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UPGRADE OF AGS RF CAVITIES FOR INCREASED BEAM LOADING

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BOOSTER TECHNICAL NOTE
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INTRODUCTION

The AGS RF System must be upgraded to accommodate an increase in beam loading. The system has two major facets. One is the power amplifier; the second is the cavity. This note addresses the problems associated with the cavity.

Increased beam loading due to the injection of a bunched beam from the booster into the AGS has two aspects. During the accelerating phase, steady state beam loading imposes a limit on the drive (or output) resistance of the amplifier, the Robinson resistance. The injection of a bunched beam induces a transient response in the cavities. This transient response manifests itself as a phase delay and amplitude modulation of the gap voltage, and is dependent on the product of the gap capacitance and gap voltage.

TRANSIENT RESPONSE

The transient response has been analyzed[1,2]. Each injected bunch induces a phase delay in the RF gap voltage. The delay is given by

$$SIN^{-1}\, N\, \frac{\Delta Q}{CV} \qquad (1)$$

where
- ΔQ = charge/bunch
- C = cavity (station) capacitance
- V = cavity peak voltage
- N = numerical, depending on charge distribution of the bunch

For an impulse N = ½, for a half-wave sinusoid N = $\pi/8$, for a rectangular distribution N = $1/\pi$. Limiting the induced phase shift to 30° requires that

$$CV > \Delta Q.$$

Design parameters of the AGS cavity are:

ΔQ: based on 6 x 10^{13} protons per pulse, with a 50% safety factor ΔQ = 1.2 x 10^{-6} coul/bunch.

C : the equivalent capacitance of 4 gaps in series. Initially we believed that the gap capacitance was in the range of 300 - 330 $\mu\mu$F. Subsequent measurements indicate that the capacitance is 400 - 410 $\mu\mu$F/gap or 100 $\mu\mu$F/cavity.

V : the peak accelerating voltage. With injection at full voltage V = 40KV/cavity.

Thus the CV product is 4 μ coul.

Injection consists of the sequential injection of 3 bunches from the booster, for an injection of 3.6 μ coul/Booster pulse. The duration of the transient produced by each pulse depends on the cavity quality factor Q_0. For the transient to decay in one RF cycle Q_o must be less than 2. The cavity, loaded by the amplifier output resistance has a Q_0 greater than 15. Thus the sequential injection of the three Booster pulses is equivalent to a transient disturbance produced by a ΔQ of 3.6 μ coul. The CV product of 4 μ coul is marginal and should be increased to approximately 8 μ coul.

UPGRADE

The increase of cavity capacitance and voltage are not independent of each other and is limited by the Q-loss phenomenon, and ferrite dissipation. Q-loss[3,4] is a time-dependent magnetic phenomena. For a constant input power the output voltage is characterized by a period of constant output followed by a decrease of output voltage. The output voltage can be held constant by increasing the drive following the on set of Q-loss. A properly functioning AGC loop can hold the output voltage constant over its linear range. During the high loss period the output voltage appears noisy. Oscillograms depicting Q-loss are included and described within the Appendix. In the references cited and in the older literature this phenomena is called high-loss effect.

The minimum voltage at which Q-loss develops was measured as a function of gap capacitance and is given in Table 1. Measurements leading to Table 1 were made with the AGC loop open.

Table 1. On Set of Q-Loss
F = 4.5 MHz

Gap Capacitance $\mu\mu$(F)	On Set of Q-Loss (Kv)
400	14
500	12
700	11
800	7
1,000	6.5

As the value of gap capacitance is increased, the stored energy and associated ferrite dissipation also increase.

In addition, the upgrade must provide for cavity operation over a frequency range from 1.7 MHz to 4.5 MHz. The lower limit is based on a RHIC operational requirement. Based on the existing gap capacitance of 400 $\mu\mu$F, the capacitance must increase to at least 610 $\mu\mu$F.

Choosing 700 $\mu\mu$F as the gap capacitance and 10 Kv as the gap voltage yields a CV product of 7 μF. The ferrite bias is limited to 1100A.

The ferrite tuning current was measured and is given in Figure 1. The CW dissipation for a gap voltage of 10 KV was measured as a function of frequency and is given in Figure 2.

Additional measurements were obtained for the AGS test cavity and are included in the Appendix.

PERFORMANCE

With an added capacitance of 300 $\mu\mu$F/gap (including a 100 to 150 $\mu\mu$F contribution from the power amplifier) and a gap voltage of 10 KV the following additional parameters are projected for the test cavity.

V = 40 KV
C = 175 $\mu\mu$F
CV Product = 7 μF
ΔQ = 3.6 μF
Ferrite CW Dissipation = 65 KW, or 251 mw/cc
Ferrite Shunt Resistance = 12.3 KΩ
Amplifier Output Resistance = 6.4 KΩ

Based on class AB operation of the EIMAC 4CM300,000 and an external 1:1 transformer:

Output Resistance	= 4.2 KΩ
Robinson Resistance	= 6.35 KΩ
Peak Beam Power	= 125 KW
Q_o of Cavity	= 19

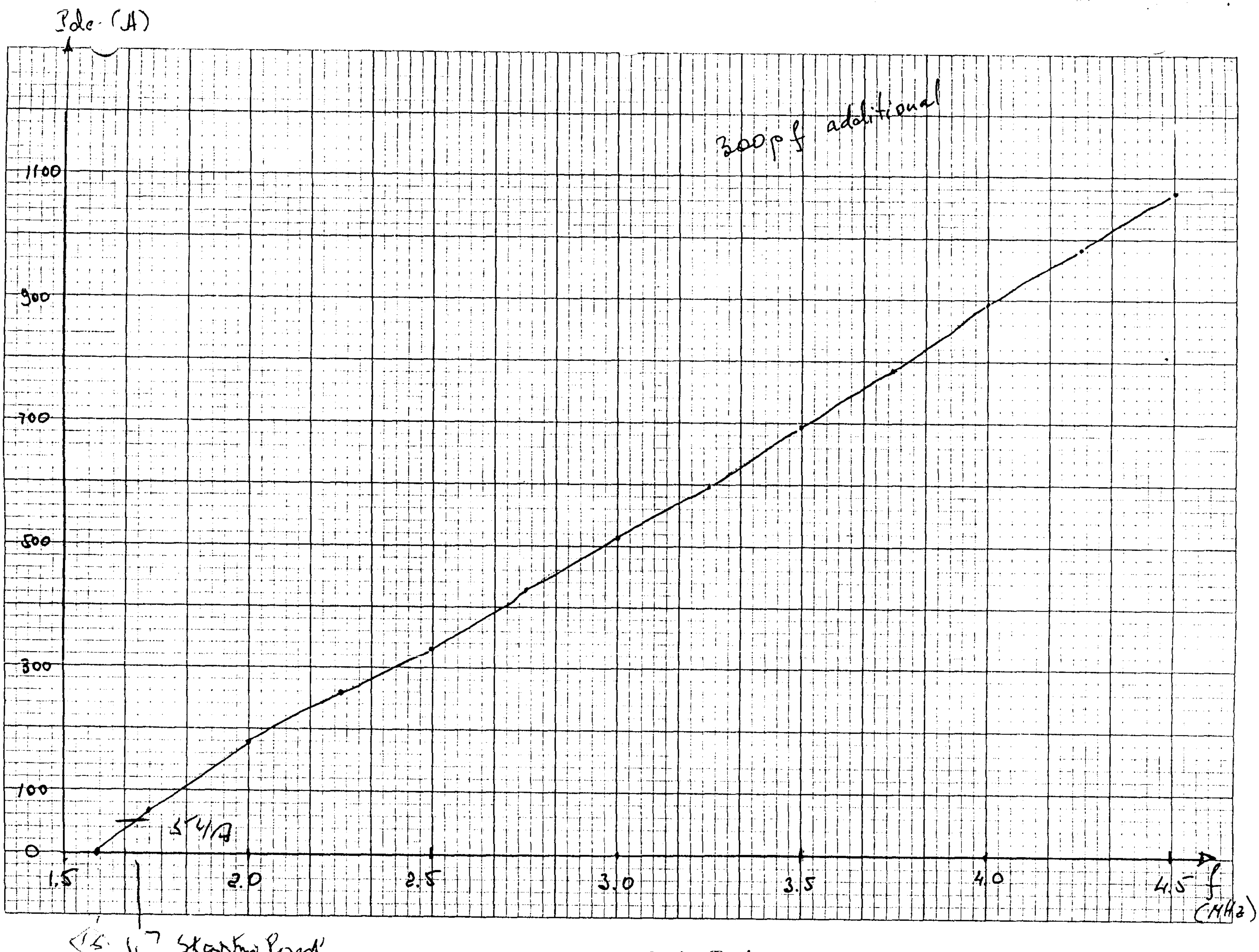

Figure 1. Cavity Tuning

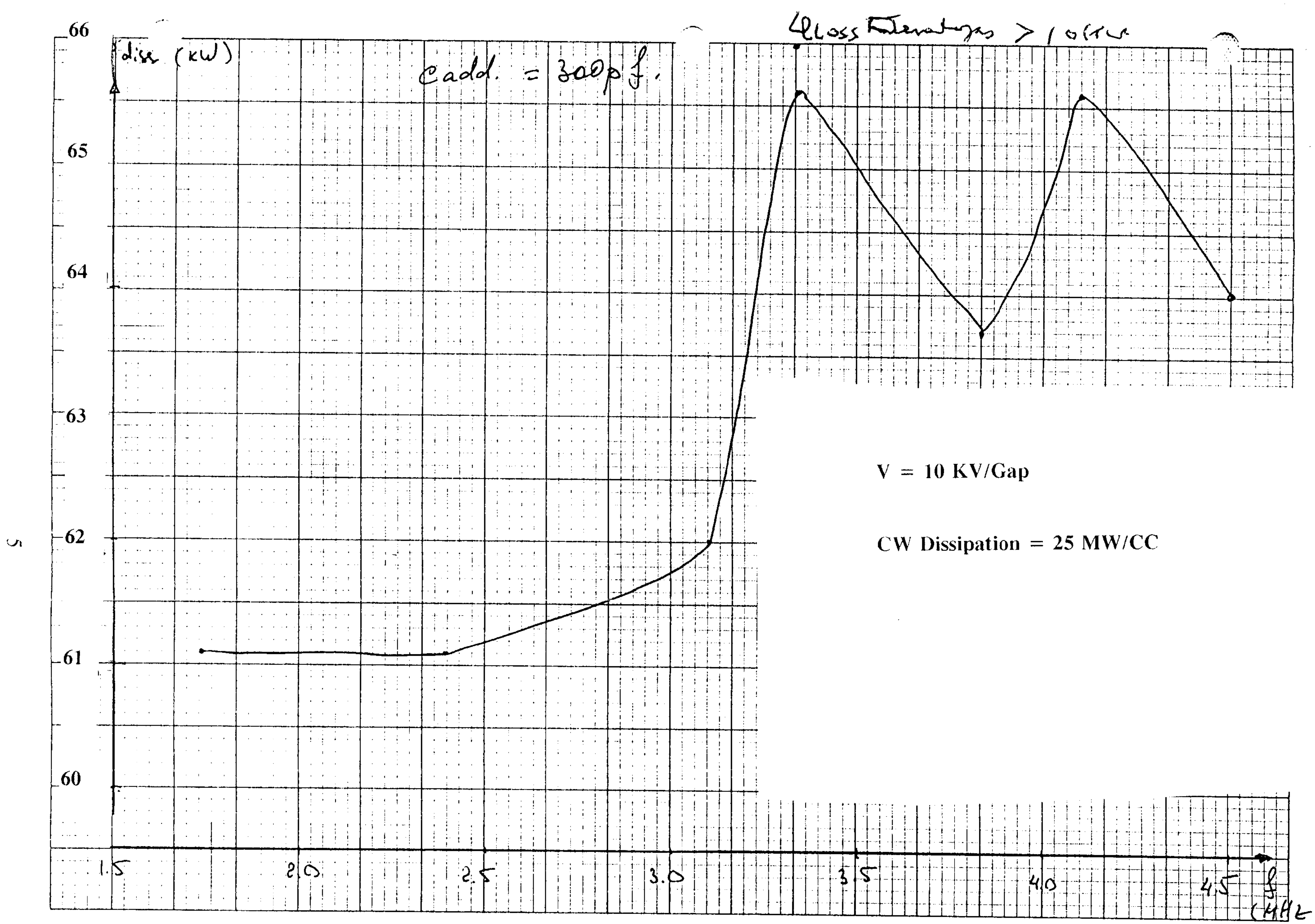

Figure 2. Cavity Dissipation

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3. Kerns, Q.A. and Sandberg, B.R.; The Ferrite Teting Program at NAL, IEEE Trans. Nucl. Sci., NS-18; 244, 1971.

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APPENDIX

The tuning curves for additional gap capacitance of 620 $\mu\mu$F, 720 $\mu\mu$F and 925 are included and given in Figure A-1.

Oscillograms depicting Q-loss are given in Figure A-2. Measurements were made with 300 $\mu\mu$F of capacitance added to each gap (C = 700 $\mu\mu$F/gap) and driven from a 4.5 MHz power source. A 1000:1 voltage probe was employed, such that the vertical sensitivity is 5 KV/cm. In Figure A-2 (A), the cavity drive is adjusted for an output of 10 KV-peak, the AGC loop is open and the response is free of Q-loss. In Figure A-2 (B), the drive is adjusted for an output of 12 KV, the AGC loop is open and Q-loss is present. Note the noise during the high-loss phase. In Figure A-2 (C), the AGC loop is closed and adjusted for an output of 12 KV. Note the constant output voltage level but the manifestation of noise during the high-loss phase.

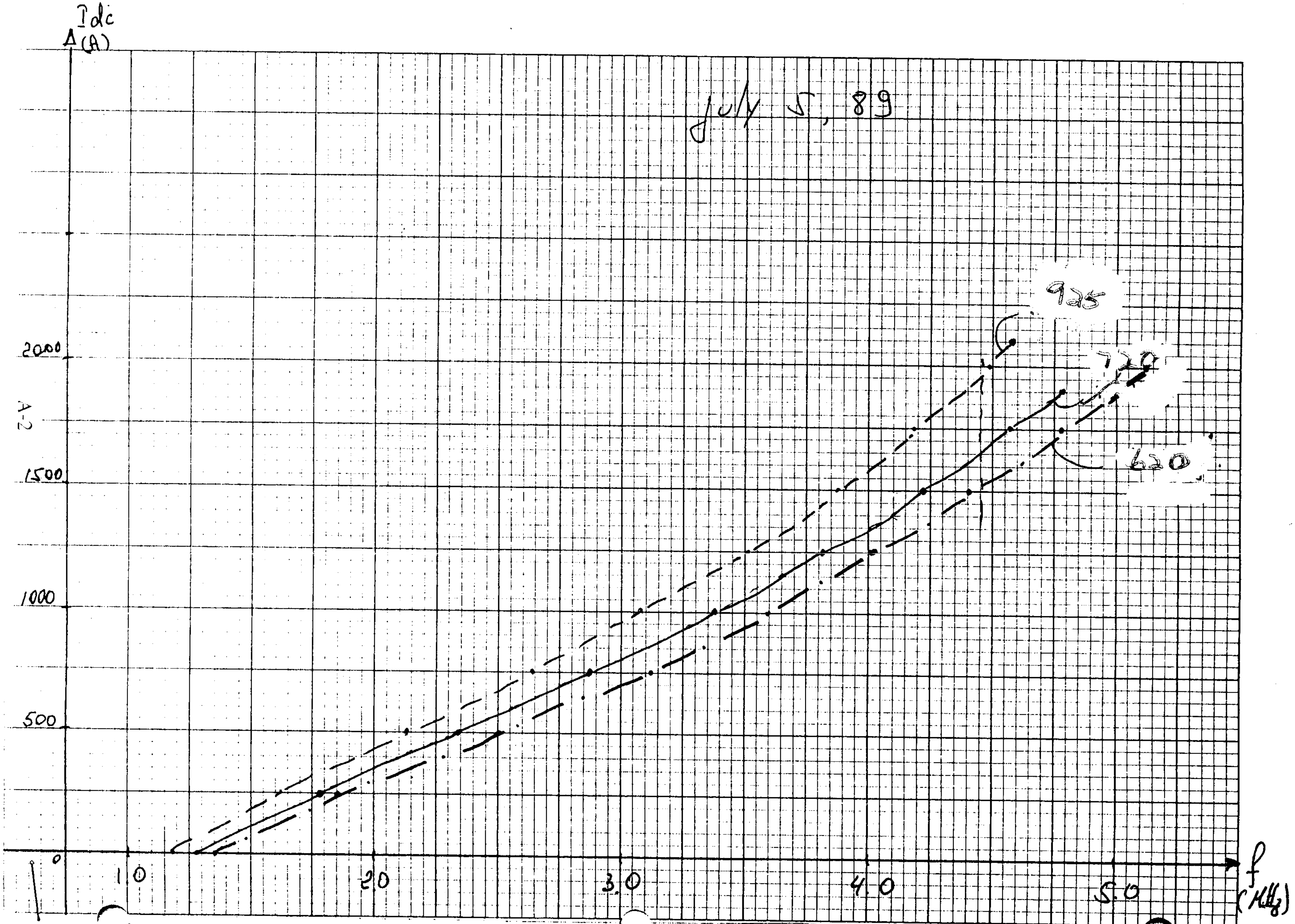

Figure A-1. Tuning Curves
Additional Gap Capacitance of 620, 720 and 925 $\mu\mu F$

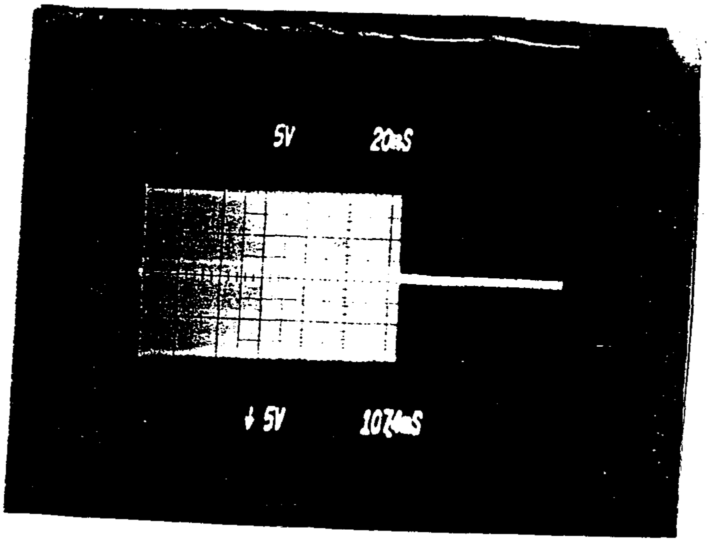

Fig. A-1(A)
AGC Loop Open
V = 10 KV

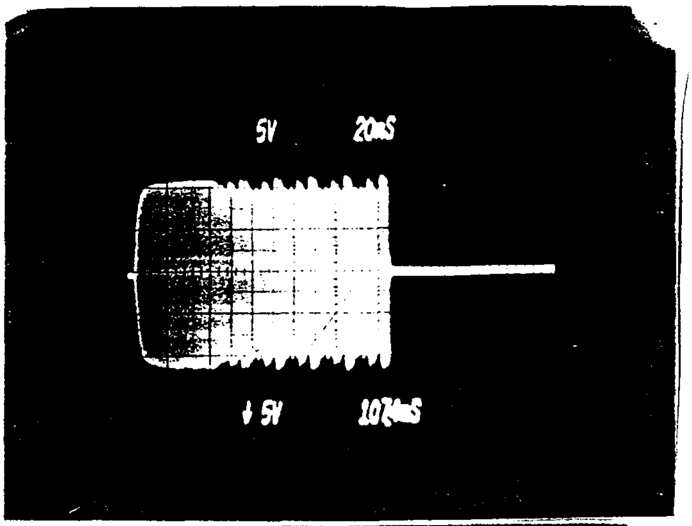

Fig. A-2(B)
AGC Loop Open
V ≥ 12 KV

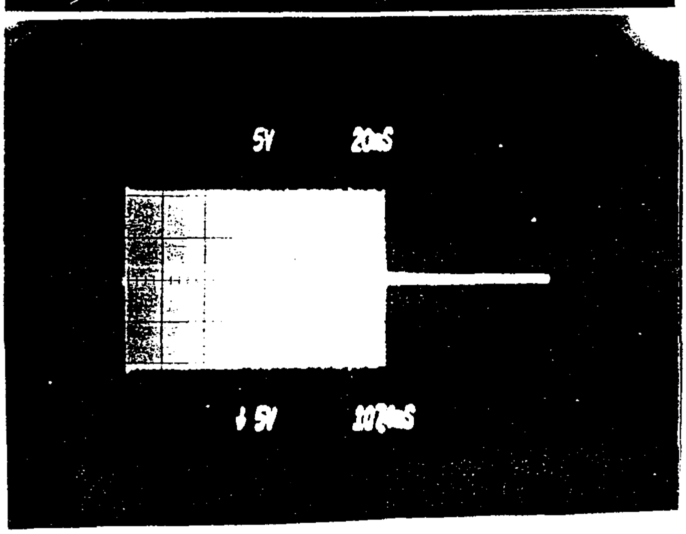

Fig. A-2(C)
AGC Loop Closed
V = 12 KV

Fig. A-2 Oscillograms Depicting the Q-Loss Phenomena
F = 4.5 MHz
C = 700 $\mu\mu$F/Gap
Probe = 1000:1