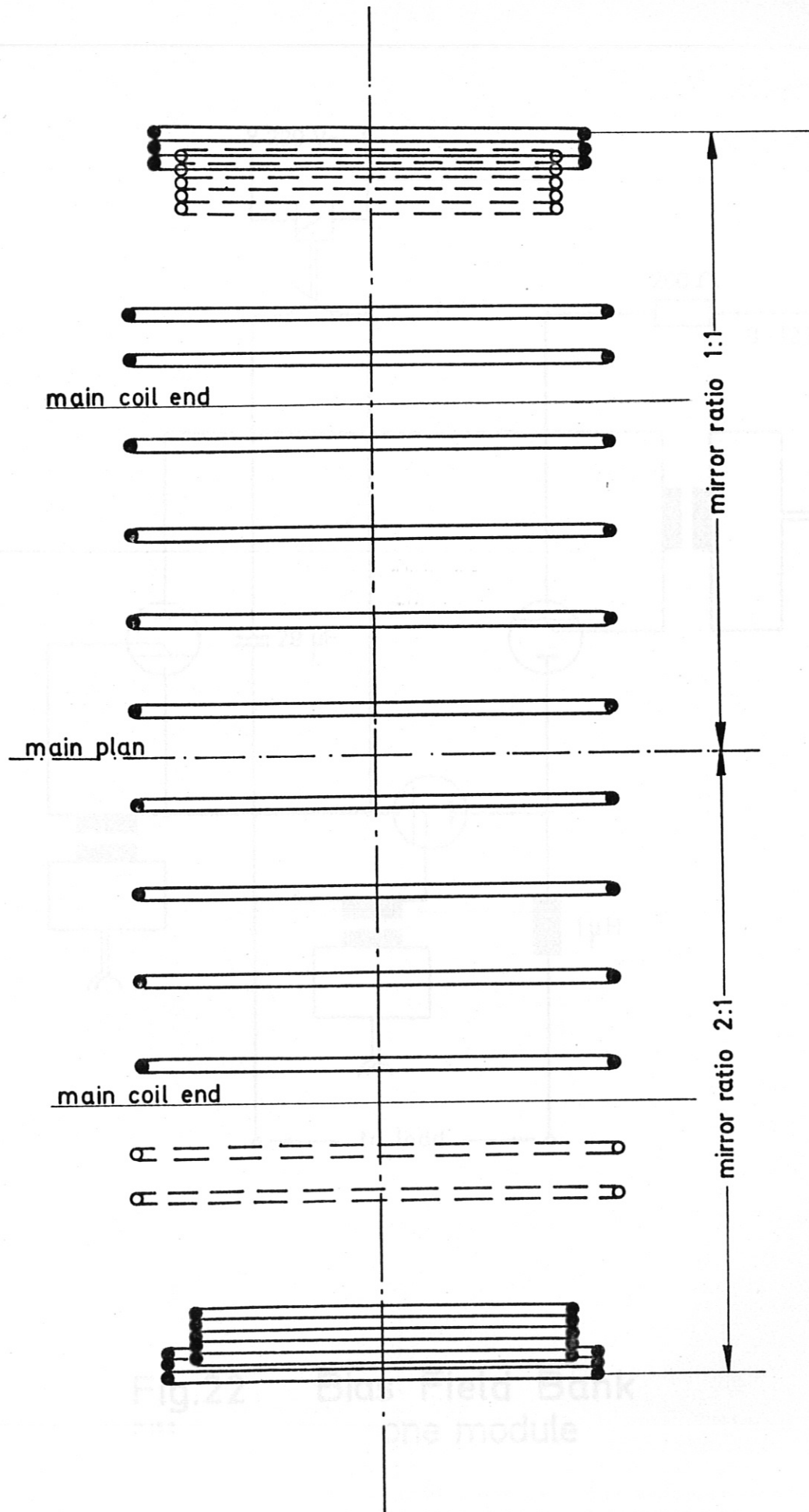


Fig.21 Bias field coils

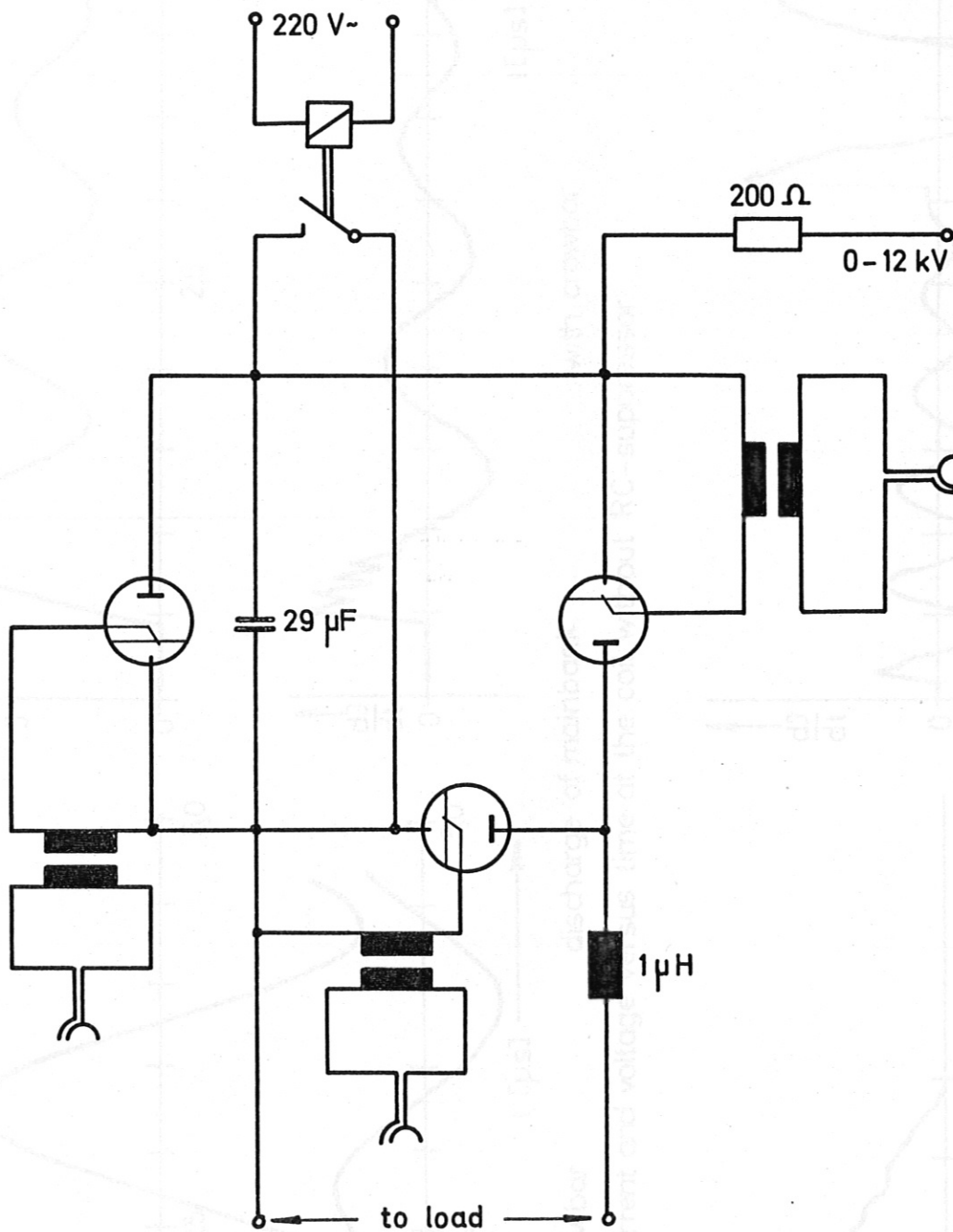


Fig.22 Bias Field Bank
 one module

P 152

voltage at the coil
 preionisation and main discharge

voltage at the coil with FC-suppressor

Fig. 23

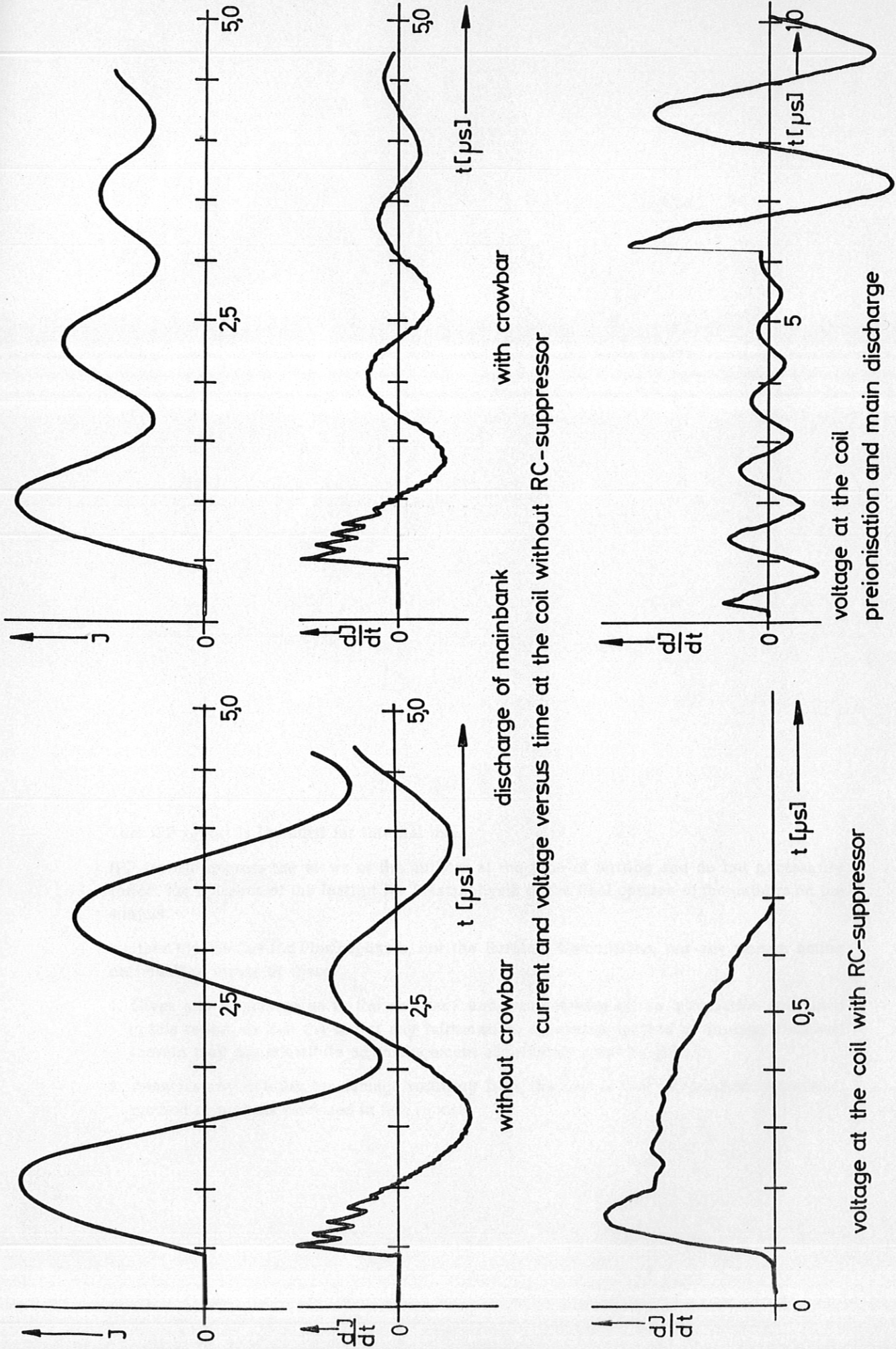


Fig. 23
P. 153