Microwave Frequency Stabilizer

by

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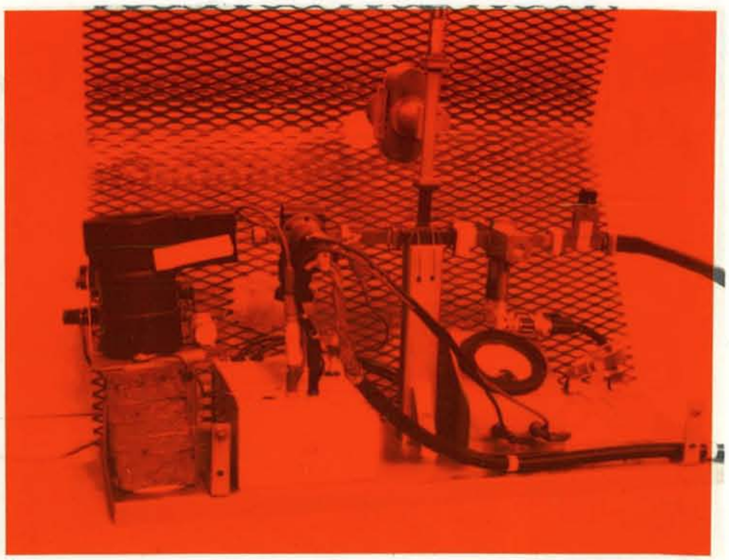

Frontispiece - Klystron and Stabilizer

A number of useful plasma diagnostic techniques require a stable source of microwaves. We describe here a simple and flexible stabilizer which has proven useful with reflex klystrons in the 20-30 GHz range and could be modified for use at other frequencies.

THEORY

Figure 1 is a block diagram of the stabilizer.

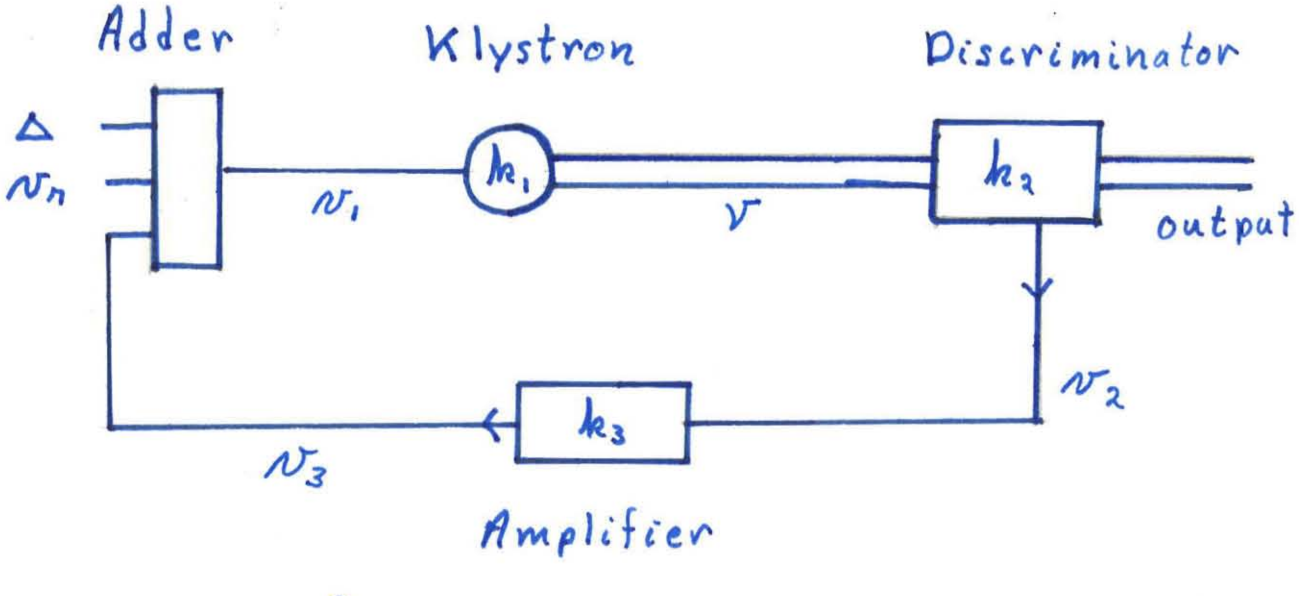

fig. 1

ν = frequency of the klystron's oscillations

k_1 = klystron's electric tuning sensitivity (in $\frac{Mc}{V}$)

k_2 = discriminator's sensitivity (in $\frac{V}{Mc}$)

k_3 = amplifier gain

v_r = repeller supply voltage

Δ = all the perturbations which tend to change the frequency of the klystron including fluctuations in v_r, thermal drift, mechanical vibration, etc.

As in R.J. Chafin's thesis, PLP 138, we have:

$v_1 = \Delta + v_r + v_3$

$\nu = \nu_o + k_1(v_1 - v_r)$

$v_2 = k_2(\nu_1 - \nu)$

$v_3 = k_3 v_2$

where ν_o = klystron's frequency when $\Delta = 0$, $v_3 = 0$.

ν_1 = center frequency of the discriminator characteristic (see Fig. 6)

These equations imply

$$\nu = \nu_1 \frac{k_1k_2k_3}{1 + k_1k_2k_3} + \left[1 - \frac{k_1k_2k_3}{1 + k_1k_2k_3}\right] (\nu_o + k_1\Delta)$$

Thus, if $k_1k_2k_3 >> 1$ we find that $\nu \approx \nu_1$ and the effect of the perturbations is very much reduced. If we define the stability factor, S, as the ratio of the frequency deviations without stabilization to the frequency deviations with stabilization for the same perturbations Δ, we find

$$S = 1 + k_1k_2k_3 \approx k_1k_2k_3.$$

CONSTRUCTION

The details of the stabilzer are shown in Fig. 2.

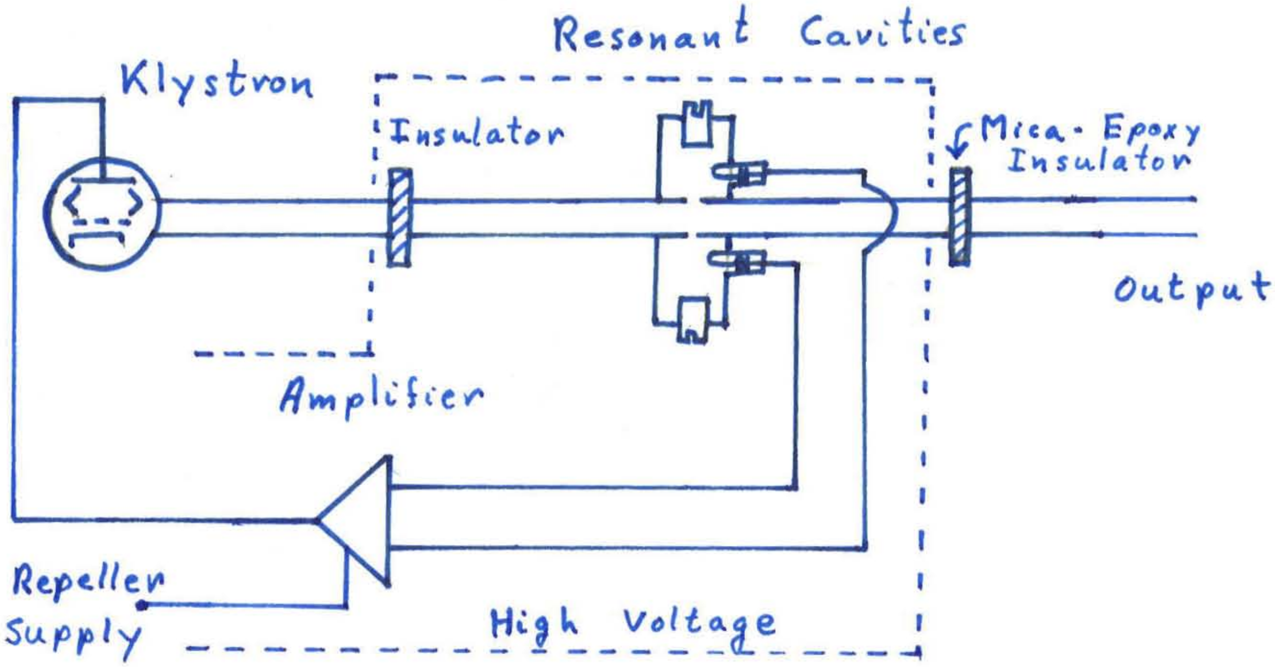

fig. 2

The discriminator consists of two resonant cavities cut in brass blocks 1 3/4" x 1" x 1", copper plated on the inside, and coupled by adjustable wire loops and 1N26 diodes to the amplifier. The cavities are cylindrical, 3/4" in diameter, 1" long, and tunable by a 3/8" screw. Analysis shows that without the screw the cavities have low order resonances beginning near 20 GHz, and we find experimentally that there is one easily tunable high Q (~ 6000) mode as well as a number of other resonances (too broad to be useful) in the 20-30 GHz range.

The coupling loops and diode mounts are shown in Fig. 3.

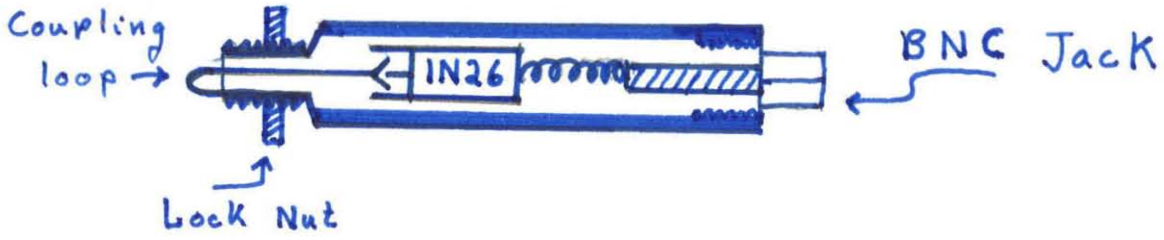

fig. 3 Detectors

The cavities are soldered to the (1/2" wide) waveguide and coupled to it through small (< 1/16") holes. They produce no noticeable loading of the klystron or waveguide. For operation at the center of its characterstitic, the discriminator is, of course, insensitive to amplitude variations in the klystron's output.

The amplifier is built with two Fairchild 702 integrated circuit operational amplifiers. Its schematic diagram is given in Fig. 4. The low-pass filter between stage 1 and stage 2 is necessary to prevent the phase shift of the feedback loop from reaching 180° while the gain is greater than unity.

Since the repeller of the klystron is biased at ~ 2000 volts negative with respect to ground (for a 2K33) and because it was inconvenient to connect the amplifier in the return lead of the - 2000 V

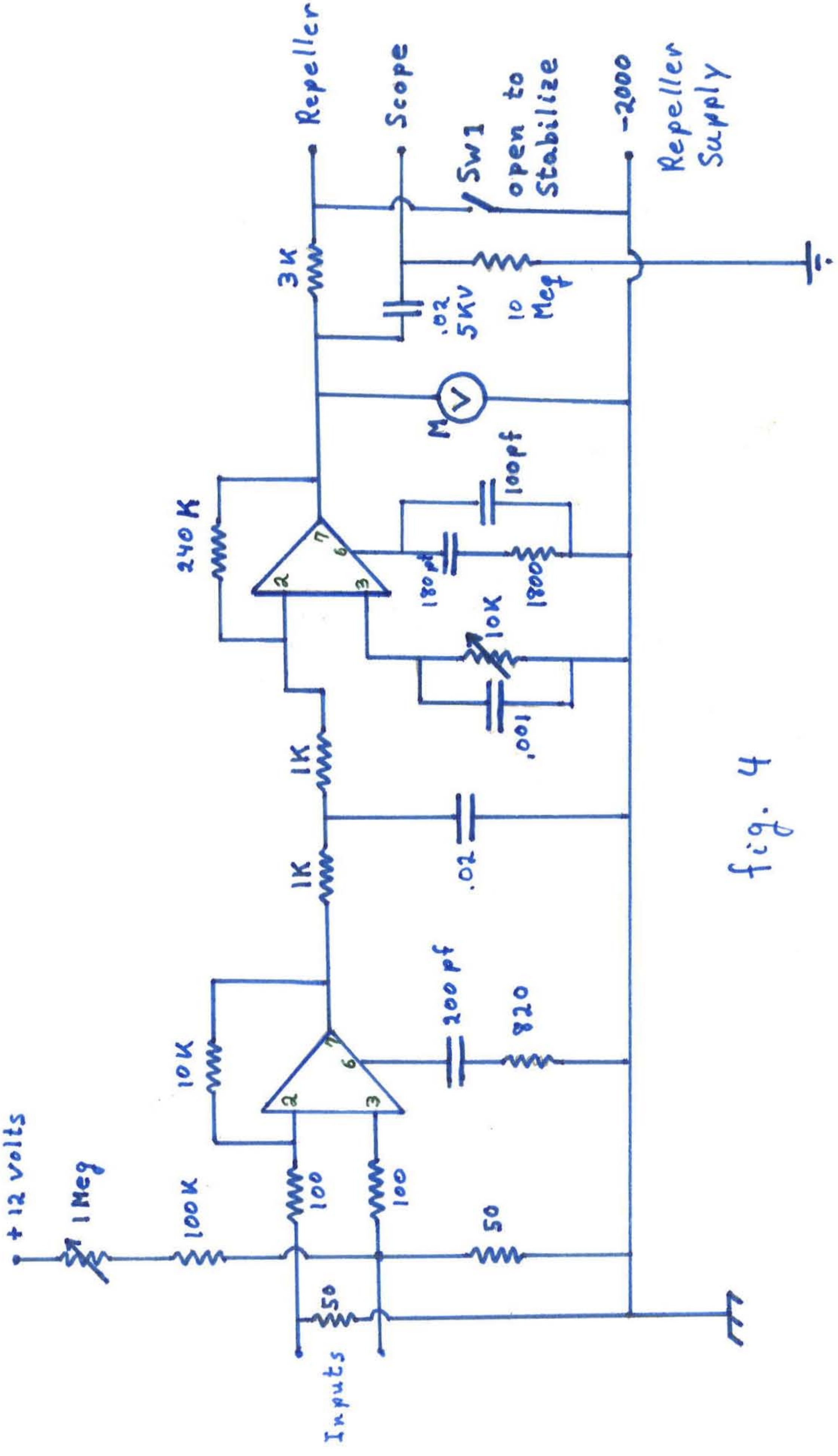
+12 volts
1 Meg
100K
100
100
50
50
Inputs
10K
2
3
6
7
200 pf
820
1K
1K
.02
240K
2
3
6
7
180 pf
1800
100pf
10K
.001
M
V
3K
.02
5KV
10
Meg
Repeller
Scope
Sw1
open to
Stabilize
-2000
Repeller
Supply

fig. 4

supply, the resonant cavities and the amplifier ride at - 2000 V. This causes no great difficulty, however.

OPERATION

Initial alignment is accomplished by disconnecting the amplifier and cavities from the repeller supply and operating the klystron unregulated in its most useful mode. A sawtooth sweep is applied to the repeller and the two leads from the discriminator output are connected to the differential inputs of a C.R.O. The tuning screws and coupling loops are then adjusted until a discriminator characteristic resembling the one shown in Fig. 6 is obtained.

If the amplifier is now inserted in the repeller lead and connected to the discriminator while the sawtooth sweep is still imposed on v_r, the voltage at the repeller will appear as shown in the lower trace of Fig. 7b. The horizontal portion of the graph represents the region over which the stabilizer is controlling the klystron frequency. (The whole klystron mode is approximately 30-40 Mc wide.)

The upper trace in Fig. 7b depicts the voltage produced by the detector at point A in Fig. 1 (i.e. the klystron's mode shape - we're far from the wave meter's resonance). Monitoring this waveform enables one to correct large scale drift in the klystron's frequency such as occurs during warm-up. This drift causes the flat portion of the trace (i.e. the stabilized portion) to move to one side of the klystron mode and can be corrected by a small adjustment in either the klystron's cavity size or its grid voltage.

Frequency stabilized operation is obtained by switching the klystron power supply to CW (repeller voltage constant - no sawtooth sweep) and adjusting v_r or the klystron grid voltage until the regulator "locks-on". Voltmeter M in Fig. 4 is useful in recognizing this condition. During operation, the meter reading may gradually move away from zero, indicating that the regulator is working harder and harder to hold the frequency constant. In this case v_r should be adjusted to return the meter to zero thus preventing the amplifier from saturating and eliminating any sensitivity of the discriminator to amplitude variations.

PERFORMANCE

As mentioned above, the performance of the regulator can be rated in terms of the stability factor $S = 1 + k_1k_2k_3$. In the present case we have

k_1	1/2 Mc/volt
k_2	.01 volt/Mc [for 50 Ω load]
k_3	10,000

so that $S \approx 50$. This stabilization factor can be measured experimentally as follows. With the regulator and klystron in frequency stabilized operation, adjust the wavemeter at point A in Fig. 1 so that the regulated frequency is on the side of the wavemeter's resonance. The output of the detector at point A is then sensitive to small frequency deviations. If a small perturbation is now imposed on v_r and the resulting frequency deviation observed with, (1) switch Sw_1 open (i.e. stabilize - see Fig. 4) and (2) switch Sw_1 closed, the stabilizing effect of the regulator can be measured. The stability factor, S, is just the ratio of the

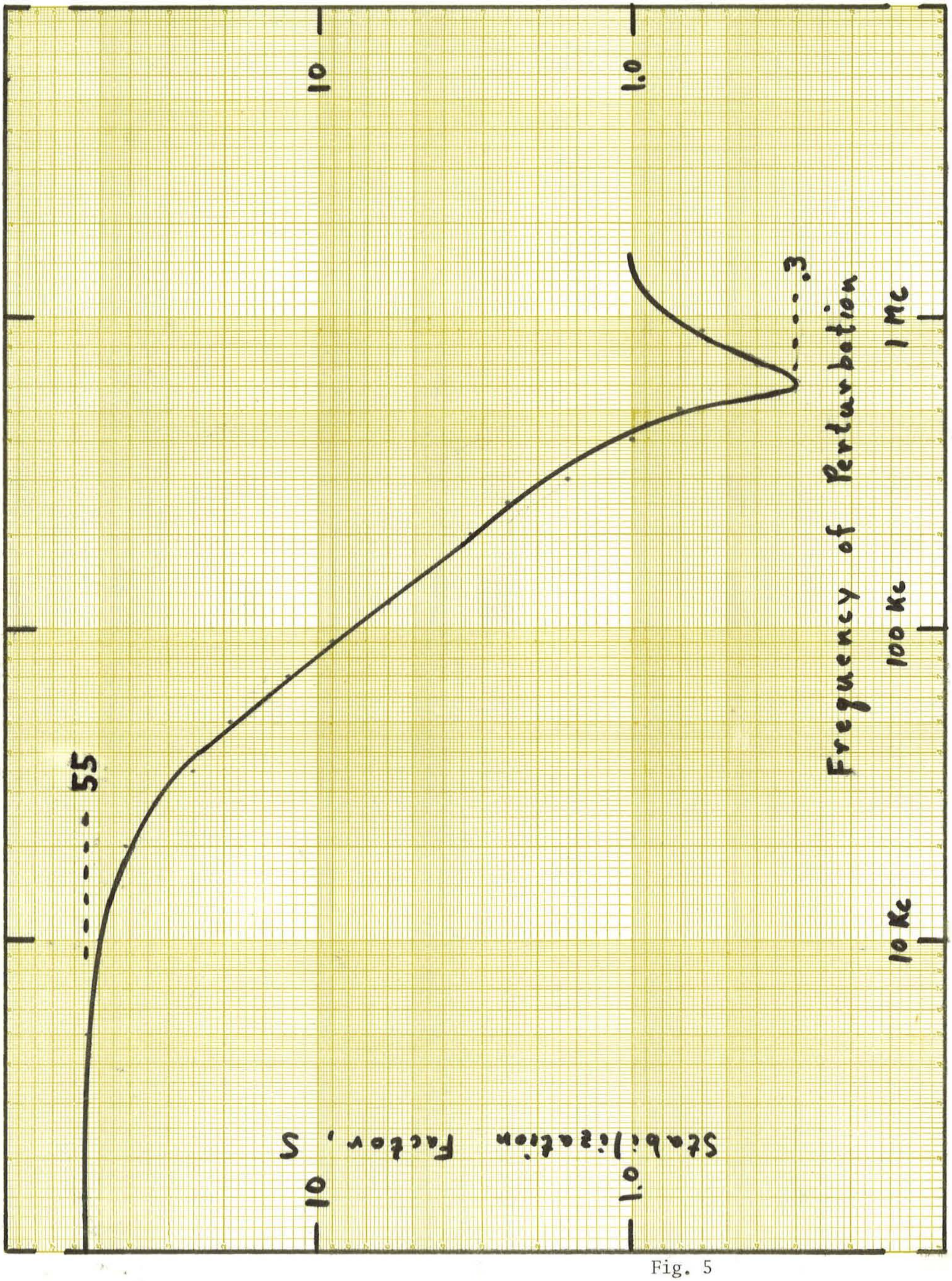
Stabilization Factor, S
10
1.0
55
.3
Frequency of Perturbation
10 Kc
100 Kc
1 Mc

Fig. 5

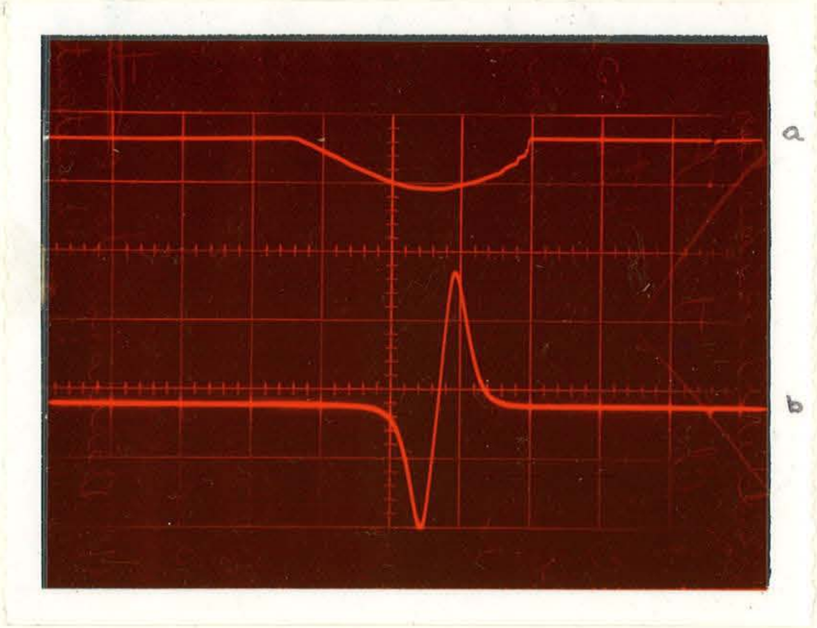

Fig. 6
a. Klystron mode
b. Discrimination characteristic

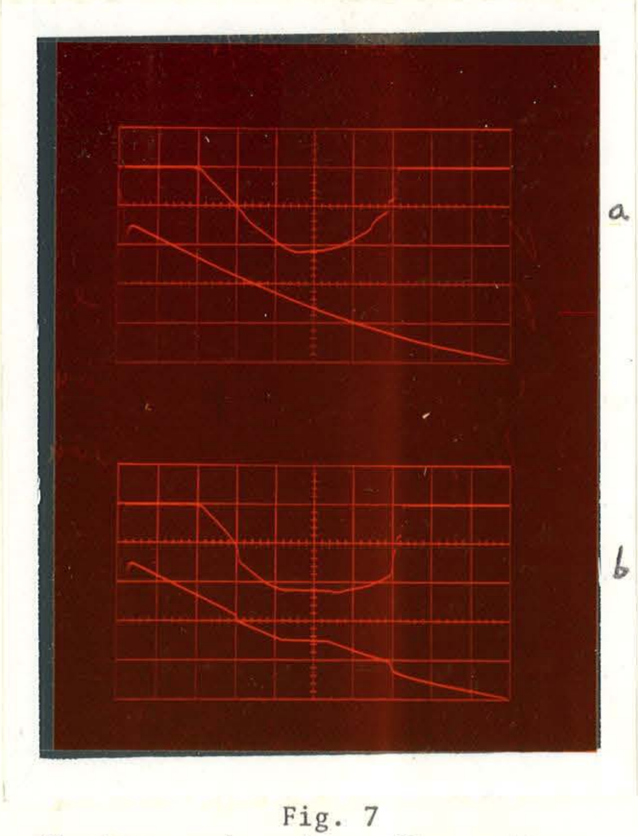

Fig. 7
Klystron mode and repeller voltage
a. Without stabilization
b. With stabilization

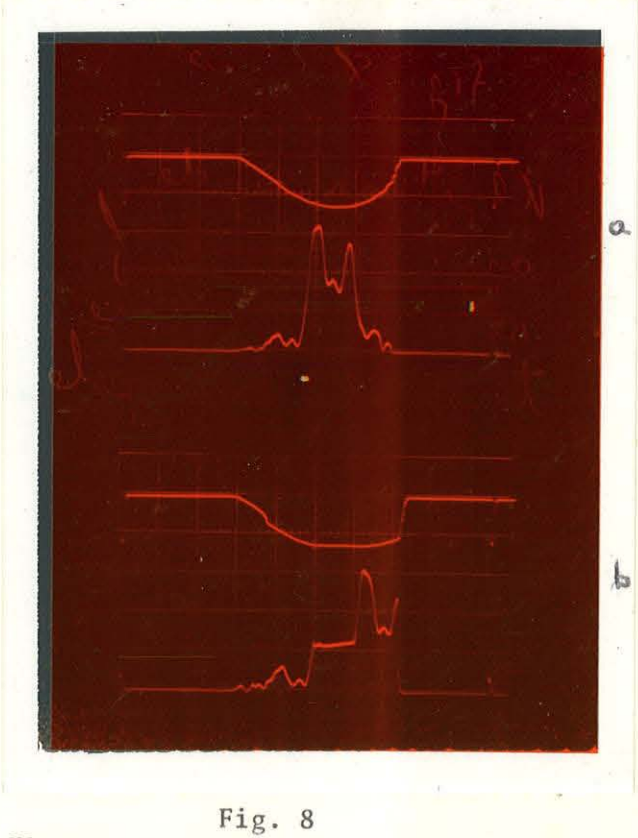

Fig. 8
Klystron mode and spectrum of resonances of the toroidal quadrupole