SLC Damping Ring Direct Loop

USPAS LLRF final presentation

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January 20, 2017

System Overview and the Problem

- SLC Damping Ring
  - 1.19GeV
  - Up to 5e10 e-/bunch
  - Two bunch operation
  - One 60kW klystron driving two RF accelerating cavities of two cells each for a total of 1MV
- Instability threshold
  - In order to prevent turbulent bunch lengthening, voltage is ramped down mid-store to keep bunch length long until extraction when voltage is ramped back to nominal
- The Problem
  - At low cavity voltage, beam loading instability occurs because cavities tuned for optimum loading angle of 0 when at max voltage
  - Cavity tuning angle fixed during store due to mechanical tuners not fast enough to compensate

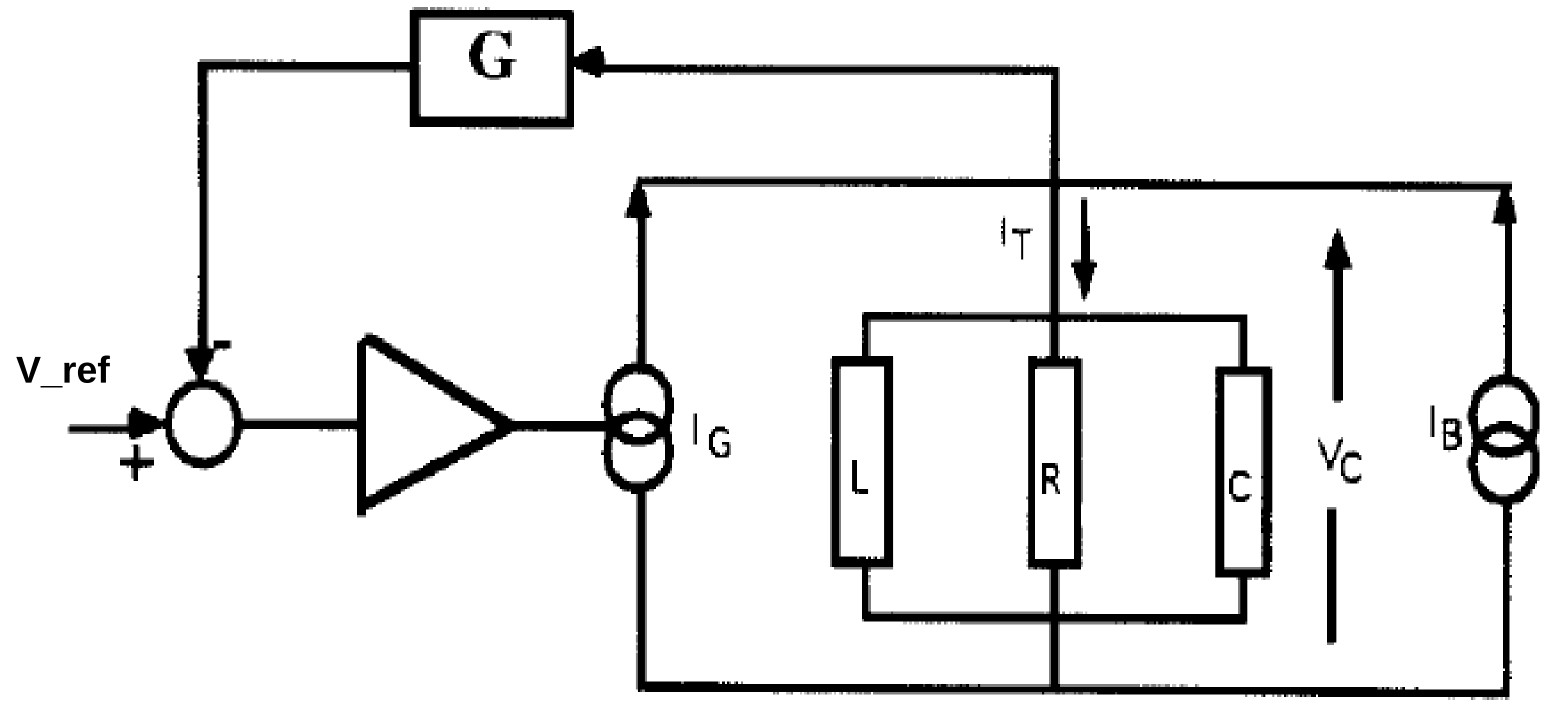
Inside the ring

Klystron in ring to right

Temperature stabilized to 105F

System Representation

Model the system as a resonant cavity driven by two current sources: the klystron and the beam.



I_T=current in cavity

I_B=beam current

I_G=generator current (klystron)

V_c=voltage of cavity

G=RF feedback

V_ref=Klystron Drive Signal

Phasor Representation of Currents

I_O=Real part of total current in cavity

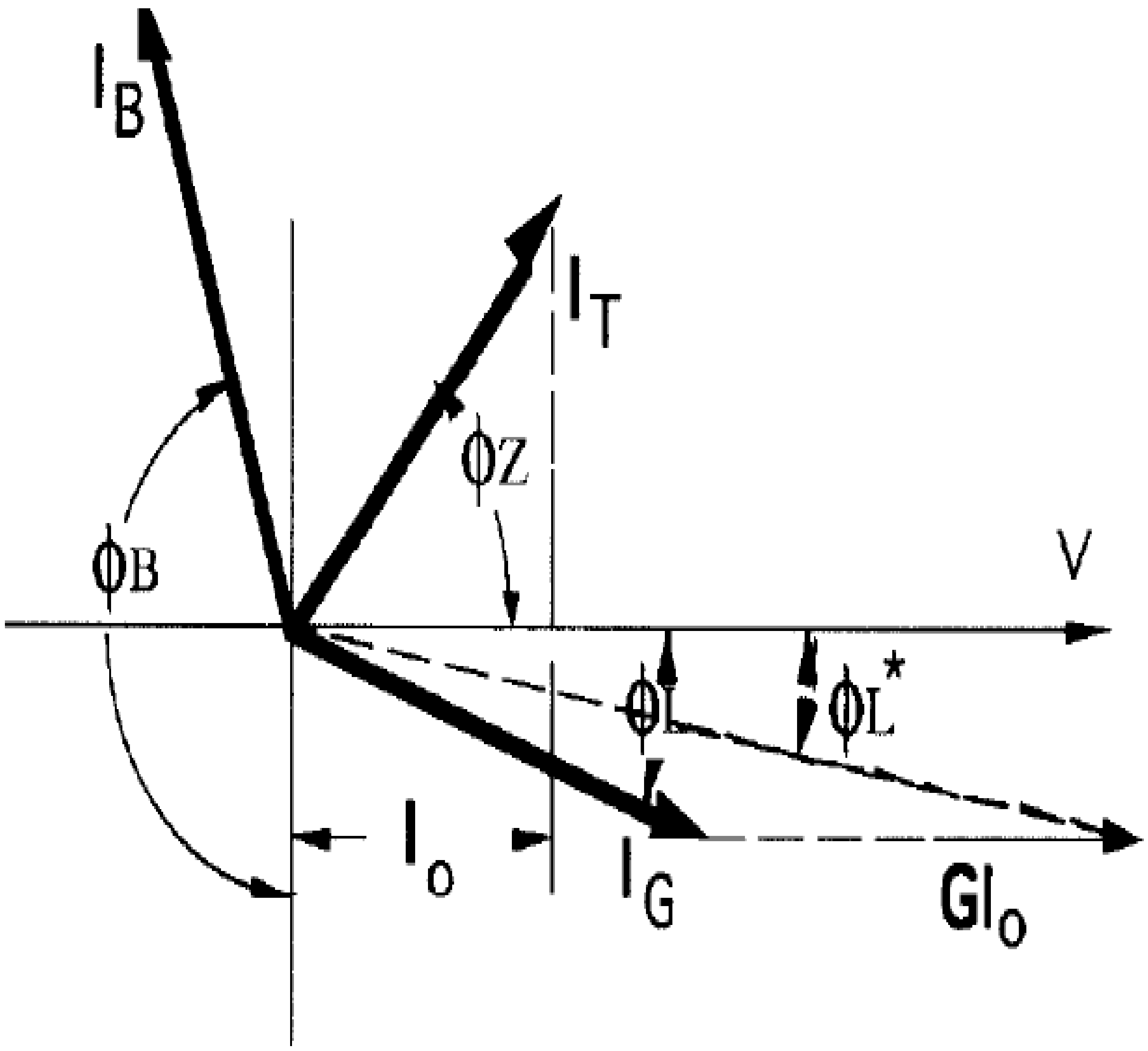
Φ_B=Beam phase—determined by synchronous phase of particle

Φ_Z=Impedance angle—determined by cavity tuning wrt klystron

Φ_L=Loading angle—determined by angle between klystron current and cavity voltage

$$\mathrm{I_G} = \frac{I_O(1 + sin\varphi_B)}{\cos(\varphi_L)}$$

$$tan\varphi_L = \frac{tan\varphi_Z - Ycos\varphi_B}{1 + Ysin\varphi\_B}$$



Modeled Behavior

$$Z(j\omega) = \frac{j\omega \cdot \omega_n \frac{R_{SH}}{Q_L}}{(j\omega)^2 + j\omega \cdot \frac{\omega_n}{Q_L} + \omega_n^2}$$

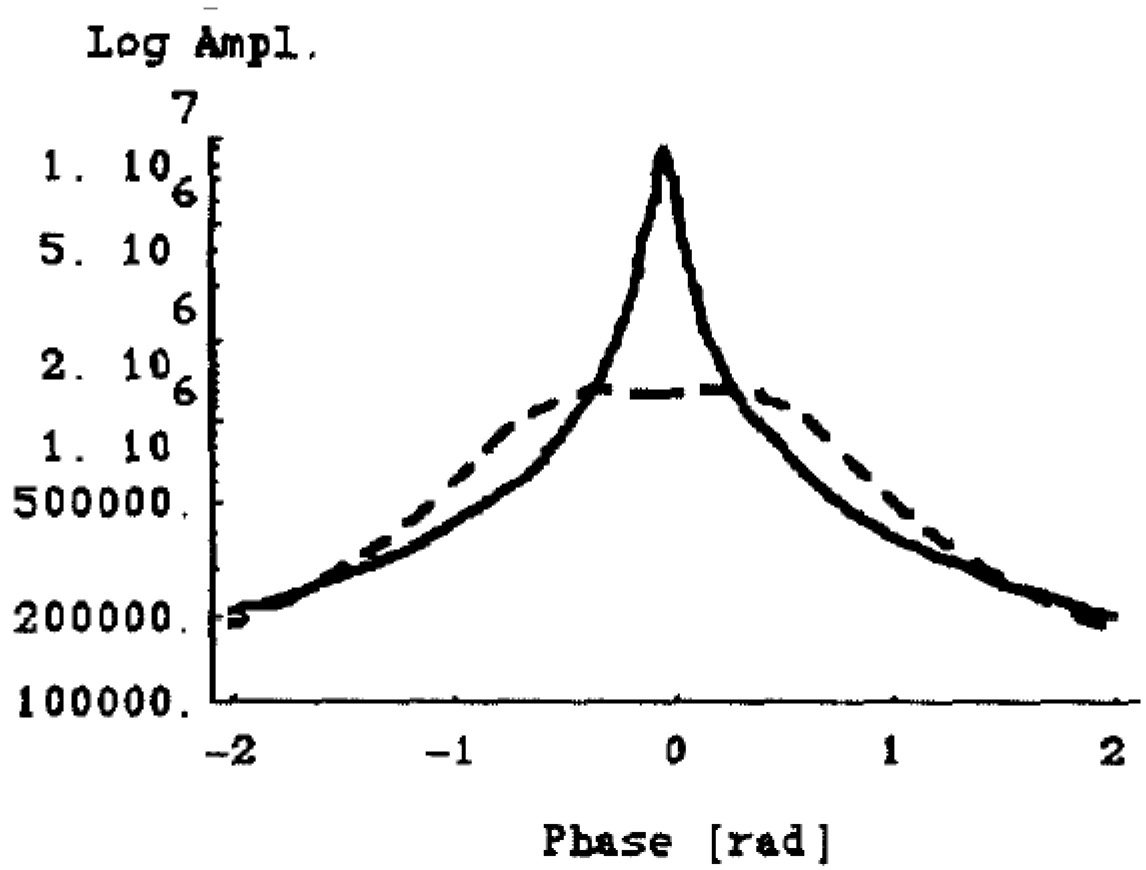
Impedance function for ring parameters

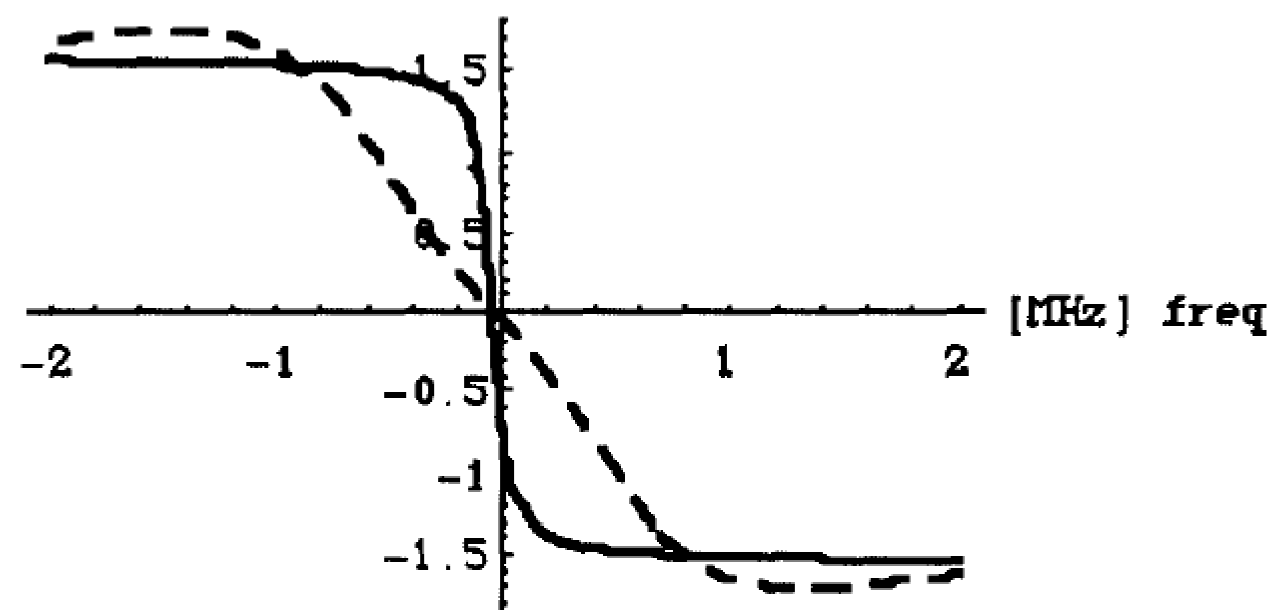
$$G(j\omega) = \frac{G_o}{R_{SH}} \cdot e^{-j\omega\Delta T}$$

Feedback transfer function where G_O= gain, R_{SH}= cavity shunt impedance, and ΔT=delay

$$Z'(j\omega) = \frac{Z(j\omega)}{1 + G(j\omega)Z(j\omega)}$$

Impedance for cavity plus feedback





Gain and stability limits

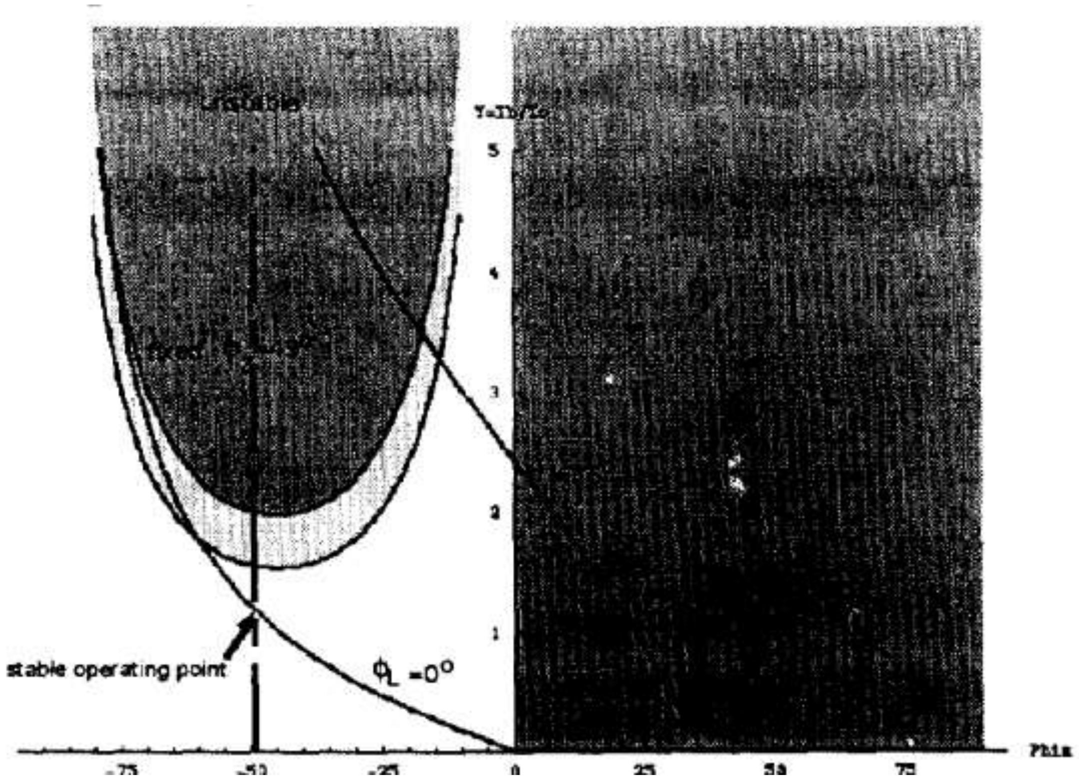
Stability criteria: $$\frac{2\cos\phi_B}{Y} < \sin 2\phi_Z < 0$$

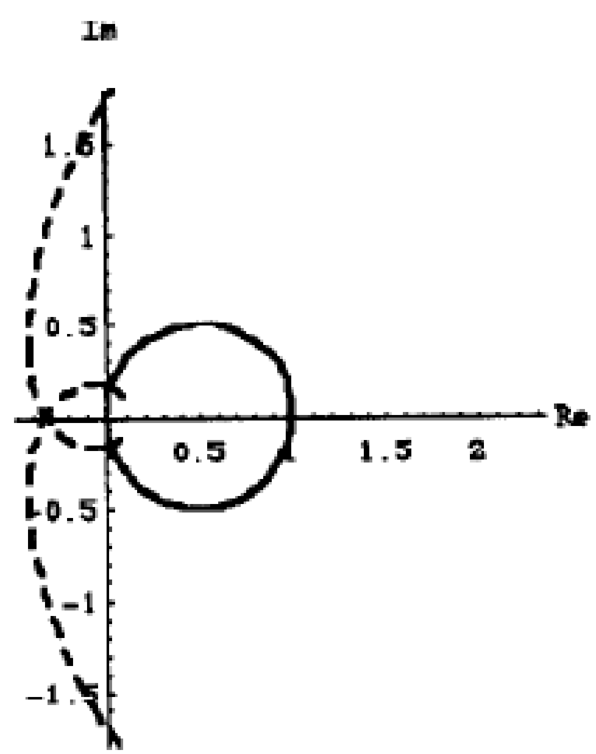
Shaded region in plot at positive phase is anti-damping of synchrotron oscillations. Curved region on left is exponential growth. Vertical axis is Y=I_B/I_O.

At cavity frequency, Z=R_SH and G=G_0/R_SH, so effective impedance is reduced as 1/(1+G_0). Real part of cavity current increase by (1+G_0) and raises the shaded region on left by this amount.

Nyquist plot on right shows stability limit with (dashed line) and without feedback.

Phase shifts cause rotation and gain increase push curve to left. Allowing for phase margin limits effective impedance reduction

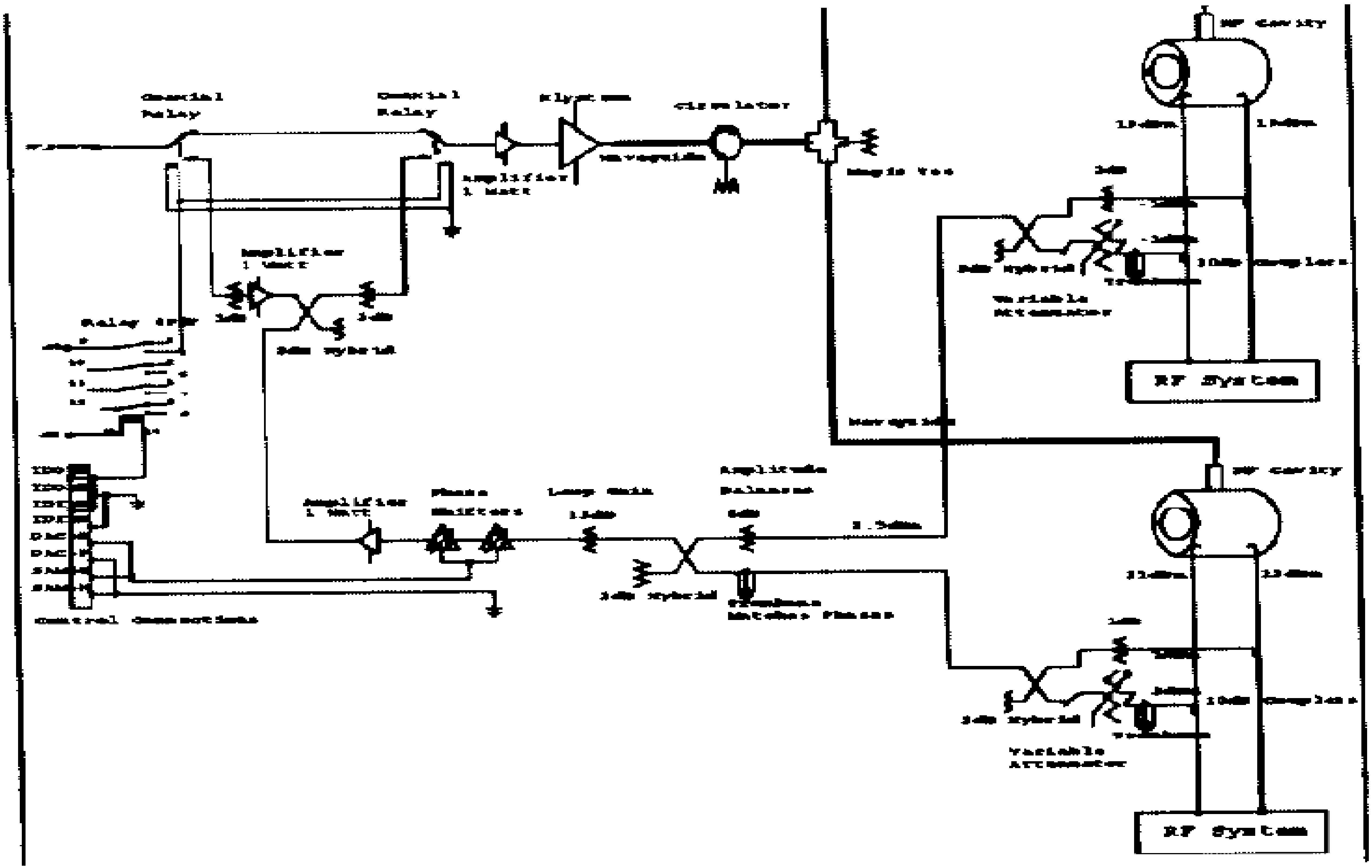




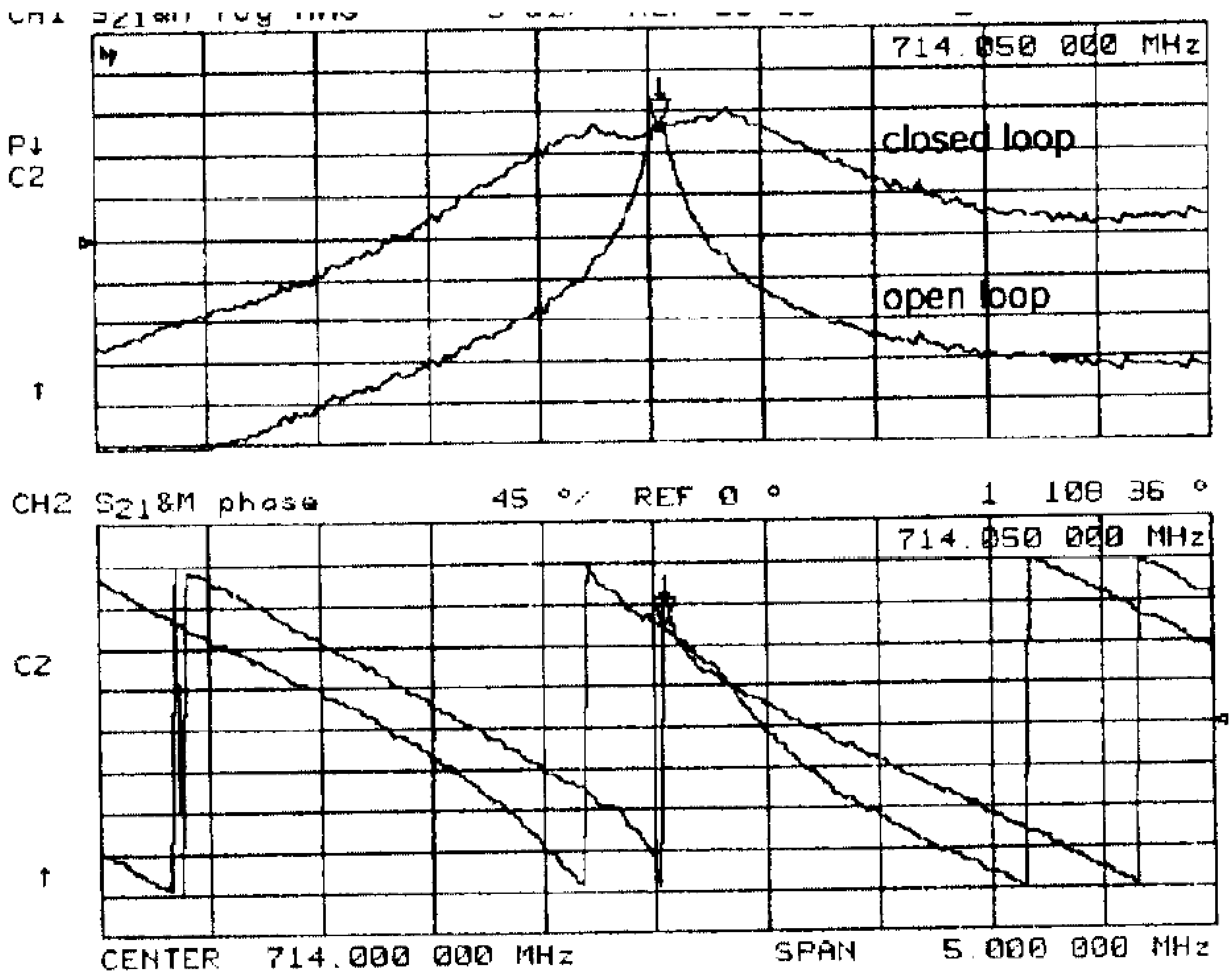
Direct Loop RF Feedback Implementation

- Klystron and cavities are in tunnel, so signal path lengths are short
- Two-cell cavities have a non-accelerating 0-mode which is close to the accelerating pi-mode
- Probe signals from the cells combined with phase shifters and attenuators to suppress 0-mode
- Cavity signals are then combined with phase shift and attenuation
- Common phase and attenuation to tune feedback parameters remotely

Implementation



Measured Response



Observations

- Direct Loop behaves as predicted from model
- Suppresses beam loading instability
- Straight forward implementation
  - Relatively simple design
  - Robust
- Allows for physics parameters to be pushed