Laboratori Nazionali di Frascati

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M. Beneventano, U. Pellegrini, B. Rispoli, G. Sacerdoti, P.G. Sona, R. Toschi: A γ RAY SPECTROMETER FOR ENERGIES UP TO 1 GeV.

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A GAMMA-RAY SPECTROMETER FOR ENERGIES UP TO 1 GEV.

In order to calibrate the electron beam, of the electrosynchrotron of the Italian National Laboratory in Frascati whose energy is to be 1000 MeV (i. e. Bremsstrahlung spectrum of γ's) a pair spectrometer has been designed, now under construction and which shall be operating at the beginning of 1959.

The pair spectrometer has been designed with the pourpose to calibrate the γ-beam of the electrosynchrotron; the design takes into account the possibility of using the same arrangement for eletrodynamic experiments.

We shall give here below a brief description of the different parts of the spectrometer which are the following:

1) Magnet;
2) Target which converts photon into electron pairs;
3) Scintillation counters;
4) Electronic equipment.

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1) The magnetic deflector, designed by curselves, is now under costruction in the shop.

The total weight of the magnet is 19.000 Kg and maximum magnetic induction in the air gap of 100 ± 0,1 mm is 2 Wb/m^2.

The pole faces flat and parallel have trapezoidal shape; the dimensions are: the basis 1100 mm and 300 mm rispectivity and the height 850 mm.

The maximum of current is 2100 A, stabilized at 0,1% , with 120 turns of copper water cooled. The electrical power is 400 kW.

The magnet is shown in fig. 1, 2 and 3; fig. 1 shows the superior part in which there are 36 holes for putting scintillation counters inside the magnet. The holes have been calculated in order to obtained a multichannel pair spectrometer and for electrodynamics experiments. The gap is 100 mm height so that we suppose to be possible calibrating beams 60 mm large.

Around the gap has been arranged a tank in with it is possible to obtain a vacuum of the order of some tenth of mm Hg.

As we shall see later, the first arrangement which is at present under construction, will consist of a single channel outside magnetic field as it is shown in fig. 1 where dotted lines indicate two simmetrical trajectories of the electrons having the same energy.

Fig. 4, 5 and 6 show the results of the magnetic measurements made on a model of the magnet 1/4 scale.

In fig. 7 there is a picture of the model of the pair spectrometer.

2) The target has been calculated by assuming the following hypothesis:

a) the spectrum of γ-rays is given by:

$$N(k) = \frac{\lambda N_e}{k}$$

k = energy of γ's.
λ = thickness in radiation length of the electrosynchrotron target
N_e = number of electrons circulating in the beam

b) the total cross section of pair production is given by:

$$\Phi_{tot} = \frac{Z(Z+1)}{137} \left\{ \frac{28}{9} \log (183\ Z^{-1/3}) - \frac{2}{27} \right\} r_o^2$$

where Z is the atomic number of the target, and

$$r_o = \frac{e^2}{mc^2} = 2,8 \times 10^{-13}\ \text{cm}$$

Hence if the spectrometer record only pairs of the electrons having the same energy $E \pm \delta E$, we can calculated the following expression:

number of pairs of electrons having the same energy E:

$$N_p = Q \left(\frac{\delta E}{2E} \right)^2$$

number of pairs in which a single electron has energy E:

$$N_s = Q \frac{\delta E}{E} \left(1 - \frac{E}{K_{max}} \right)$$

where K_{max} in the maximum energy of photons, and Q is given by

$$Q = \Phi_{tot} \frac{A \rho \lambda N_e X}{P}$$

where

A = Avogadro's number
ρ = the density (in g/cm^3) of the converter
P = the atomic weight
X = the thickness (in cm) of the converter

Let us call τ the resolution time of the electronic coincidence between some counters placed along the two paths of electrons, and T the length of the electrosynchrotron pulse; the ratio between spurious coincidence $2 \tau N_s^2$ and real coincidence due to two electrons of the same energy per seconds is given by

$$\eta = 8 \tau \frac{Q}{T} \left(1 - \frac{E}{K_{max}} \right)^2$$

By assuming reasonable values, for example

$N_e = 10^9$ electron per pulse $\qquad \lambda = 2 \times 10^2$

$X = 10^{-3}$ cm of Al $\qquad \tau = 0{,}01\ \mu s = 10$ ns

$T = 500\ \mu s$

we easily find

$$N_p = 130\ s^{-1} = 0{,}65 \text{ counts per pulse}$$

$$N_s = \begin{cases} 5{,}2 \times 10^4\ s^{-1} = 26 \text{ counts per pulse for } E = 0 \\ 1{,}3 \times 10^4\ s^{-1} = 6{,}5 \quad ' \quad ' \quad ' \quad ' \quad E=500 \text{ MeV} \end{cases}$$

That means for η the following numbers:

$$\eta = \begin{cases} 10\% & \text{for } E = 500 \text{ MeV} \\ 40\% & \text{for } E = 0 \end{cases}$$

Therefore, the counting rate of random coincidences is quite high even if the electronic coincidence has high resolution, and it strongly energy dependent; in addition we have to calcolate background counts due to different particles and photons which cross the counters.

3) As a consequence of the proceeding remarks we have designed the arrangement shown by fig. 1. Two different three fold coincidence record separately each electron of a given energy which depends on the magnetic field. Resolution time of each coincidence is of the order of 5 ns and random coincidences due to background particles crossing separately the counters are quite negligible.

The first and the second scintillation counters determine the energy indefinition due to energy loss and scattering of electrons inside the counters; for that reason

they have to be as thin as possible, but thick enough for giving rise to a reasonable amount of photons. A good compromise seems to be a thickness of the order of 1 mm which corresponds to an energy loss of the order of 0,2 MeV.

The arrangement designed has some advantages:

a) background coincidences are quite negligible;

b) the arrangement is much simpler because the scintillation

counters are outside magnetic field and photomoltipliers can be put directly in contact wich scintillators;
c) the possibility of measuring simultaneously the real coincidences due to electron pairs of given energy and the random coincidences due to different electron pairs each having a single electron of the right energy. This can be done very easily by measuring simultaneously the prompt and delayed coincidences between pulses coming from the two three-fold coincidences, as shown in fig.1.

Therefore the difference between prompt and delayed coincidences gives the correct number of pairs of electrons having the same energy as a function of the energy, which depends from magnetic field, i.e. from the current energiting the magnetic deflector.

Of course we have to pay something for those advantages: we must indeed take into account the effect of the fringing field and correct by using conventional methods, for example the floating wire method for testing electron trajectories and resolution of the apparatus.

4) The block diagram of electronics is shown in fig. 8. Three-fold coincidences are obtained by means the circuit shown in fig. 9. The anodes of the tubes E180F are connetted in parallel by means of inductances which form with stray capacitances a trasmission artificial line of characteristic impedance Z_0 and delay per section τ_0.

The grids of the tubes are connected to the anodes of photomoltipliers by mean of a coaxial cable of ~~the same~~ characteristic impedance Z_0 terminated with a pulse forming cable shorted at the end; the cables connecting photomultipliers and tubes are sligtly different in length just for compensating the delay introduced by one section of the line between the anodes. Negative pulses of photomultipliers cut-off the tubes and if all tubes are cut-off one after the next with time delay just equal to τ_0, all positive pulses on the anode line will arrive at the end in the same time giving rise a pulse which amplitude is 3 or 1.5 times the amplitude of the pulses given by single or two-fold coincidences. The resolving time of this circuit can be made easely of the order of 2-3 ns(x). Both three-fold coincidences are placed near the electrosynchrotron; the imputs are directly connected to the anodes of RCA 6810A photomultipliers by means coaxial cables and the outputs are brought by means of coaxial cables to the control room (about 30 m distance where are all electronic equipments).

As fig. 9 shown, the three-fold coincidences feed two distributed amplifiers whose outputs are connected to the inputs of the 'prompt and delayed coincidences'. The amplifiers used for this purpose are the 'fast amplifiers' mod. AR62 produced by 'Italelettronica' having the following characteristics: input and output impedance 200 Ohm; gain 31.6 db when output is matched; rise time 3.5 ns.

The prompt and delayed coincidences are shown in fig. 9; the inputs are connected to two lumped delay of the same characteristic impedance 200 Ohm but having different number of sections. Using the circuit just described, one gets from the same lines the pulses for prompt coincidence (tubes V_1, V_2) and for delayed coincidences (tubes V_3, V_4). The resolving time is about 5 ns and the delay is of order of 20 ns. The outputs of these coincidence circuits are quite conventional and connected to scalers and counting circuits.

(x) This circuit has been described in Nuovo Cim., 9, 171 (1958)

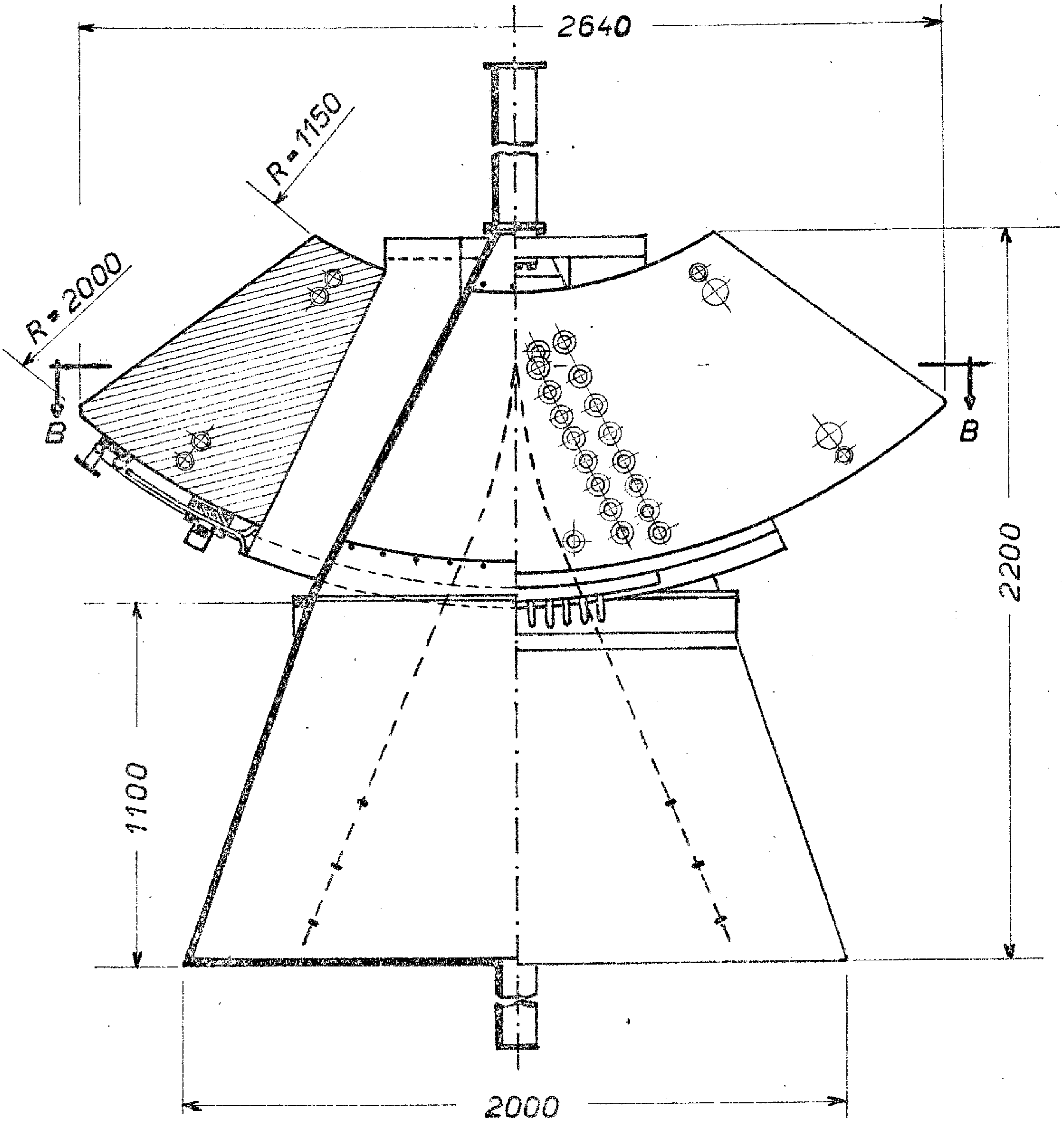


FIG. 1

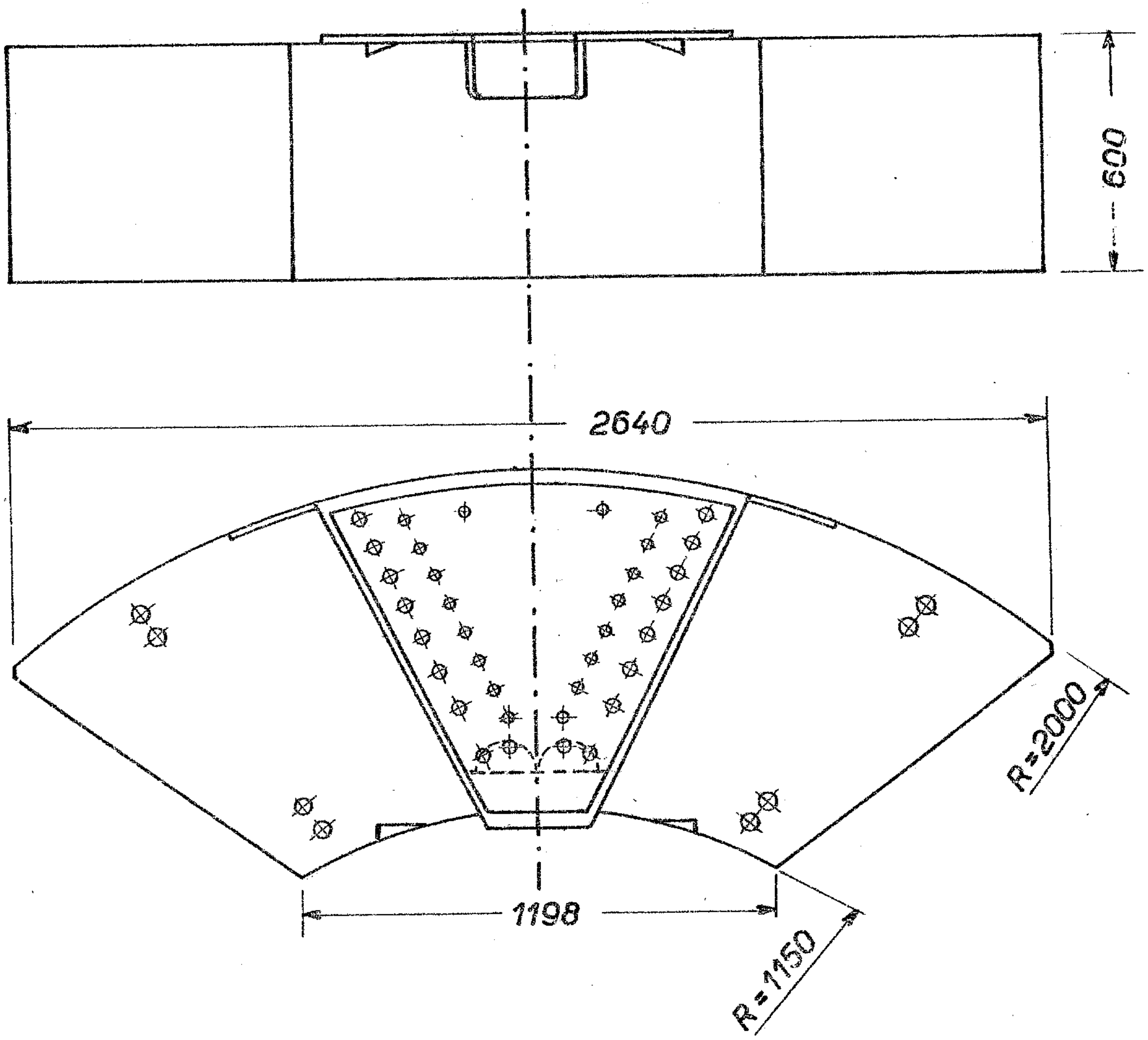


FIG. 2

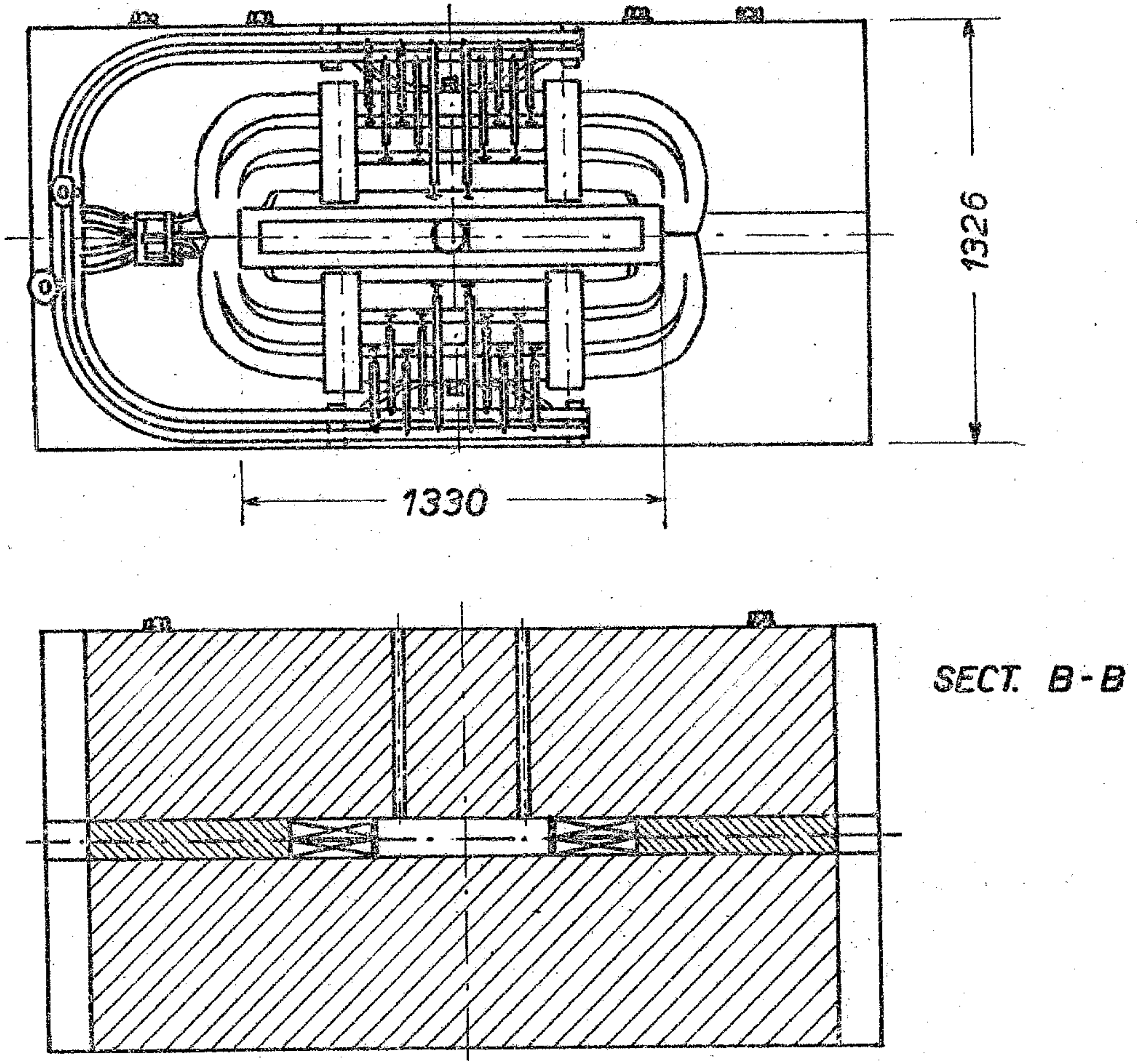


FIG. 3

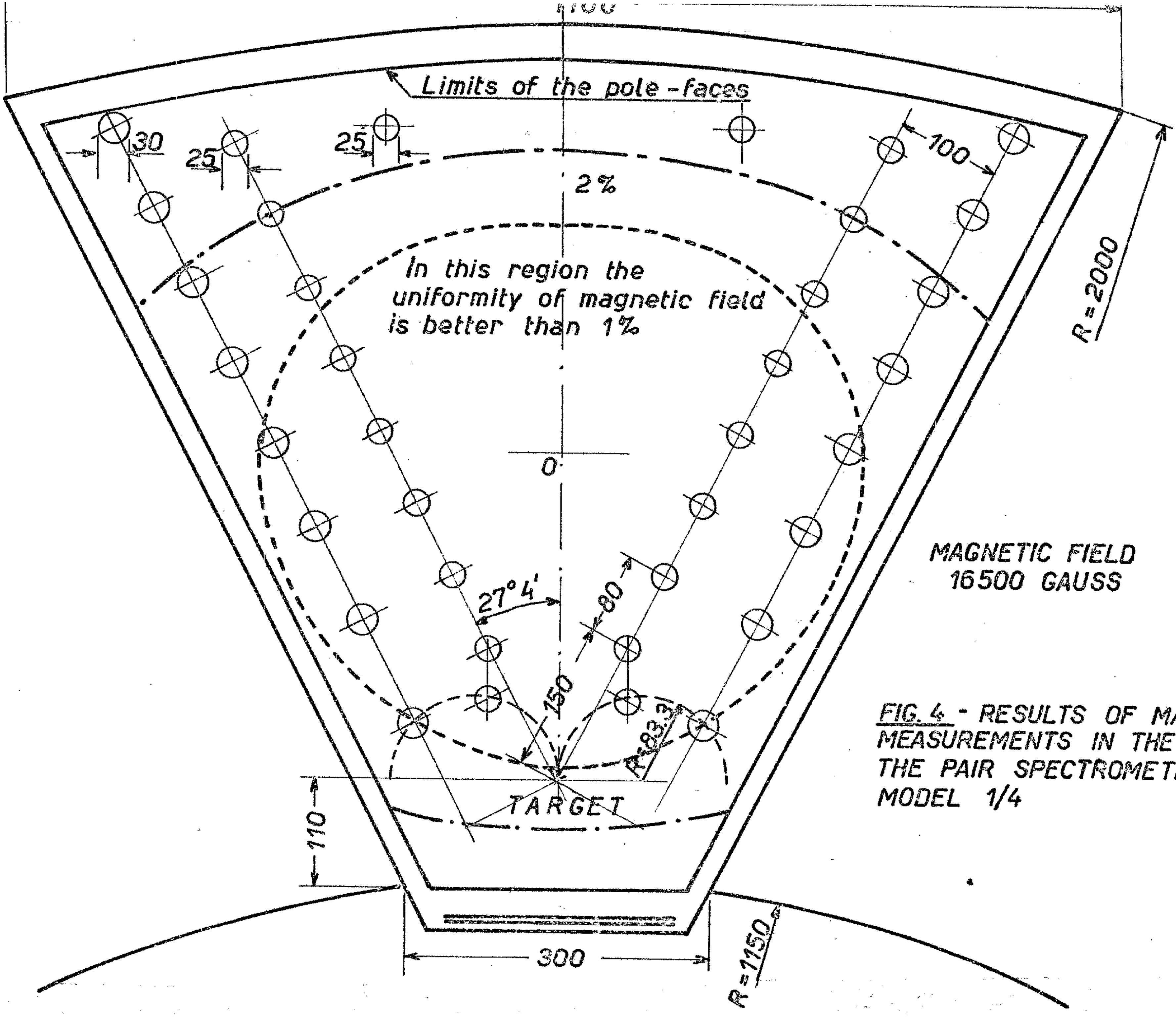
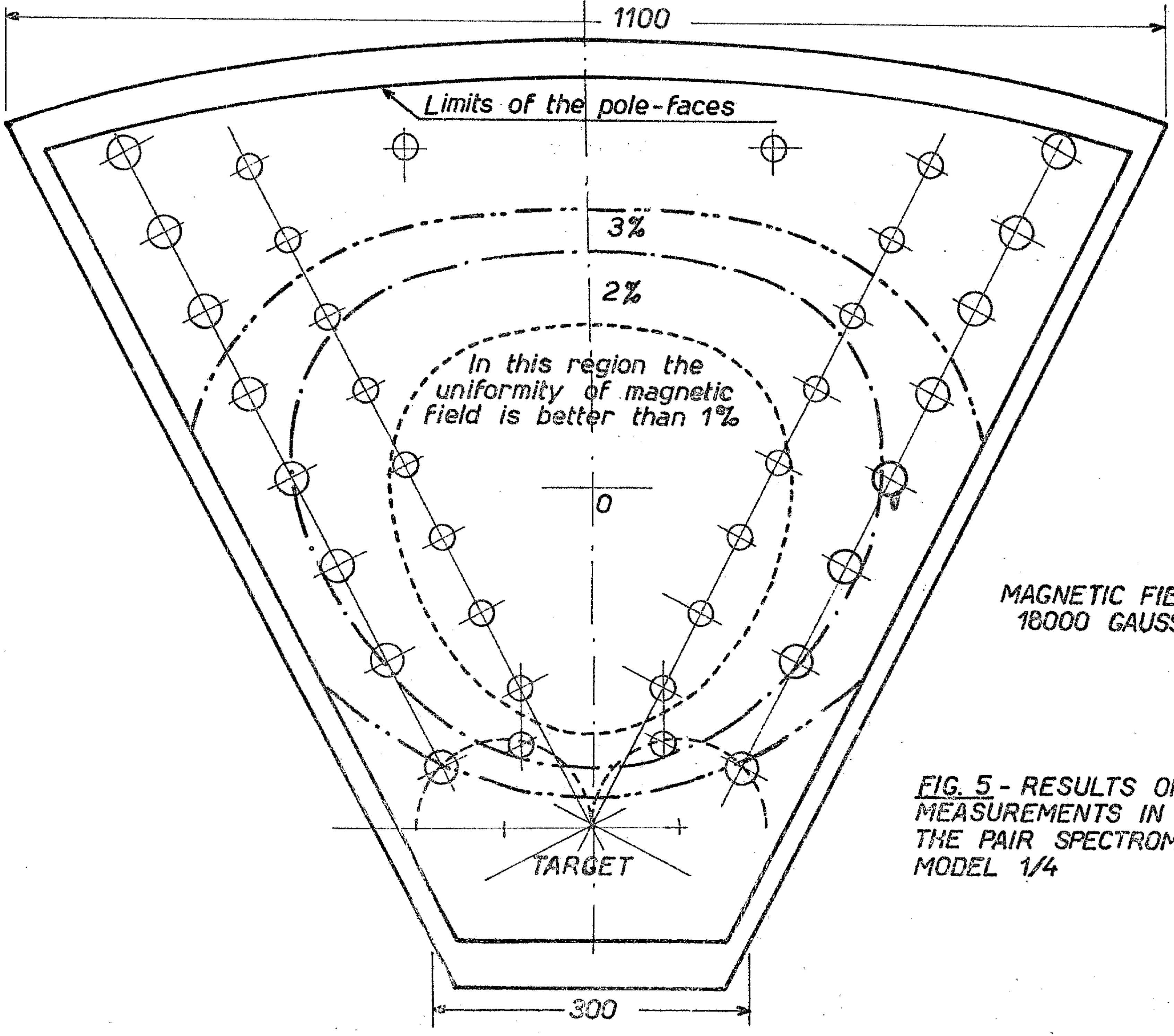
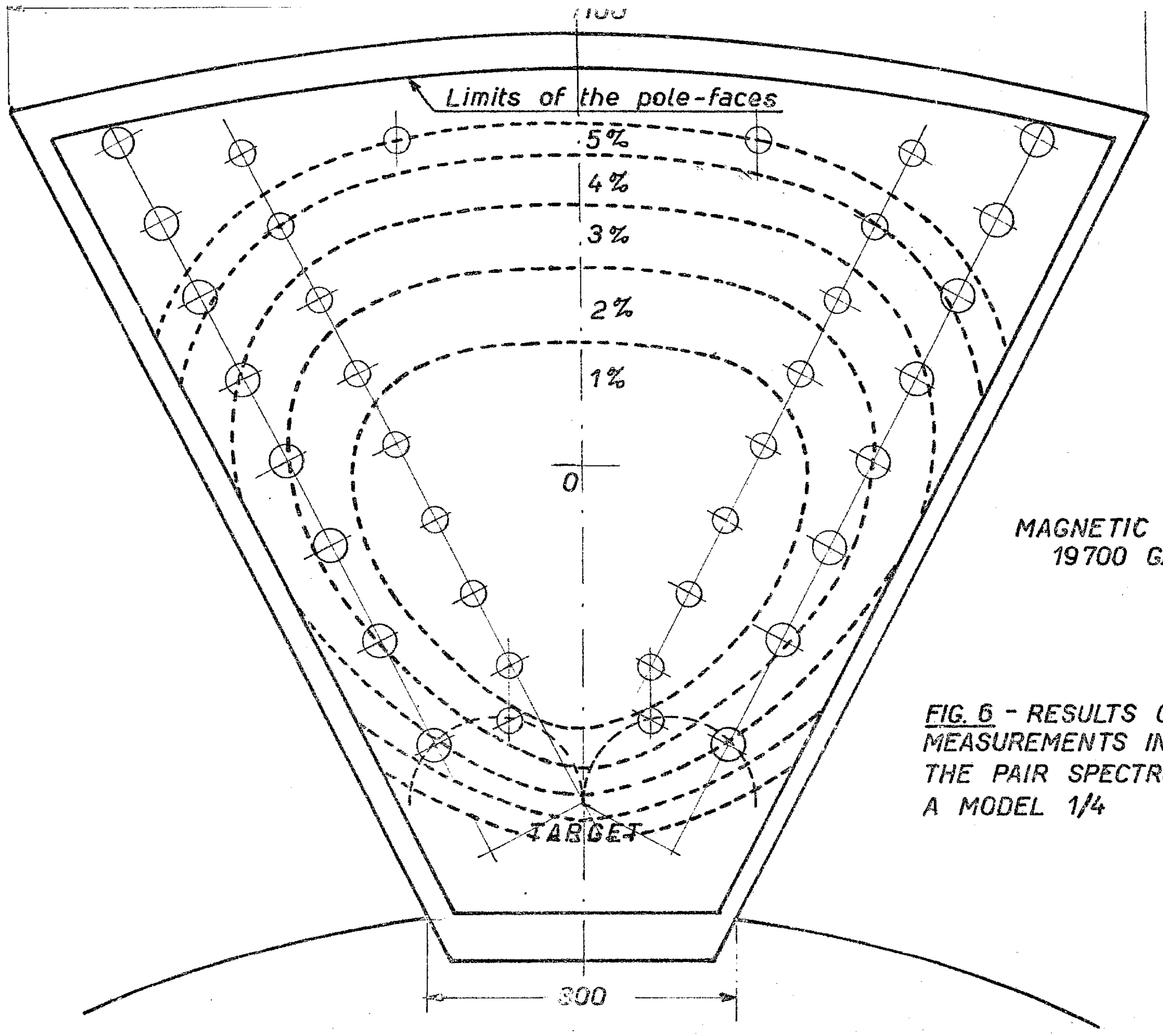


FIG. 4 - RESULTS OF MAGNETIC MEASUREMENTS IN THE GAP OF THE PAIR SPECTROMETER ON A MODEL 1/4



MAGNETIC FIELD
18000 GAUSS

FIG. 5 - RESULTS OF MAGNETIC MEASUREMENTS IN THE GAP OF THE PAIR SPECTROMETER ON A MODEL 1/4



MAGNETIC FIELD
19700 GAUSS

FIG. 6 - RESULTS OF MAGNETIC MEASUREMENTS IN THE GAP OF THE PAIR SPECTROMETER ON A MODEL 1/4

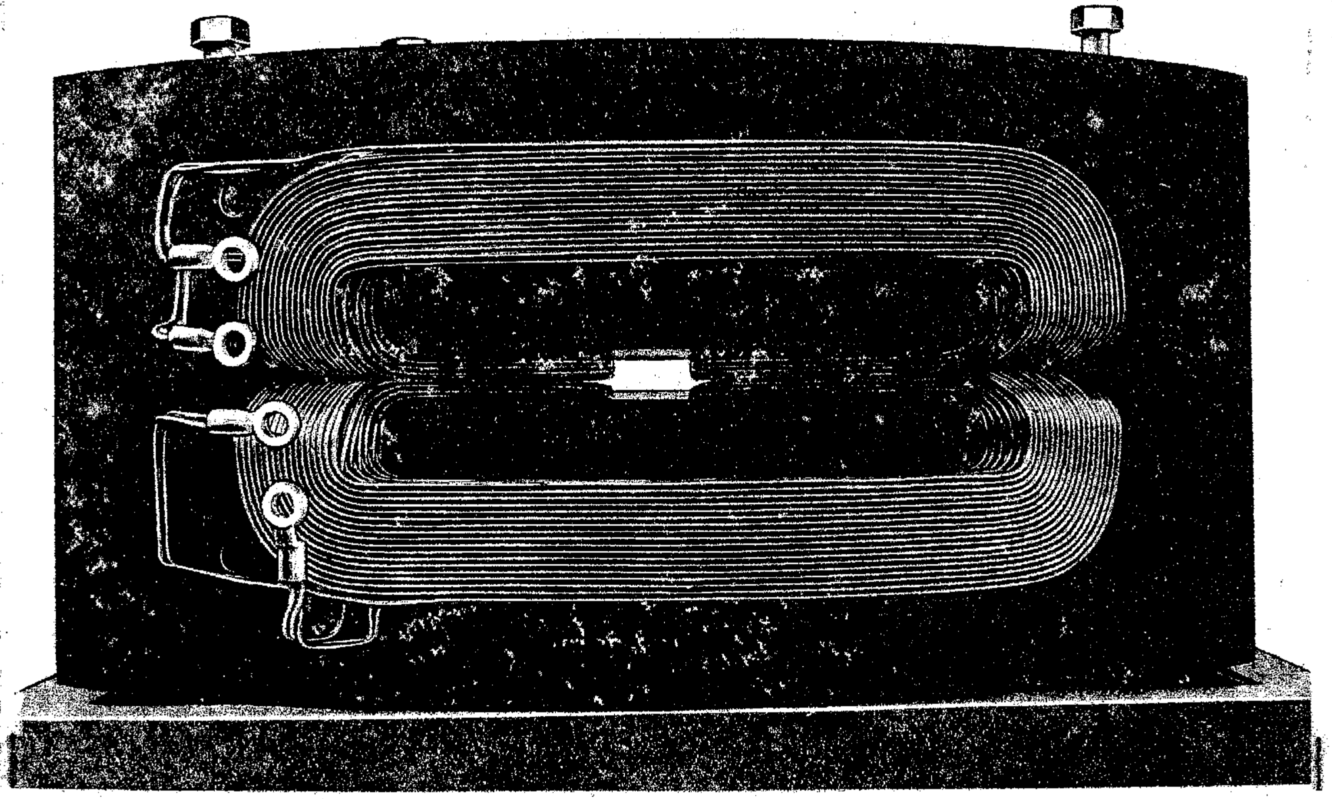


FIG. 7

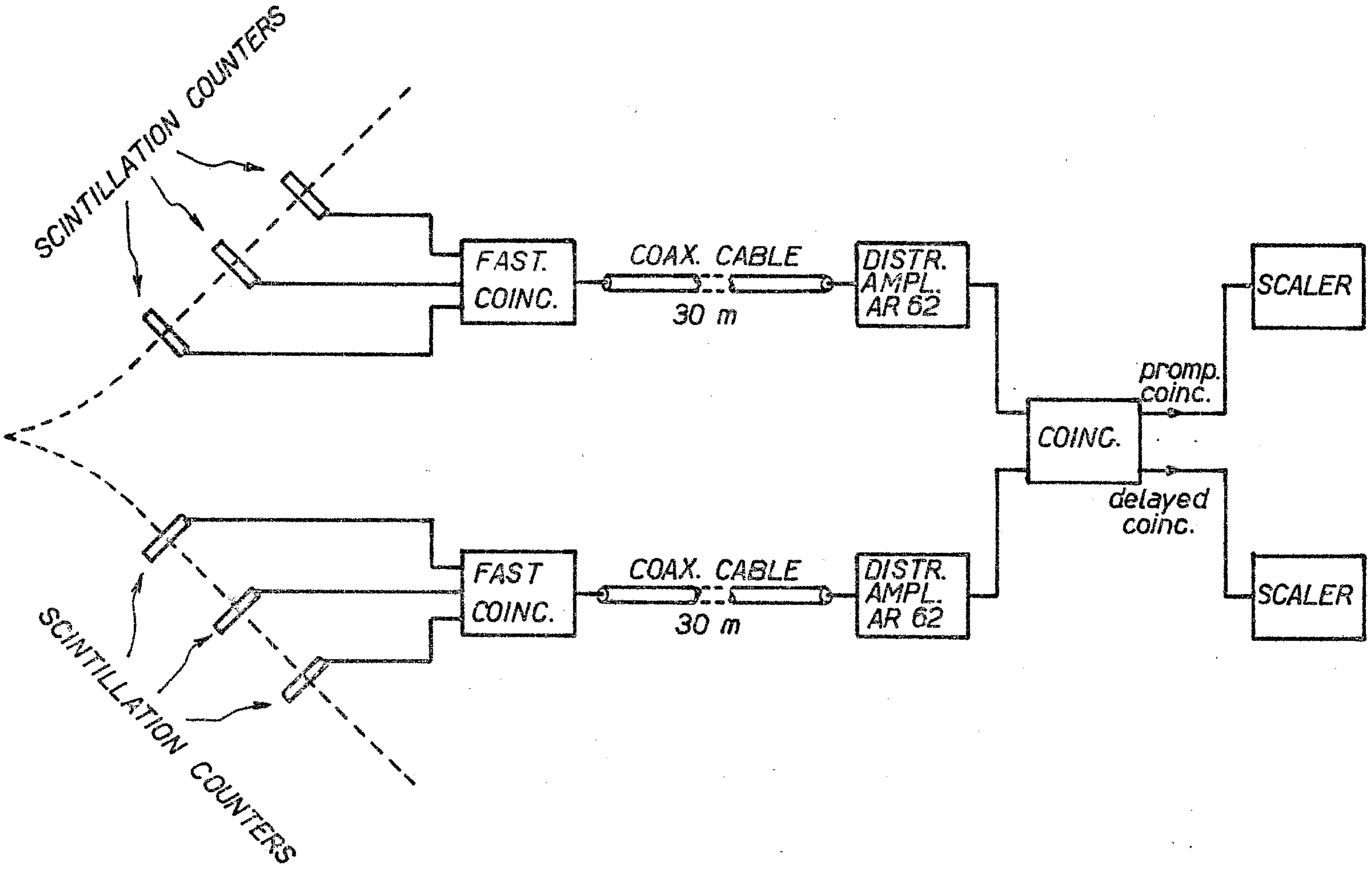
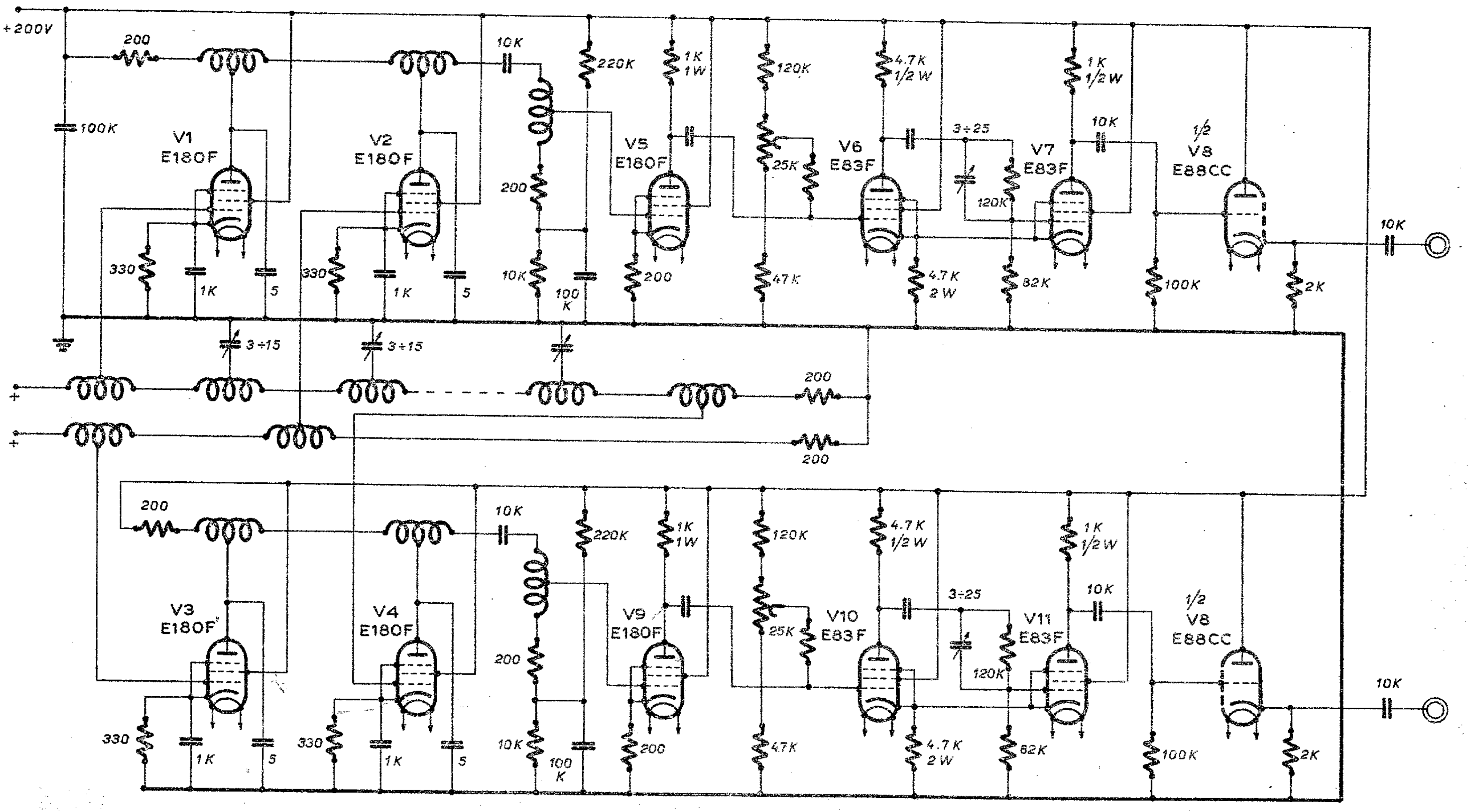

SCINTILLATION COUNTERS
FAST. COINC.
COAX. CABLE
30 m
DISTR. AMPL. AR 62
COINC.
promp. coinc.
SCALER
delayed coinc.
SCALER
DISTR. AMPL. AR 62
COAX. CABLE
30 m
FAST COINC.
SCINTILLATION COUNTERS

FIG. 8


+200V
200
100K
V1
E180F
330
1K
5
V2
E180F
330
1K
5
10K
200
10K
220K
100
K
V5
E180F
1K
1W
200
120K
25K
47K
V6
E83F
4.7K
1/2 W
4.7K
2 W
3÷25
120K
V7
E83F
1K
1/2 W
82K
10K
1/2
V8
E88CC
100K
2K
10K
3÷15
3÷15
200
200
+
+
200
V3
E180F
330
1K
5
V4
E180F
330
1K
5
10K
200
10K
220K
100
K
V9
E180F
1K
1W
200
120K
25K
47K
V10
E83F
4.7K
1/2 W
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2 W
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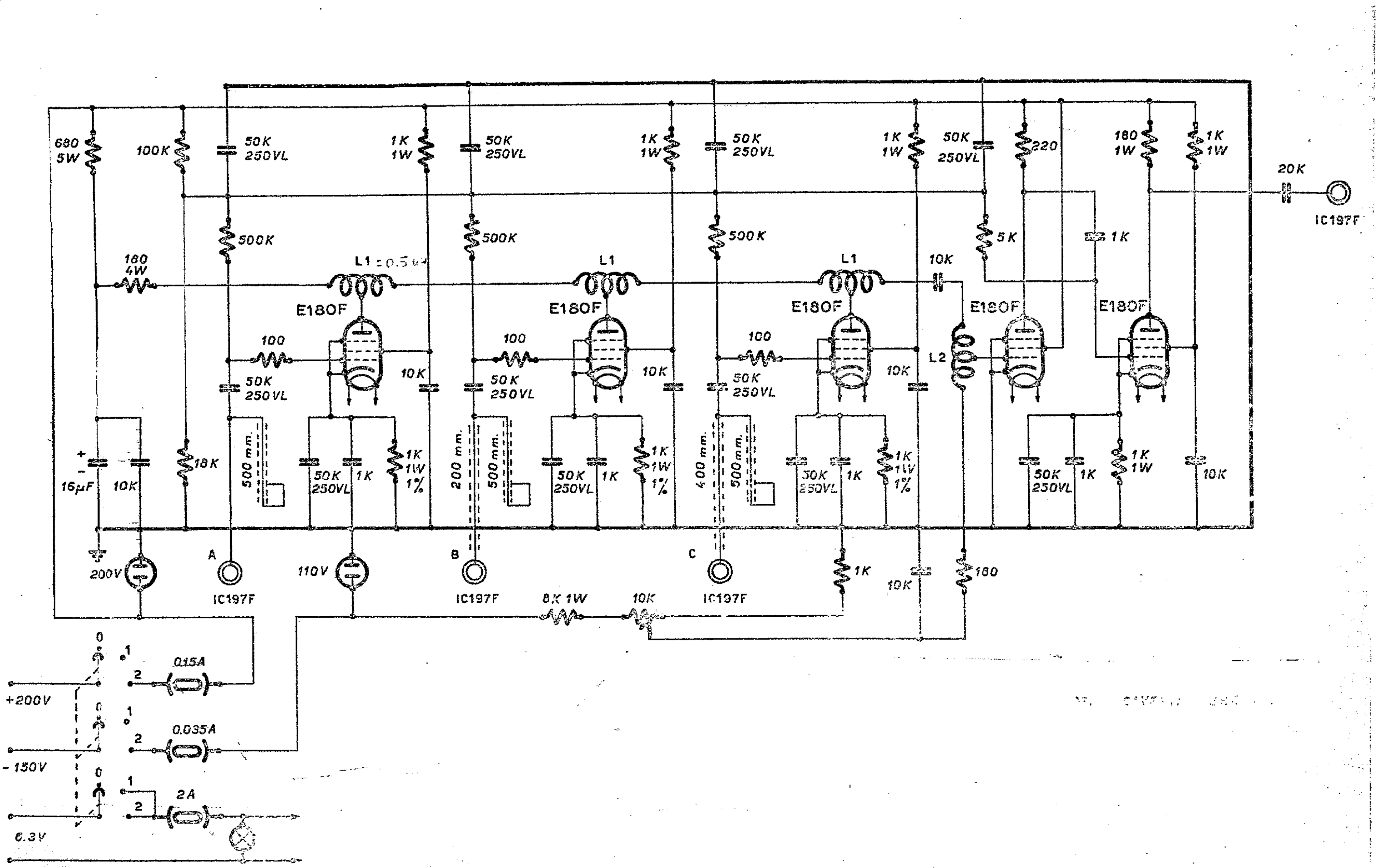
680
5W
100K
50K
250VL
500K
180
4W
L1 = 0.5 µH
E180F
100
1K
1W
10K
16µF
18K
500 mm.
1K
1%
200V
A
IC197F
110V
B
C
200 mm.
400 mm.
L1
L2
220
5K
20K
8K 1W
0.15A
0.035A
2A
+200V
-150V
6.3V
0
1
2

FIG. 9