Logarithmic DC-Amplifier with Earth-Isolated Input

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Abstract

In order to observe the current of an earth-isolated double-probe on the plasma-column, an intermediate stage amplifier was built which enabled the survey of DC-current in the range of 10^{-5} and 10^{-9} A in logarithmic scale on a grounded oscilloscope. The earth-isolation of the measuring probe is guaranteed with $R = 10^{12}\,\Omega$, C = 15 pf.

This amplifier also can be adapted for other linear measurements on abjects which ask for a potential separation towards the grounded oscilloscope.

In the Institute for Plasmaphysics in Garching a logarithmic DC-amplifier was developed which has an input completely isolated from ground. This amplifier is determined for monitoring the current of a double-probe on a plasma column. The current range covers 10^{-5} to $1o^{-9}$ amps. The frequency response is DC to 1 kcps.

The set consists of a transmitter and a receiver (fig. 1).

Transmitter

It consists of an operational amplifier with logarithmic feedback loop and a frequency-modulated oscillator. Both units are fed by batteries. The total leakage to the grounded case is approx. 10^{12} ohms paralleled with 15 picofarads.

a) Logarithmic Converter

A miniature built in battery produces the current for the plasma probe. This current flows into the input impedance of 1 Megohm. The corresponding voltage has to be logarithmized. This can be done by different means. One method is to use a logarithmic voltage divider (figure 2) where "D" is a diode with true exponential characteristic. This component "D" has to be of low impedance relative to R_S and R_L for true logarithmic response. At very small currents normal diodes have a large resistance hence R_L and R_S ought to be very large resistance values.

This problem can be solved better by incorporating the logarithmic component in the feedback loop of an operational amplifier (figure 3). Tests with various values of the series resistor R_S showed a rather small loading effect for the logarithmic component (a zener diode ZF 3,8 in forward direction).

Further progress brought an article of W.L. Paterson: "Multiplication and Log. Conversion by Operational Amplifier Transistor Circuits", Rev.Sc. Instr., Vol. 34 No. 12, Dec. 63. with a carefully selected transistor the input current may run over some 10 decades with satisfactory logarithmic response.

With a transistor 2N 697 we measured the response of figure 5 which was accurate enough for our DC measuring purpose. Yet for fluctuation of the input current (AC) the junction capacitance as well as wiring capacitances have a large influence. Hereby the internal resistance of the semi-conductor is changing (simultaneously)with the passing current and this results a greater time constant at smaller currents.

In figure 6 several oscilloscope traces were superimposed, with input current steps of 10 to 1 ratio. The step function 10^{-5} to 10^{-6} amps yields a time constant 0,1 msec, the current step 10^{-8} to 10^{-9} (amps) shows already a 12 msec time constant.

b) FM-Oscillator

A freerunning multivibrator with a tank circuit in one collector lead was used as an oscillator. It proved to be very simple and sufficiently stable. The frequency is controlled by means of a silicon capacitance diode; its value is given by the output voltage coming from the logarithmic converter.

The oscillator signal is coupled out by a secondary winding, which is connected to case. The leakage between primary and secondary winding establishing the insulating impedance to ground is satisfactorily high.

Receiver

It is a conventional 1o,7 mcps IF-amplifier with four stages. The bandwidth is ± 35o kcps. The amplified signal is demodulated by a frequency discriminator. The output signal amounts to a maximum of ± 0,5 v.

Measurement Results

The signal after demodulating is 48 mv per input current decade. It may be connected directly to oscilloscopes with 1 Megohm input impedance.

In order to set a survey of the operating range a current signal with exponential decay (time constant 1 msec) is fed into the input of the log. amplifier. From figure 7 we can see that the system response is truely logarithmic for the range 10^{-5} to 3 x $1o^{-9}$ amps. Below this value it starts to be crooked, although the values of the DC-current are fixed in equal distances on the calibration line.

Appendix

Without the logarithmic part the set can be used as a linear amplifier with earth-free input.

The dielectric strength of the insulation is approx. 5 kv. The input voltage can directly be connected to the modulator; in this case the modulator-voltage-swing of o.5 v causes a frequency deviation of ± 160 kHz resulting in a demodulation voltage at the receiver output of ± 0.4 v. Deviation from linearity is below 1 per cent. The bandwidth of the transferred signal is 0...1 kHz.

(3 db at 2.5 kHz). The zero-stability is 1 mv per 10 minutes.

The power supply for the transmitter, a separate unit, is well isolated and of low-capacitance to case placed in the transmitter case. It consists of two 15 v storage batteries. The receiver is fed from the mains. The calibration voltage source is placed in the receiver unit too. Only for calibration it is connected with the transmitter by using a cable which must be removed during operation for guaranteeing the earth-isolation of the transmitter.

The complete wiring diagram of the log. DC-amplifier with earth-free input is shown in figure 8.

This work was performed under the terms of the agreement on association between the Institut für Plasmaphysik and EURATOM.

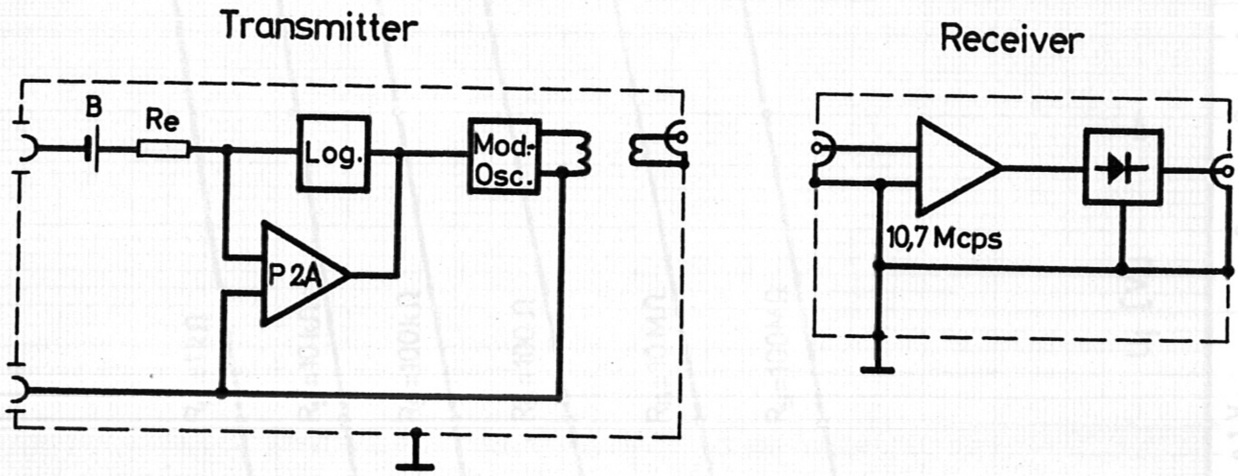

Transmitter
B
Re
Log.
Mod.-
Osc.
P 2A
Receiver
10,7 Mcps

Fig.1

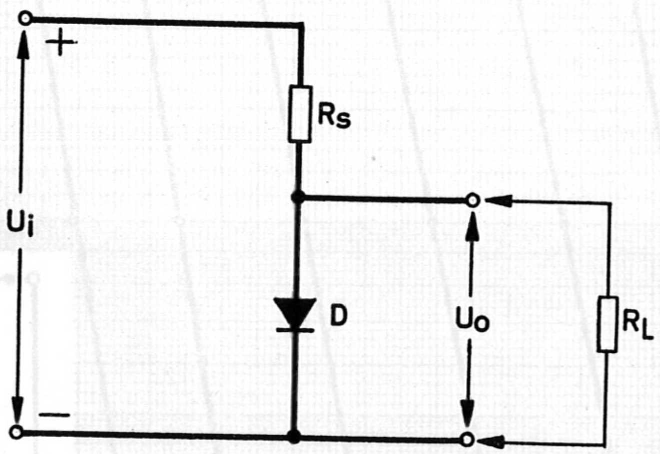
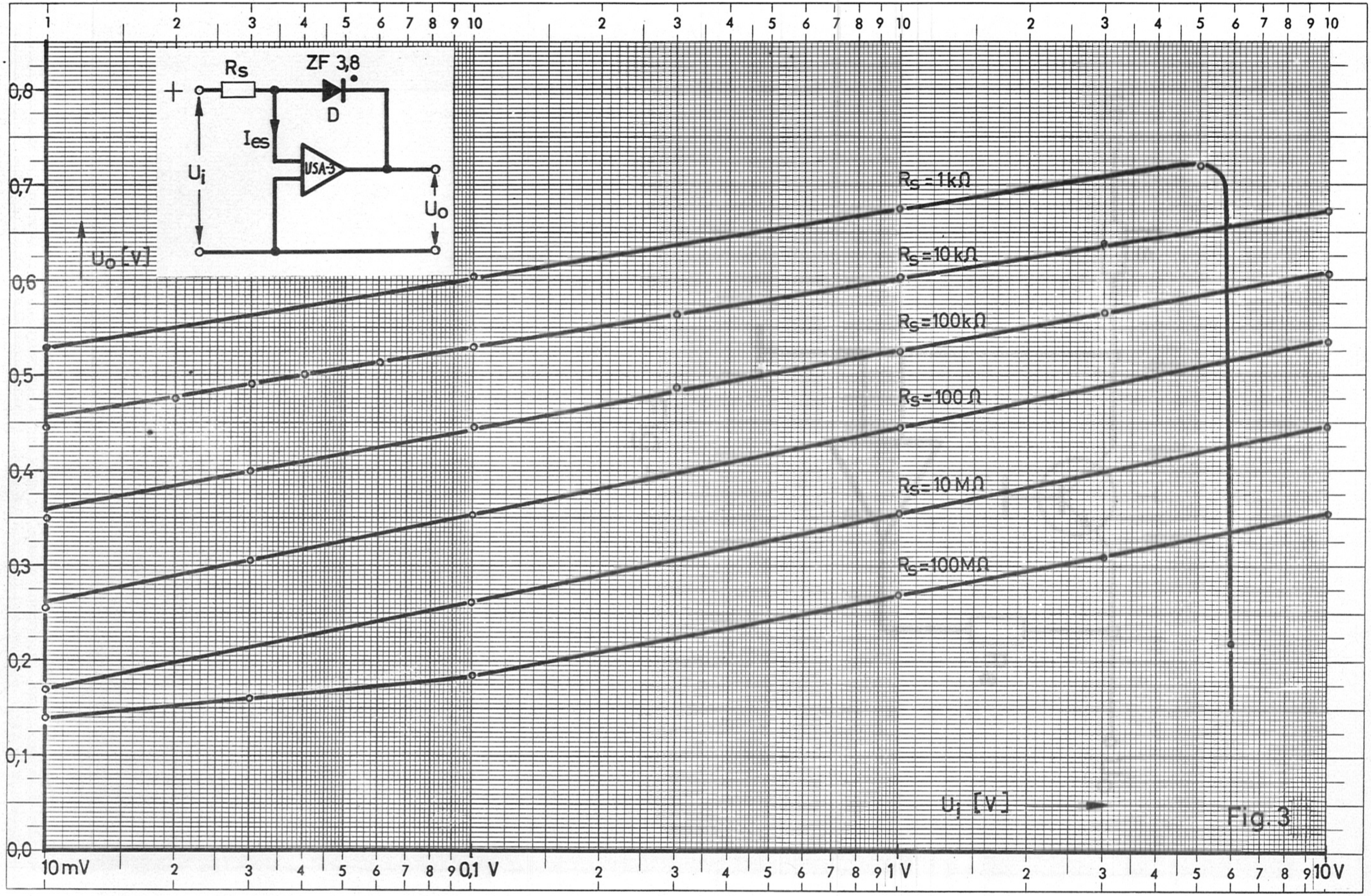

+
Rs
Ui
D
Uo
RL
−

Fig.2



Rs
ZF 3,8
D
Ies
USA-3
Ui
Uo
Uo [V]
Rs = 1 kΩ
Rs = 10 kΩ
Rs = 100 kΩ
Rs = 100 Ω
Rs = 10 MΩ
Rs = 100 MΩ
Ui [V]
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
10 mV
0,1 V
1 V
10 V

Fig. 3

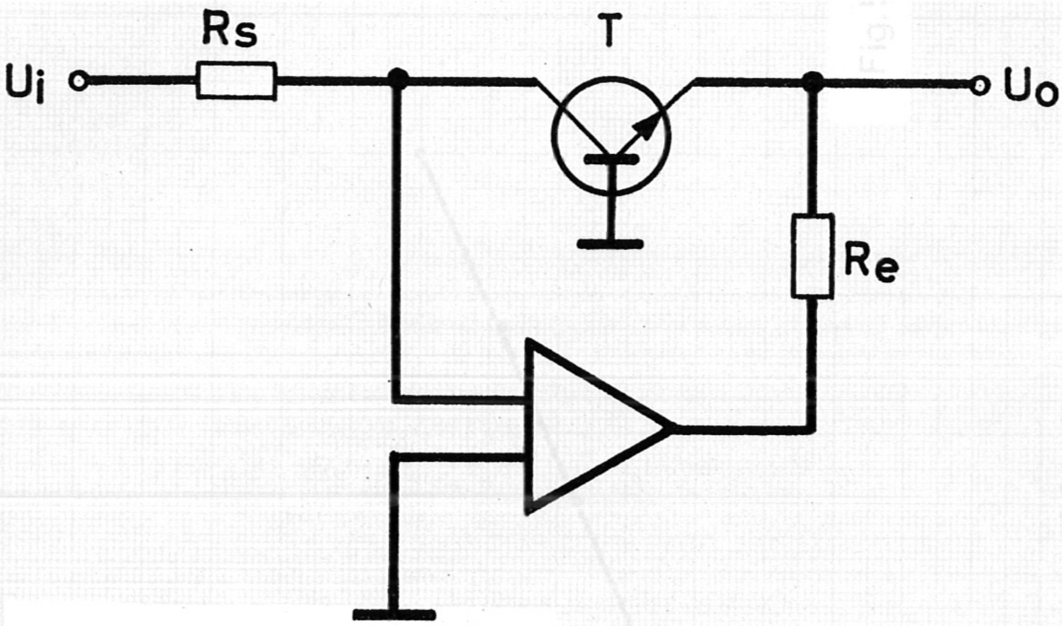


Fig.4

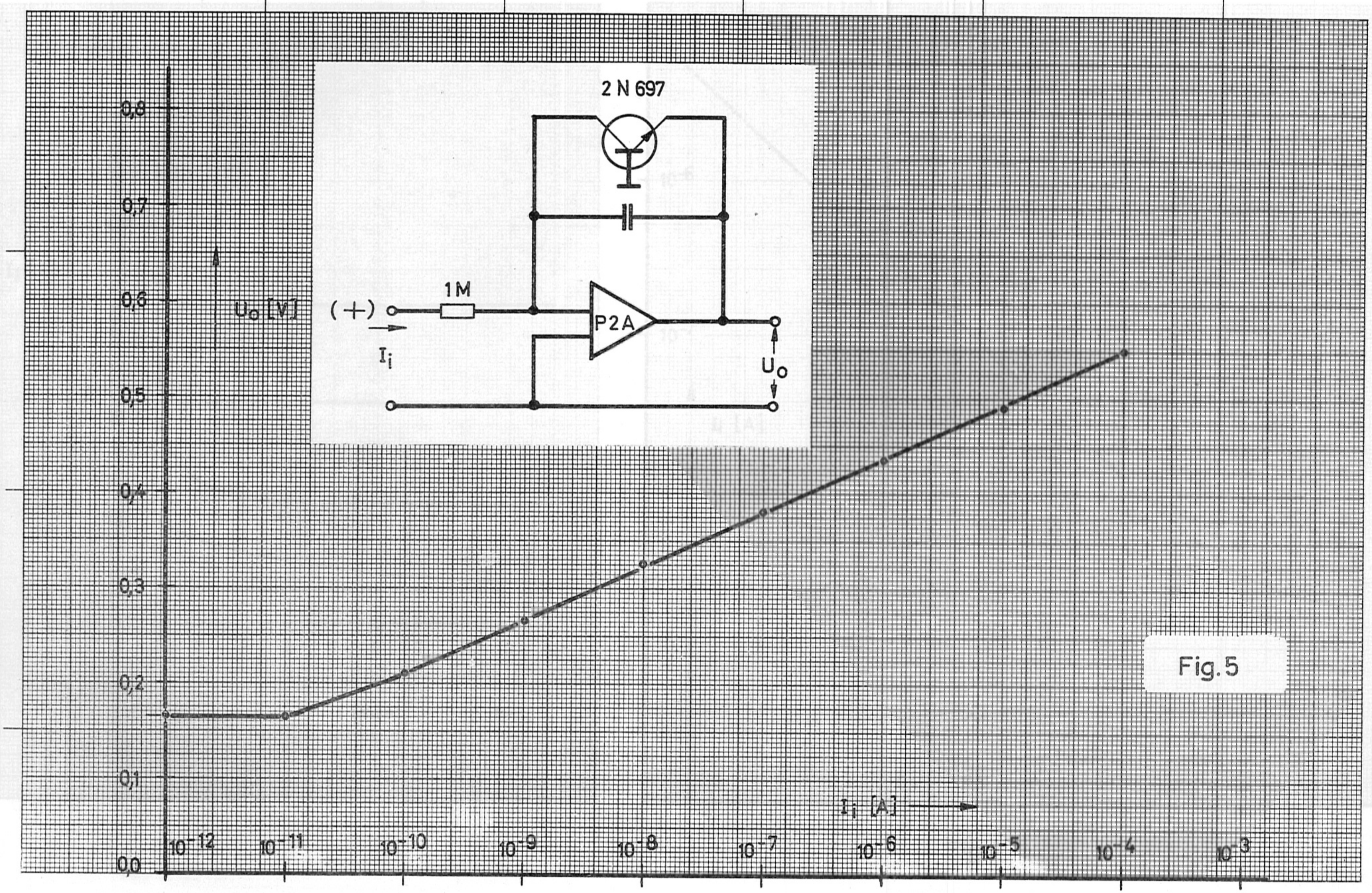
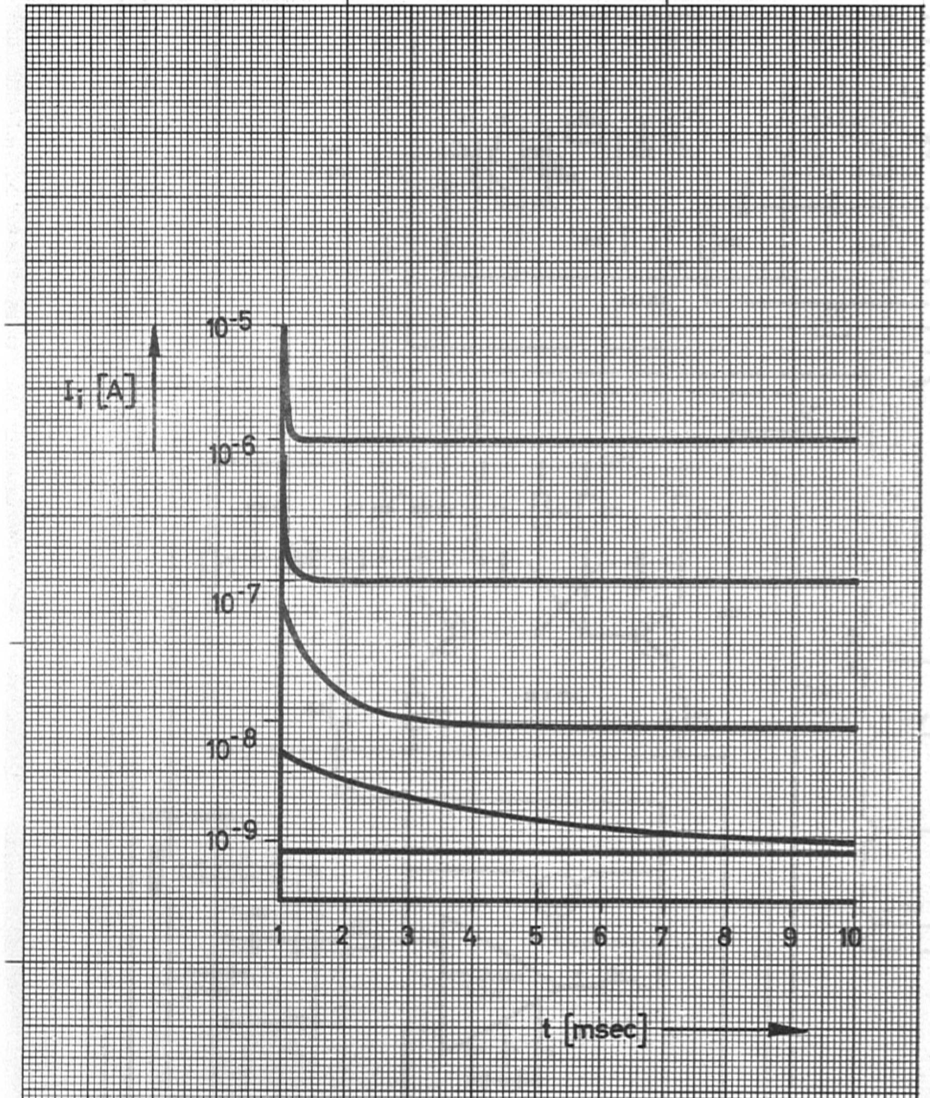
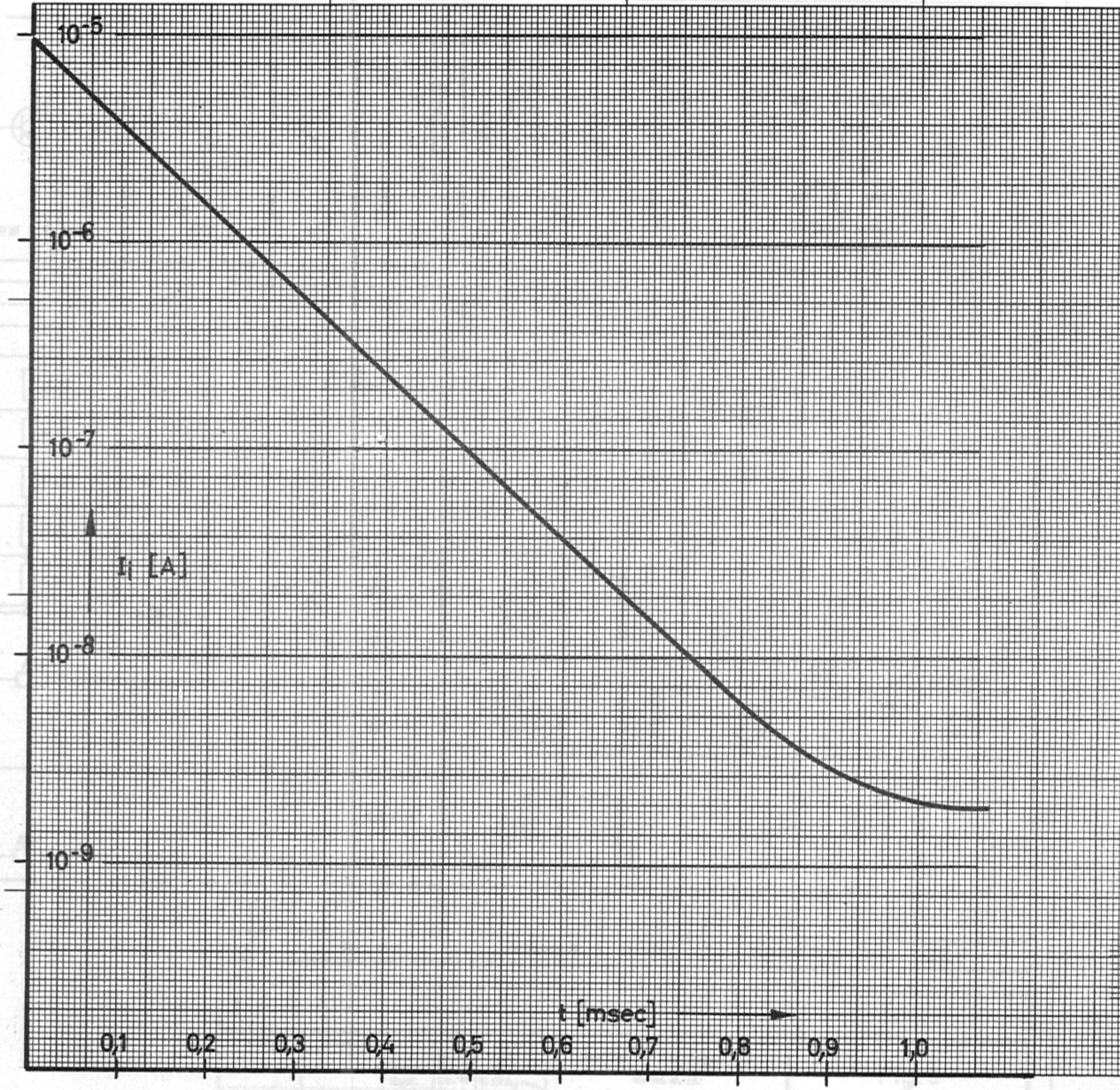

2 N 697
1 M
(+)
I_i
P2A
U_o
U_o [V]
I_i [A]
0,0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
10^{-12}
10^{-11}
10^{-10}
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}

Fig. 5



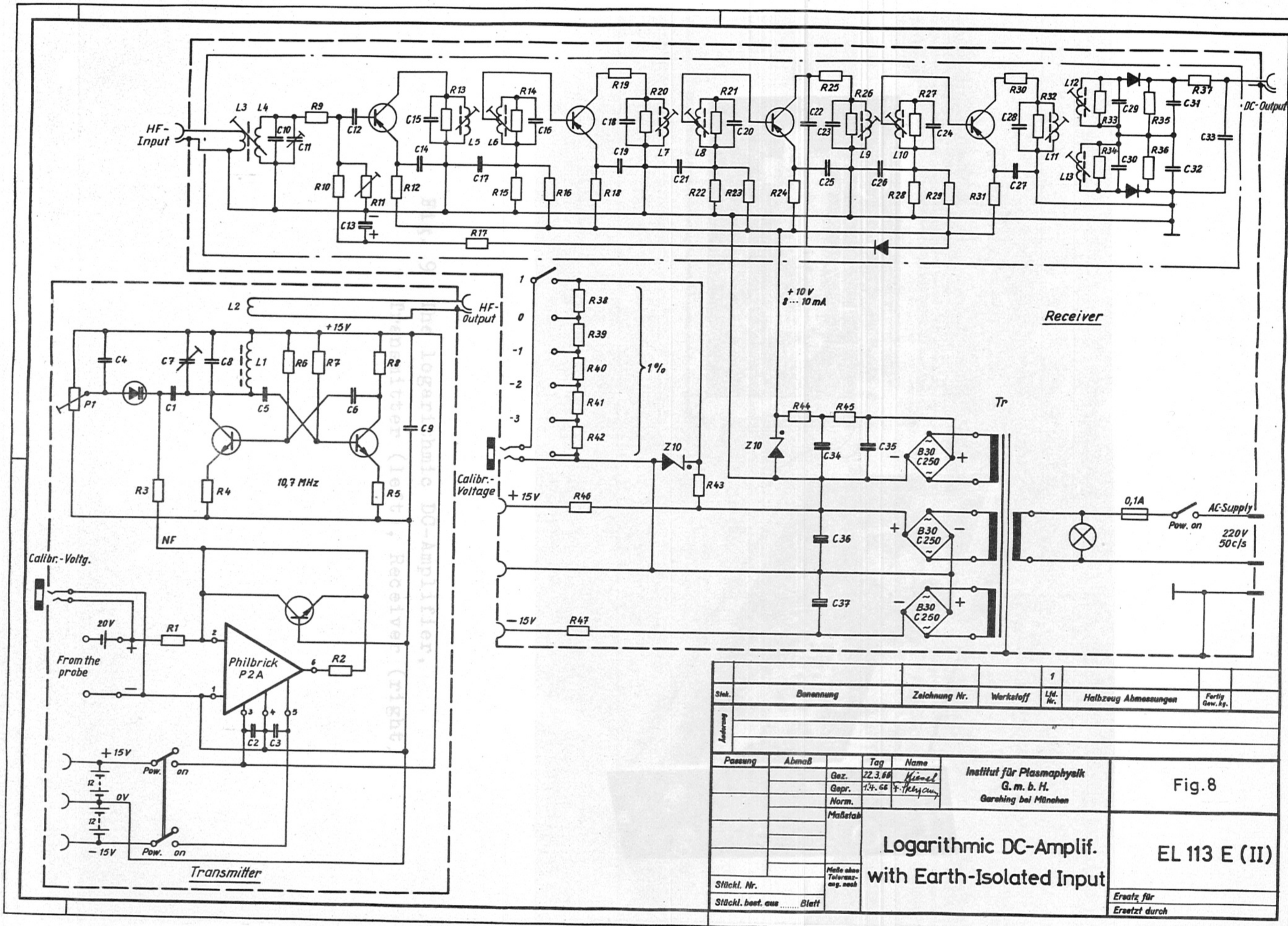
I_i [A]
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
1 2 3 4 5 6 7 8 9 10
t [msec]

Fig.6



10^{-5}
10^{-6}
10^{-7}
I_i [A]
10^{-8}
10^{-9}
t [msec]
0,1 0,2 0,3 0,4 0,5 0,6 0,7 0,8 0,9 1,0

Fig.7


HF-Input
DC-Output
Receiver
+10 V
8 … 10 mA
HF-Output
+15V
10,7 MHz
NF
Calibr.-Voltg.
From the probe
Philbrick P2A
Transmitter
Calibr.-Voltage
+15V
−15V
1%
Tr
B30 C250
0,1A
Pow. on
AC-Supply
220V 50c/s
Benennung
Zeichnung Nr.
Werkstoff
Halbzeug Abmessungen
Institut für Plasmaphysik G. m. b. H. Garching bei München
Gez. 22.3.66
Gepr. 1.4.66
Fig. 8
Logarithmic DC-Amplif. with Earth-Isolated Input
EL 113 E (II)

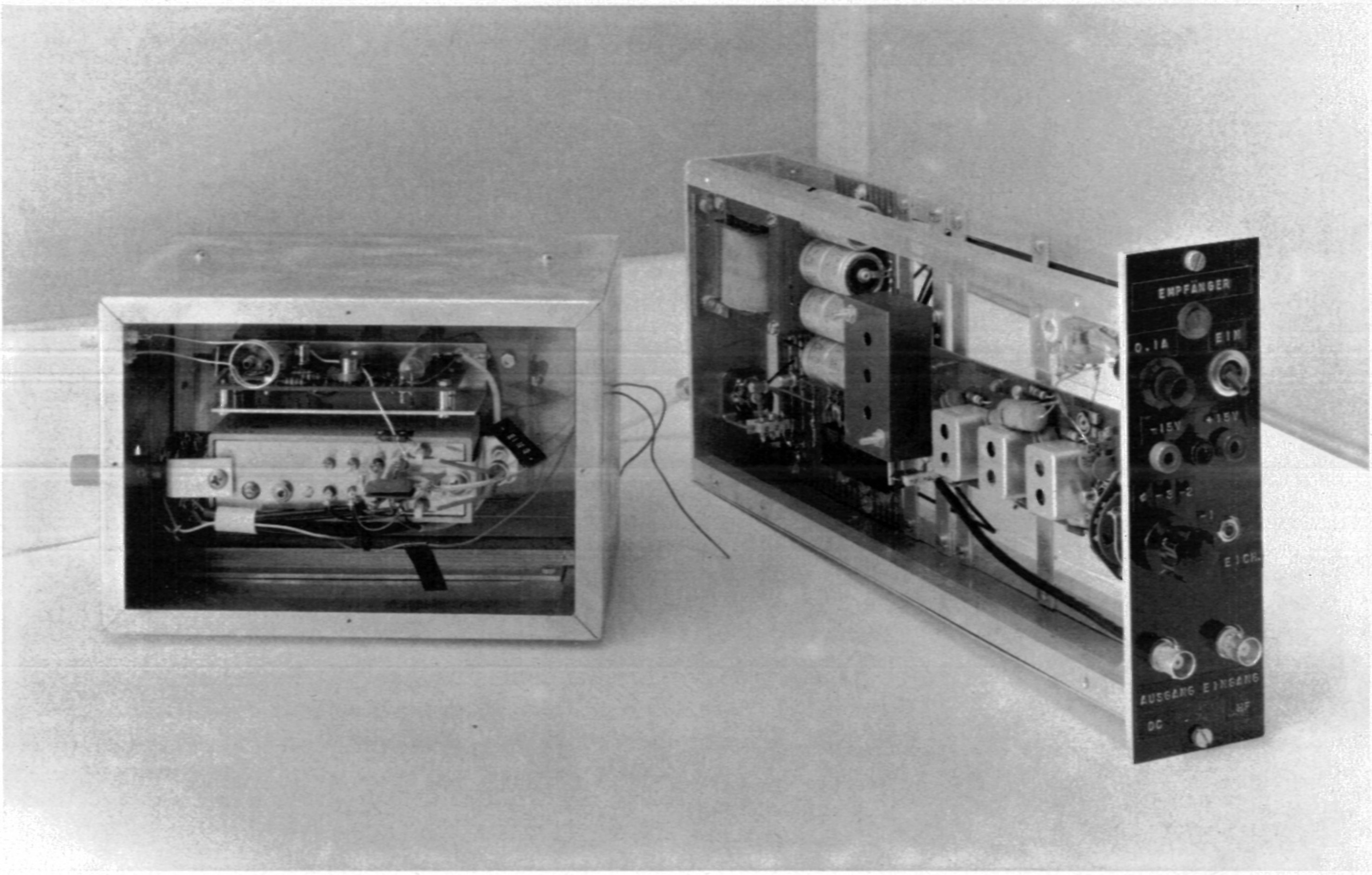


Fig. 9 The logarithmic DC-Amplifier,
Transmitter (left), Receiver (right)