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NEW RF - AMPLIFIER

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1. INTRODUCTION

The final power amplifier is one part of the new RF system. It is designed to operate in the frequency range between 2.5 and 10 MHz and to supply the accelerating voltage of 2 x 10 kV peak at the gaps, delivering the real power for the ferrites and for the beam, as well as the reactive power for an accidental or deliberate detuning of the cavity. The complete electric circuit of the power amplifier is shown in fig. 1.

2. CIRCUIT DESCRIPTION

2.1 The tube

The amplifier is built around a RS 1084 CJ. This tube is a water-cooled transmitting tetrode of ceramic and metal construction and coaxial terminal design. It can dissipate 70 kW. The amplifier operates in a grounded cathode circuit configuration in class AB, with a quiescent current of 0.5 A but can be driven up to a plate current of 10 A. The limits of the amplifier are shown in fig. 2 for operation with detuned cavity (requirement for additional stabilisation with high beam current). Under normal conditions, the tube has to deliver less power and it is hoped that the tube life expectancy can be substantially increased [1)].

2.2 Input filter and terminating resistance

The input of the amplifier is matched to the incoming drive cable with a characteristic impedance of 50 ohms by means of a band-pass network with Chebyshev characteristic with a maximum reflexion factor of $\Gamma = 7\ \%$. The design and the realization is described in detail in [2)]. The results are shown in fig. 5 and fig. 6, which show the measured reflexion coefficient and the transfer function between the input of the filter and the control grid.

The filter is terminated with a water-cooled resistance which can dissipate a maximum power of 5 kW and gives therefore a generous safety margin as compared to the maximum driver power of 1.5 kW. As the upper operating frequency of 10 MHz is relatively low, satisfactory reflexion coefficient and power distribution could be achieved by a cylindrical outer envelope, forming a constant 25 ohms impedance with the cylindrical resistor itself : a conical outer conductor could thus be avoided.

Furthermore the filter contains two voltage dividers. The first one is of use for the control of the grid bias, the second one serves for the measurement of the RF voltage at the grid for the phase discriminator. A terminating resistor of 50 ohms is provided to match the cable impedance; as the divider is therefore capacitive-resistive, the sample of the RF signal is frequency dependent.

Trouble was experienced with the feeder for the grid-bias. Condenser C18 and resistor r 4 had to be replaced by higher-rating elements to give satisfactory performance. In addition, the original sliding contact of the tuning capacitor C20 had to be bridged by a litzwire to avoid phase jumps caused by bad contacts due to oxydation of the contact-surface.

2.3 Neutralization

The positive feedback due to the internal anode-to-grid capacitance and some external stray capacitors associated with an equipment of this size, some additional unwanted coupling conductances both in the input and in the output circuit will occur, causing possibly the amplifier to oscillate and causing distortion in the pass-band of the filter.

The influence of the capacitive feedback can be shown, if we display the variation of the grid voltage by detuning the output circuit. Without feedback, the grid-voltage would not change, but as we can state a rather high influence, neutralization of the amplifier will be required. In figs 7 and 8 is this variation shown, in the first picture without, in the second one with neutralization.

The neutralization is obtained by feeding a sample of the anode voltage back to the grid via the neutralizing capacitor C20 and the wide-band transformer

T1 to provide the necessary phase reversal for negative feedback.

The influence of the capacitive feedback and the compensation by neutralizing the amplifier can be seen too in figs 9 and 10. These pictures show the frequency response of the grid voltage without and with neutralization, when the amplifier is fed by a constant amplitude at the anode.

The low impedance due to the series resonance of T1 and C20 causes the amplifier to oscillate at a frequency of 38 MHz. In order to overcome this oscillation, both a shunt-tuned circuit L3C10 in series and a series-tuned circuit L6C19 in parallel to the transformer have been added.

2.4 Coupling capacitors

The output circuit, which in fact is the tuned cavity, is fed by the tube via the coupling capacitor C23, which consists of 6 capacitors in parallel, which have both high current ratings and rather high voltage ratings. Nevertheless it turned out, that there occurred regularly flash-overs, when the atmospheric humidity was rather high. By adding spacing pieces, the difficulties could be removed to a great deal. Another possibility of improvement (to avoid the capacitor to condensate) is to coat the surface of the capacitor by a silicone.

2.5 Output filters

The dc anode supply is fed through the RF choke L9 and it forms together with the blocking capacitor C24 a low-pass filter. To reach a good attenuation of the RF, the inductance should be as high as possible, but on the other hand, there will occur some more undesired resonances, which may excite the cavity at future high beam intensities. For this reason, we had to make a compromise. As the RF was in this case not sufficiently attenuated, a second LC-filter was mounted outside the proper amplifier. As far as the undesired resonances are concerned, they can be overcome by coating the copper wire by certain alloys. In fig. 11, is shown the output impedance of the amplifier with the different resonances due to the choke and stray capacitances. The effect of coating the wire with different alloys is shown in fig. 12, where is plotted the quality factor of blank copper wire and on the other hand, the same wire coated with certain alloys vs frequency.

The anode voltage is sensed by means of a voltage divider r1 r2.

2.6 Miscellaneous

As the power output from a tetrode is very sensitive to screen voltage, the screen is fed from a well regulated power supply via a feedthrough capacitor C29 and a choke L8. It must be pointed out that in power tetrodes it is quite normal that a reverse electron flow due to secondary emission will occur. For this reason, a low impedance path must be provided for the reverse electron flow, otherwise the screen voltage will attempt to rise in an impredictable manner. By the addition of the resistor r11, the emission current is counteracted.

2.7 Cooling

The tube is cooled by demineralized water, thereby preventing large deposits forming on the anode. As the water must undergo a change in potential, a porcelain water coil is used. Fig. 4 shows the cooling diagram of the power tube without and with the pression drop of the water coil. Although it was suggested to connect the coil to the tube by a flexible metal hose, the coil had to be isolated from the power tube, otherwise there occurred dry flashovers.

To ensure that the tube is never operated without or with insufficient cooling, the amplifier is provided with a system of interlock. The correct flow of water is controlled by means of two flow relays, with an interrupting contact, which switch off all voltages as long as the flow of water is inadequate in either the tube or in the termination. Furthermore, to avoid thermal overloading when detuning the amplifier, the difference between the inlet and outlet water temperature is measured by means of two thermistors. In this case, as soon as the difference of temperature exceeds a set value, the interlock will only switch off the anode voltage. In addition, the socket of the tube is cooled by a forced draught of air by means of a blower. Its correct operation is controlled by a self-heated thermistor.

3. MECHANICAL ASPECTS

3.1 Connections

As the amplifier is mounted in a plug-in unit, most of the electrical connections are made by plug-in connectors, in particular the high voltage contacts, the RF contact to the cavity and the contacts for the filament. The RF cables and the control cables are connected by hand.

As far as the connection of the demineralized water is concerned, it is done by too quick release fittings.

3.2 Mechanical assembly

Fig. 13 shows the front view of the amplifier. It shows on the right side the power tube and all component parts, related to the output circuit, e.g. coupling capacitors, blocking capacitors, the choke, the neutralizing capacitor. On the left side, is seen the water coil, which is connected to the tube by isolating hoses and in front two flexible hoses with the quick-release fittings.

Fig. 14 shows the bottom view with in particular the filter.

4. REFERENCES

1) J. Buttkus - "Investigation to increase life expectancy of power tube RS 1084 CJ" - MPS/SR/Note 73-18.

2) Level diagram.

Distribution (of abstract)
PS Scientific Staff

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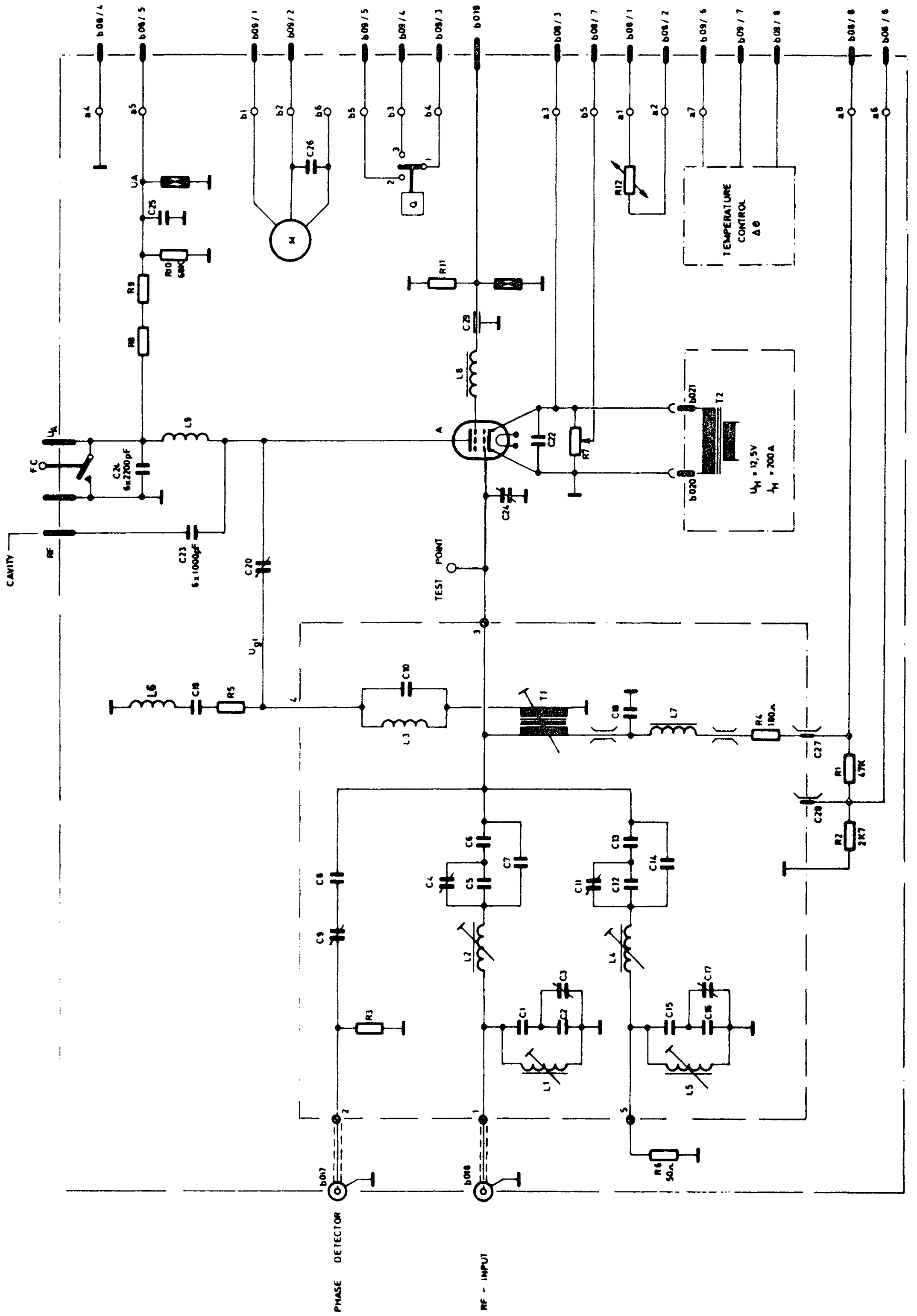
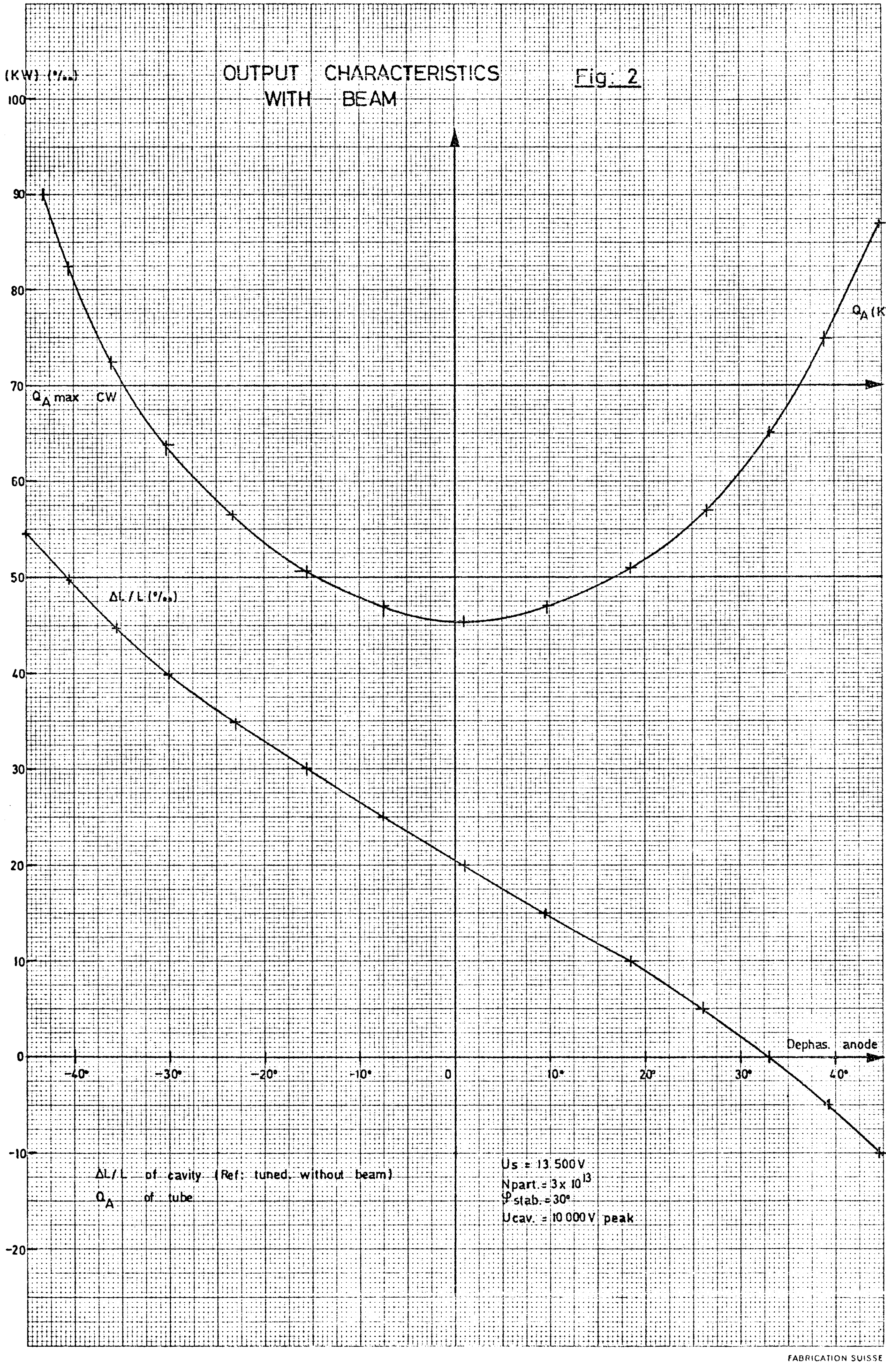
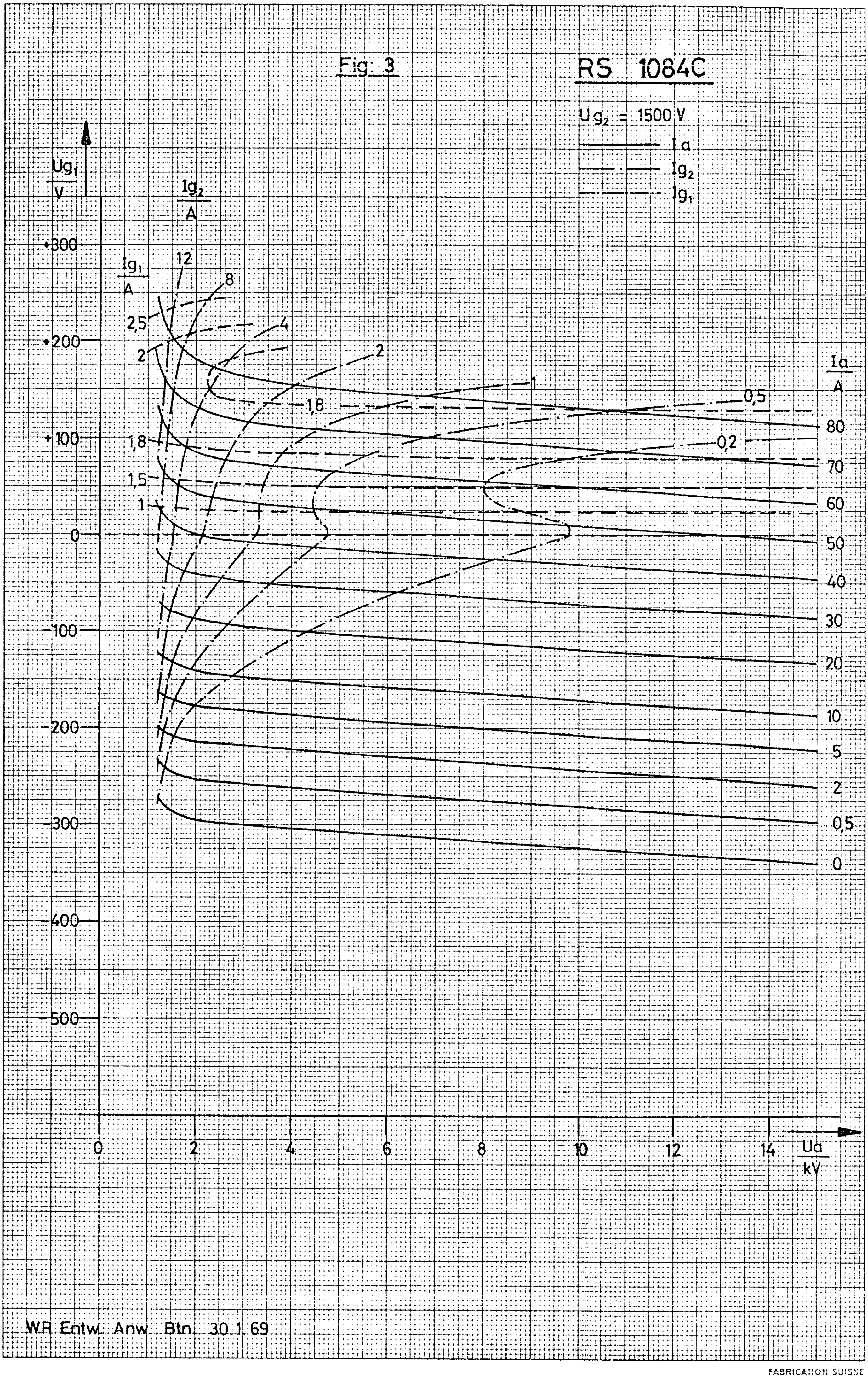
Fig: 1



TEMPERATURE CONTROL
TEST POINT
CAVITY
PHASE DETECTOR
RF - INPUT

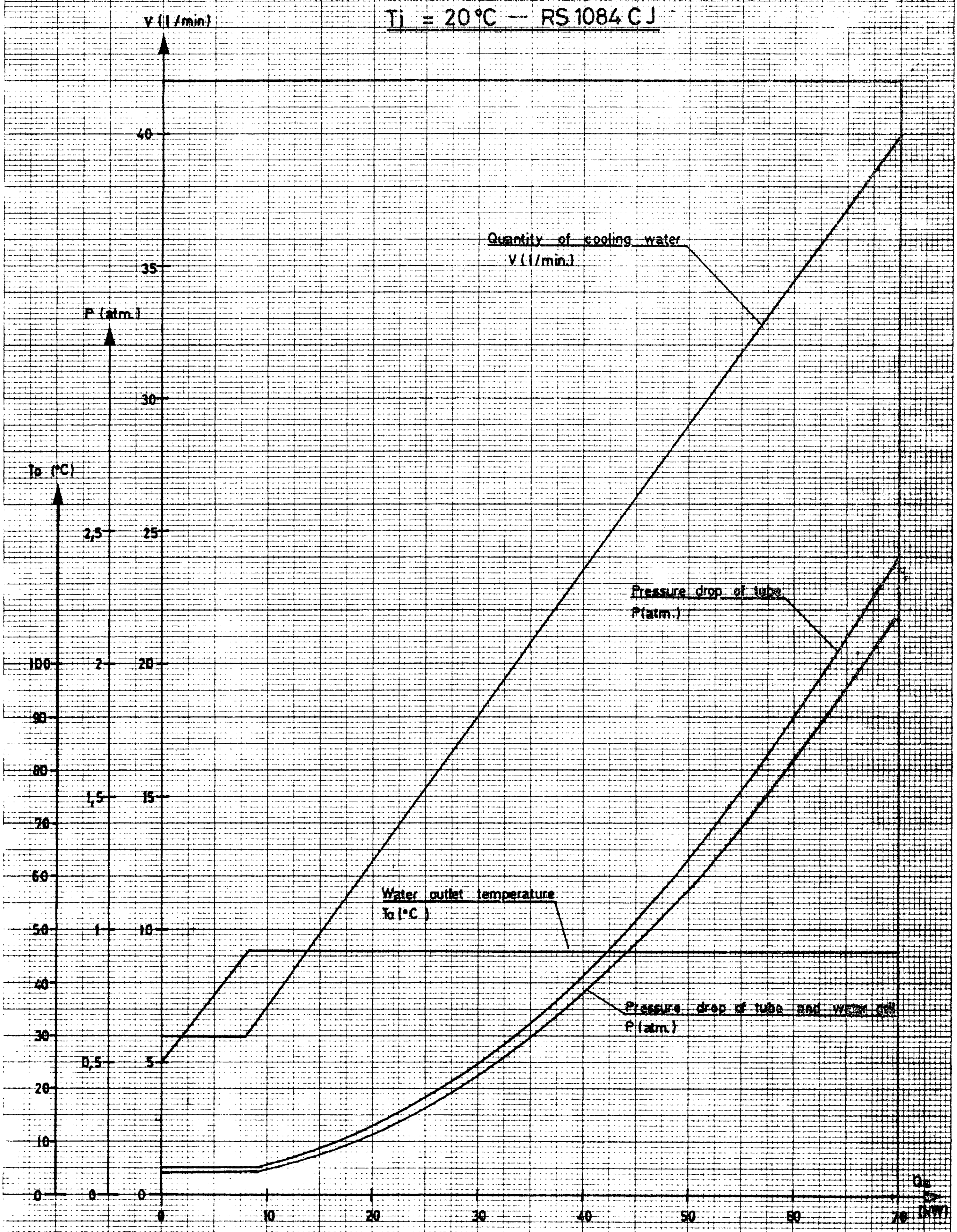

OUTPUT CHARACTERISTICS
WITH BEAM
Fig. 2
(KW) (‰)
100
90
80
70
60
50
40
30
20
10
0
-10
-20
Q_A (KW)
Q_A max CW
ΔL / L (‰)
-40°
-30°
-20°
-10°
0
10°
20°
30°
40°
Dephas. anode
ΔL / L of cavity (Ref: tuned, without beam)
Q_A of tube
Us = 13.500 V
Npart. = 3 x 10^13
φ stab. = 30°
Ucav. = 10 000 V peak



FABRICATION SUISSE

COOLING DIAGRAM
water inlet temperature

Fig : 4



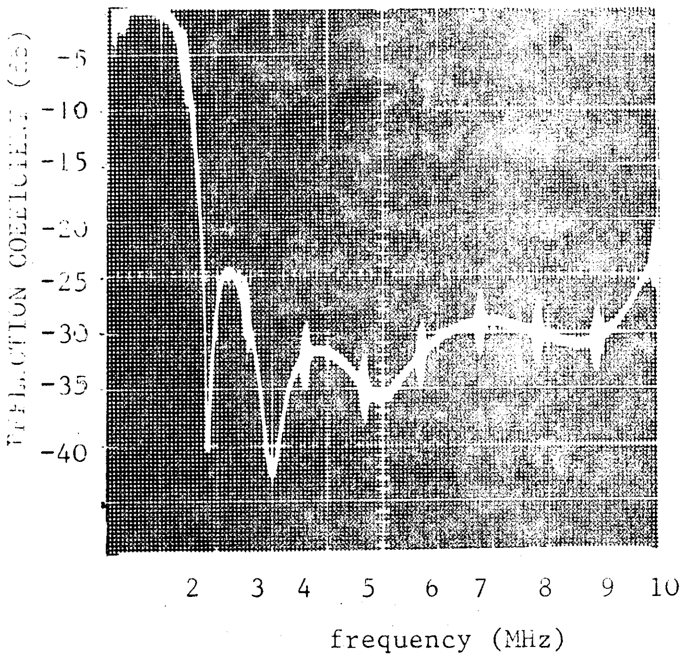


fig. 5

reflection coefficient of Chebyshev band-pass

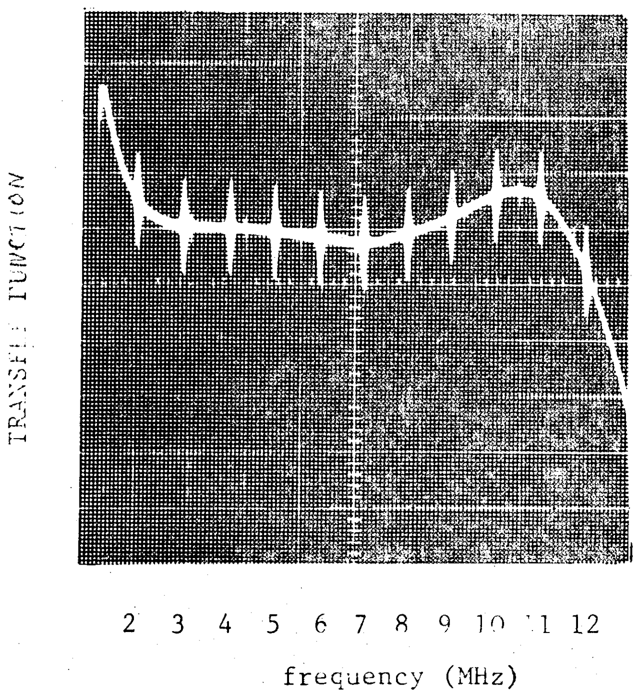


fig. 6

transfer function between control grid and input of filter
vert. 1 db/div.

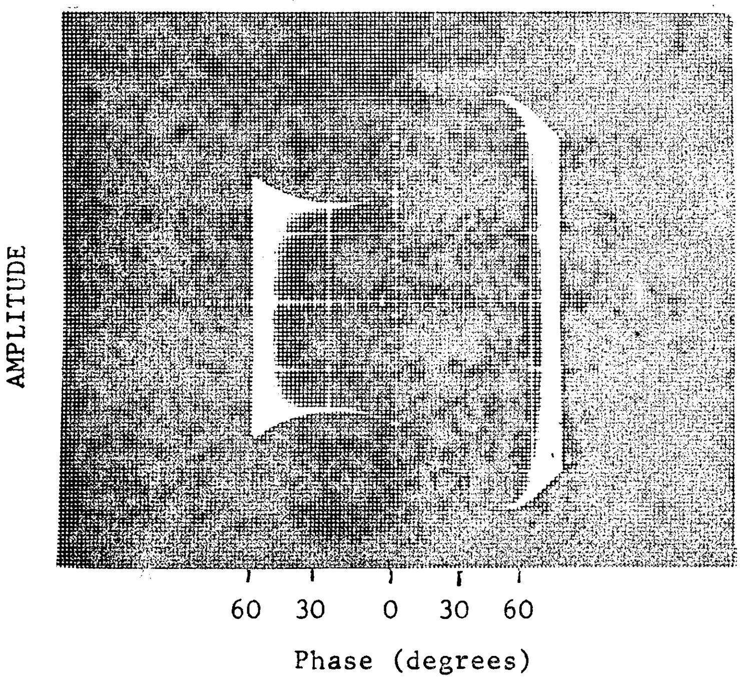


fig.7

Variation of grid voltage of RS1084 when detuning the output circuit without neutralization

fres = 9.35 MHz

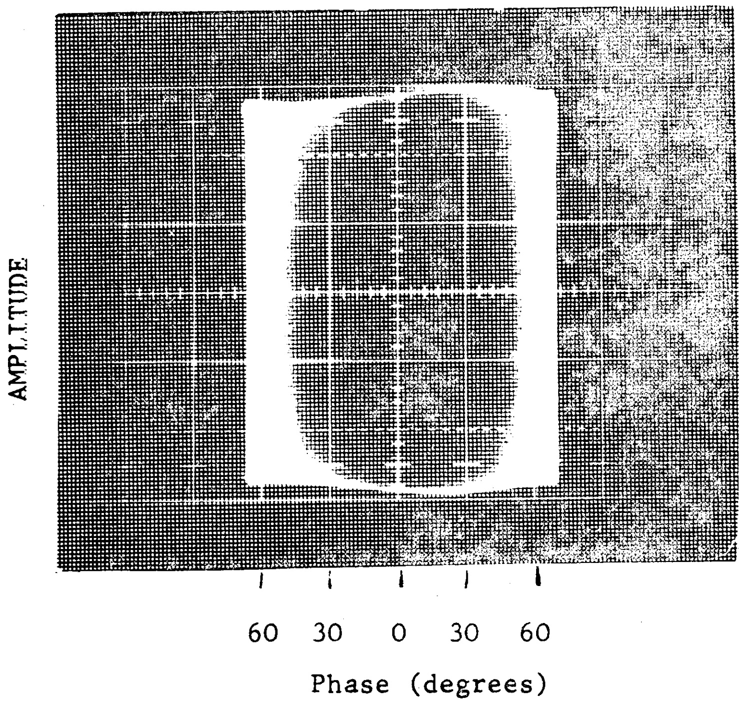


fig.8

Variation of grid voltage of RS1084 when detuning the output circuit with neutralization

fres = 9.35 MHz

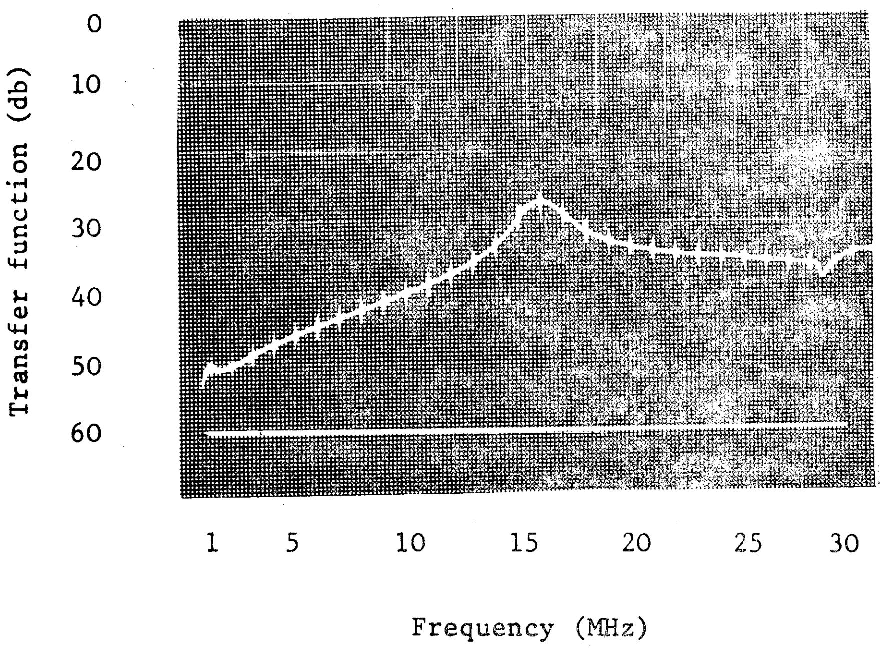


fig.9

Transfer function between plate and control grid of tube RS1084 without neutralization

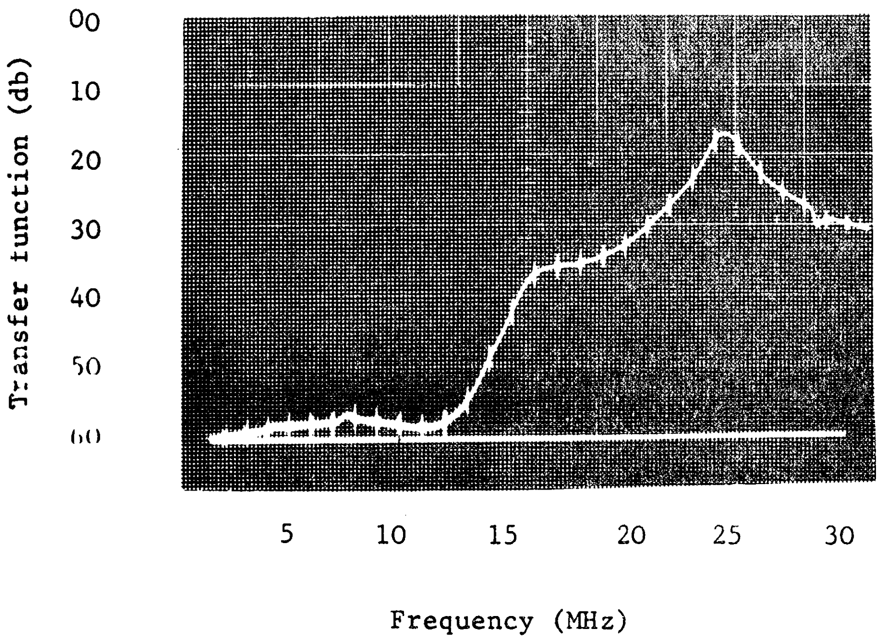
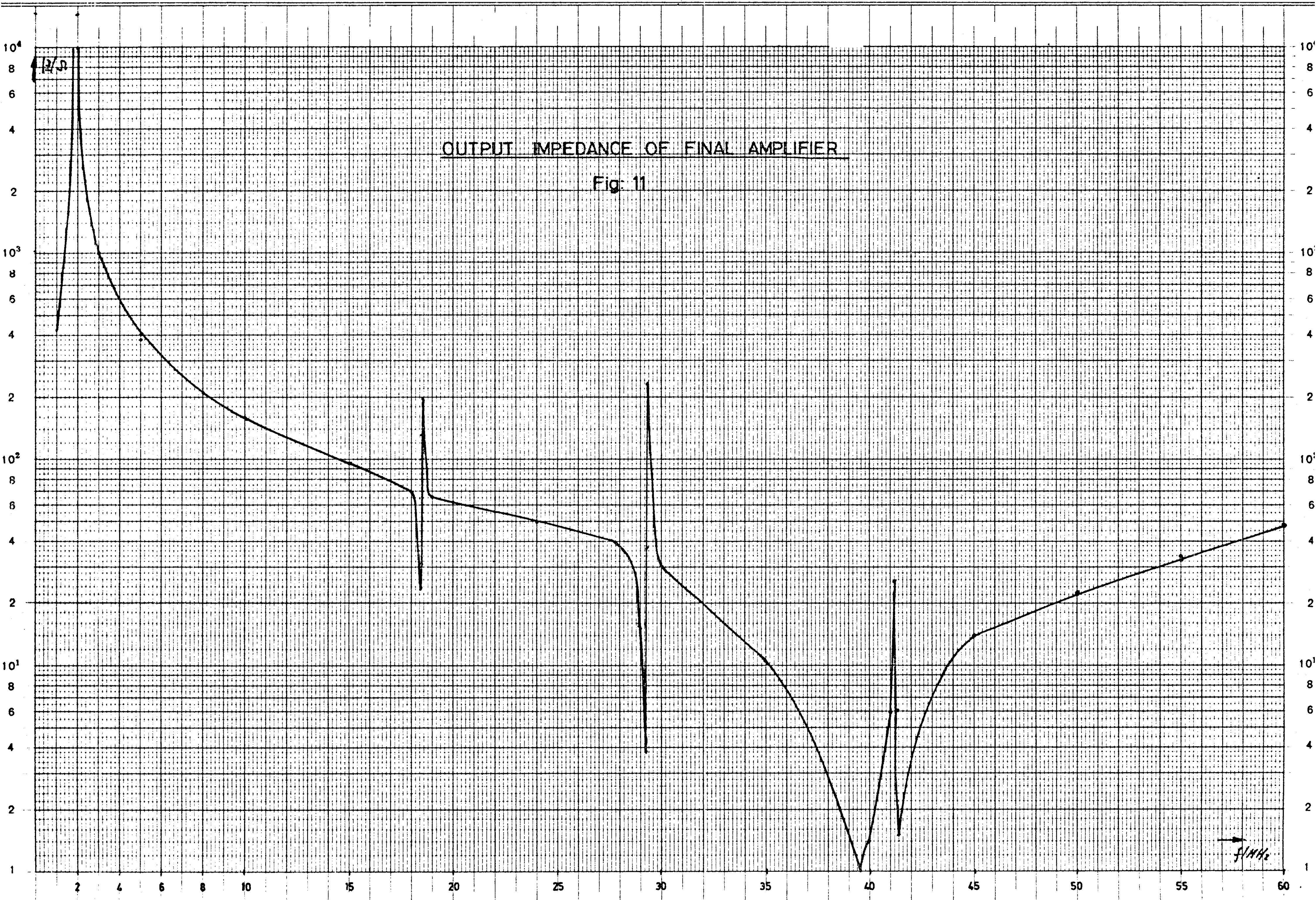
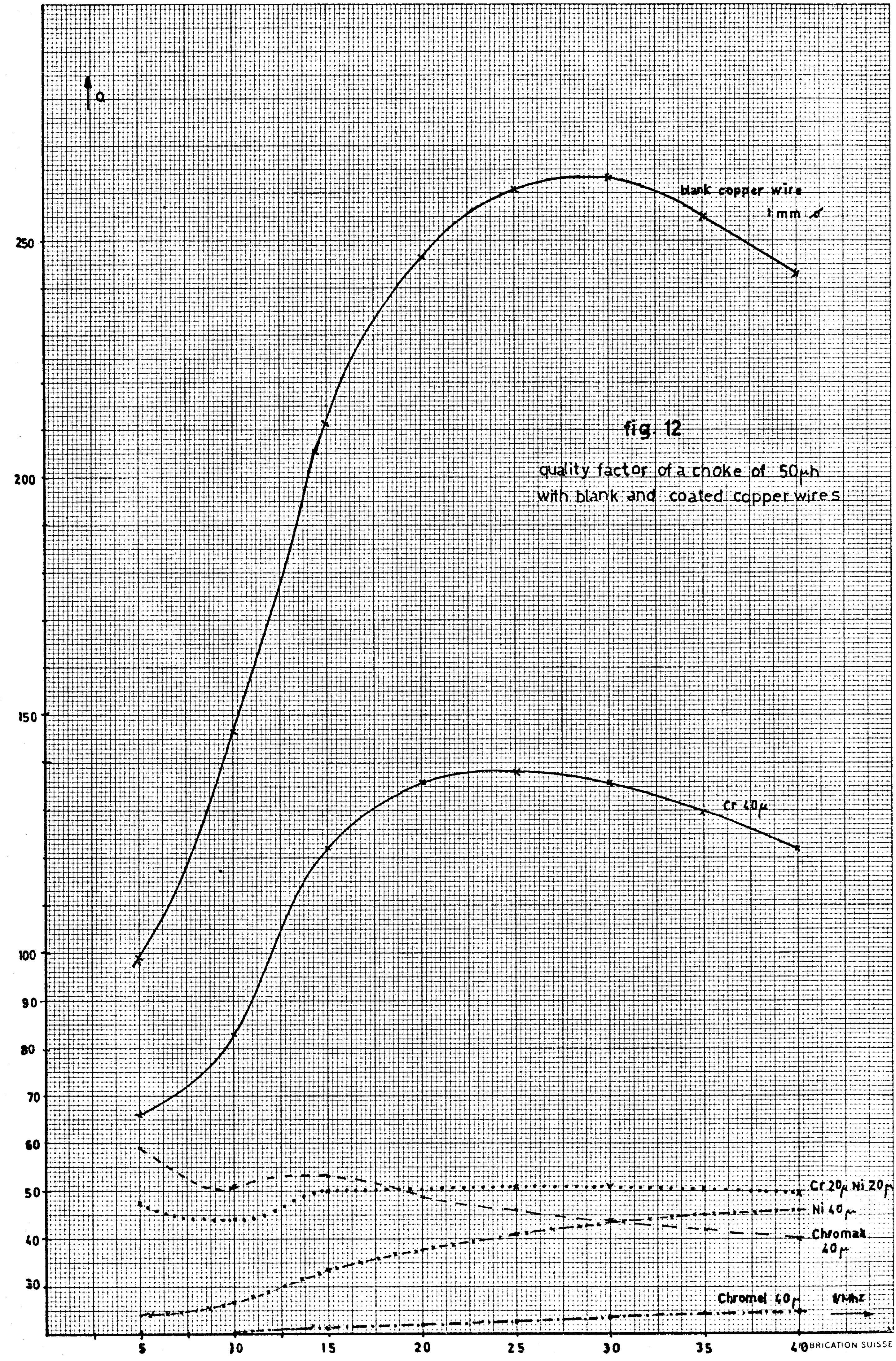


fig.10

Transfer function between plate and control grid of tube RS1084 with neutralization


|Z|/Ω
f/MHz
OUTPUT IMPEDANCE OF FINAL AMPLIFIER
Fig. 11



Q
blank copper wire
1 mm ø
fig. 12
quality factor of a choke of 50µh
with blank and coated copper wires
Cr 40µ
Cr 20µ Ni 20µ
Ni 40µ
Chromax
40µ
Chromel 40µ
f/Mhz
250
200
150
100
90
80
70
60
50
40
30
5
10
15
20
25
30
35
40
FABRICATION SUISSE

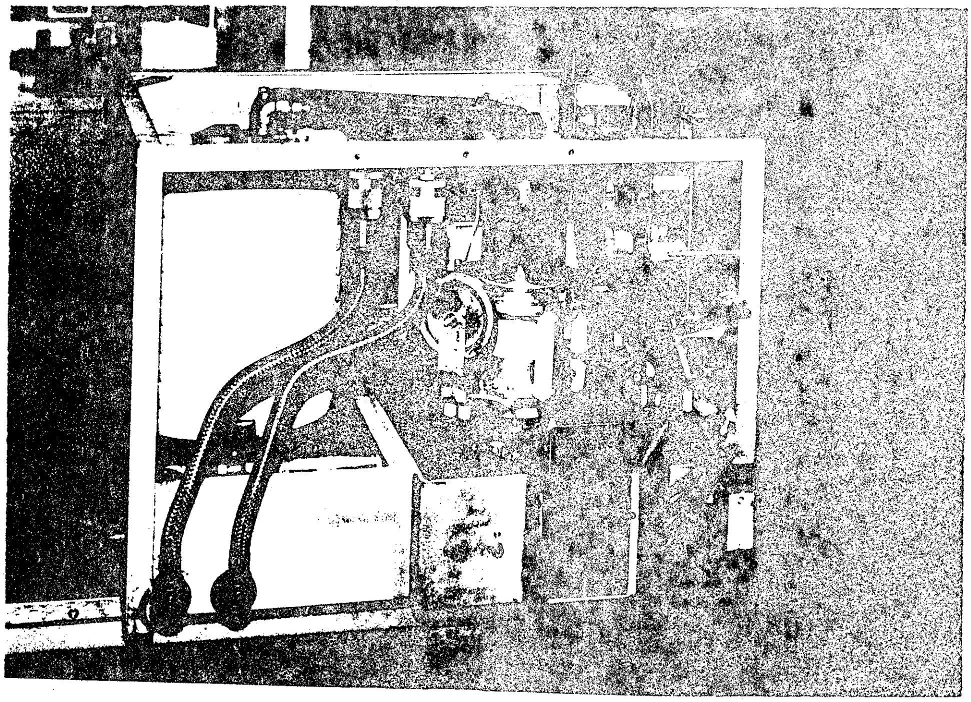


Fig. 13

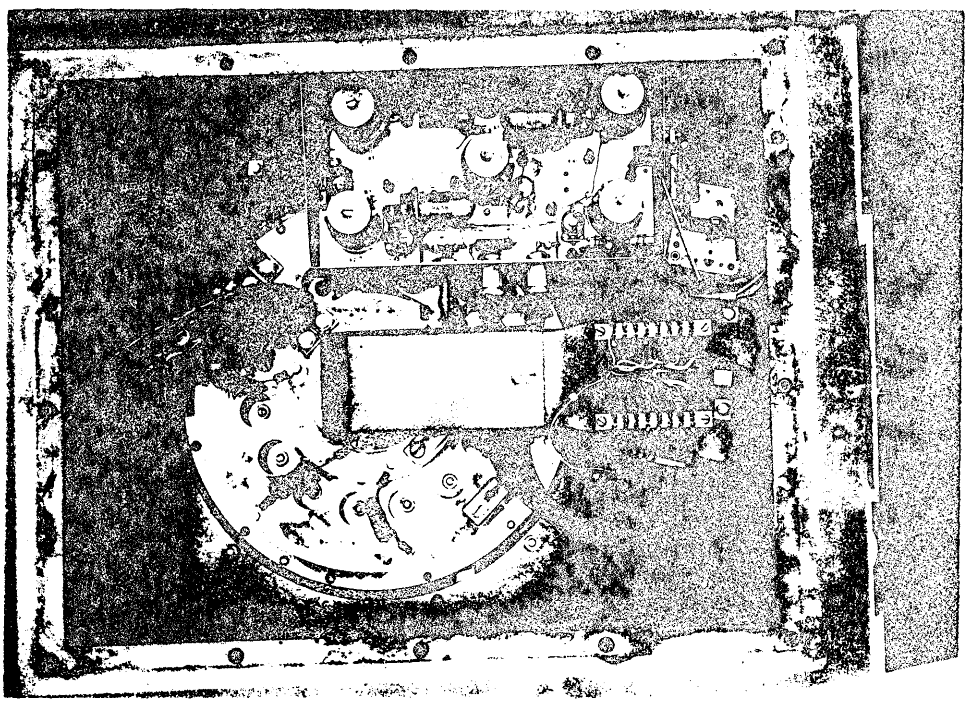


Fig. 14