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Proposed RHIC 160 MHz RF System

J. Griffin

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Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

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DISCLAIMER

AD/RHIC-RD-2

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Fermilab

July 15, 1988

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PROPOSED RHIC 160 MHz (h=2052) RF SYSTEM

Start out with a reasonable set of specs and boundary conditions. Do what comes naturaly (to me at least) and look for insurmountable obstacles.

Requirements and assumptions

I assume a maximum dc beam current of 0.3 A, 57 or 114 bunches (with ~3 or 6 missing).

RF voltage ranging from ~500 kV upward to maximum affordable or ~11.5 MV, whichever comes first.

(16 cavities, 800 kV each unit, transit time factor ~0.9)

No comments on low frequency system at this time.

- Hypothetical cavity and PA

- Beam bunch shape, F.T., rf current recipe.

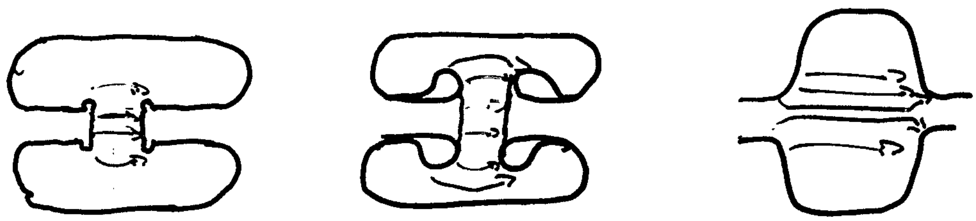
- Operation during storage
  - llrf system
  - beam loading compensation (detuning)
  - fast tuner - slow tuner
  - feed-back loop (or loops)
  - amplitude control
  - transient problem

- Operation during switching from low freq system.

- Operation during acceleration

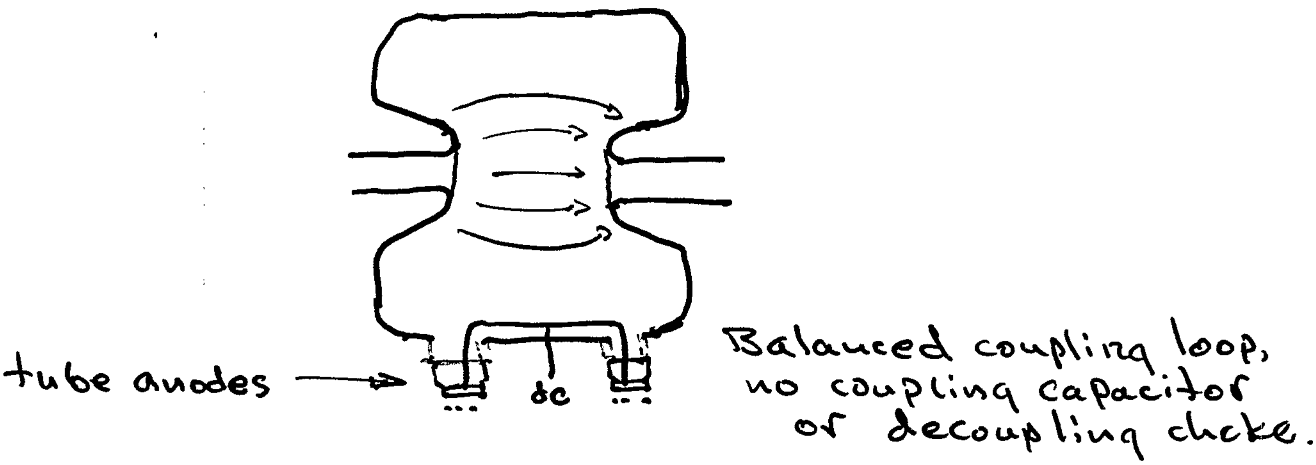
- Suggestions or wild and unruly comments

During the week we have seen several cavity design proposals..



Take average - compromise - use superfish

Result (my guess):



Assume 800 kV generated by 100 kW
(Two tubes delivering 50 kW each)

$$R_{sh} = \frac{(0.8 \times 10^6)^2}{2 \times 10^5} = 3.2 \text{ MOhm}$$

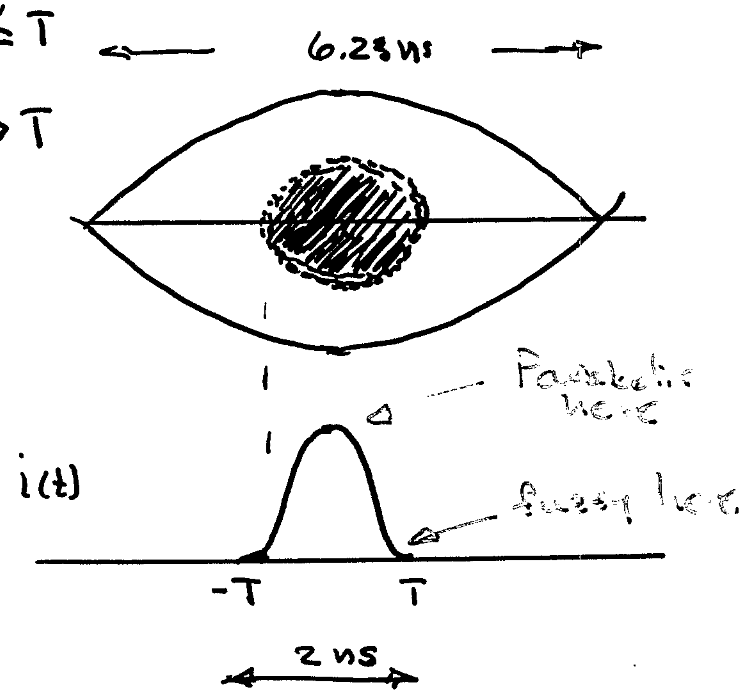
$\frac{R}{Q} = 125$ $\quad Q = 25600 \quad W_{st} = \frac{QP}{\omega} = 2.56 \text{ J}$

Time constant $\tau = \frac{2Q}{\omega} \approx 51\ \mu\text{sec}$.

(when unloaded - or driven by tetrodes!)

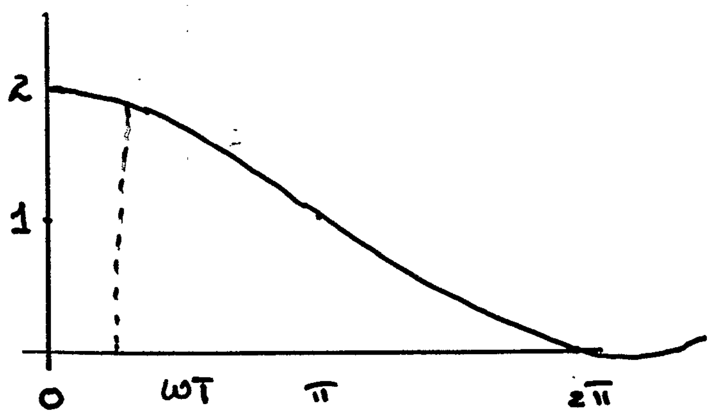
Assume bunch line charge projection

$$i(t) = I_m \cos^2 \frac{\pi t}{2T} \qquad |t| \le T$$
$$= 0 \qquad |t| > T$$



Normalized F.T.

$$F(\omega) = \frac{\sin \omega T}{\omega T} \left[\frac{\pi^2}{\pi^2 - (\omega T)^2} \right]$$



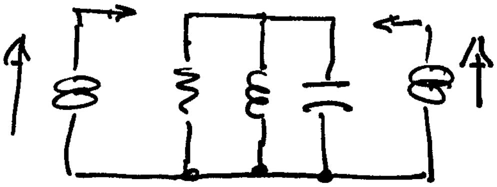
At 160.4 MHz
$\omega = 10^9$

The F.T., normalized to 2, gives the factor by which one must multiply the dc current to get the rf current at freq. ω for bunch half width T.

Here $\omega T = 1$ Factor is 1.87

RF current $I_i = (1.87)(0.28) = 0.52$ A

0.25 A i_g



i_i; beam image current ≅ 0.5 A

RF generator current (referred to gap) for 800 kV

$$i_0 = \frac{800 \times 10^3}{3.2 \times 10^6} = 0.25 \text{ A}.$$

Note - if tubes are operating at $V_a = 20$ kV and rf swing is full anode voltage, then step-up ratio is 40 : 1.

The tube - or tube pair - must be capable of delivering (40)(0.25) = 10 A of rf current. Looks ok.

Can we simply detune to compensate for beam loading?

Note - Automatic tuning (or detuning) feedback system probably uncomfortable with detuning angle > 60°.

One does not want to detune more than half (less is better) than one rotation band (78.16 kHz).

Detuning angle

$$\tan\Theta = \frac{i_i}{i_o}\cos\phi_s = \frac{i_i}{i_o} \quad \text{since } \phi_s = 180^\circ$$

$$\text{so } \tan\Theta \cong 2 \quad \left(\text{i.e. } \frac{0.5}{0.25}\right) \qquad \underline{\Theta = 63.4^\circ} \quad \sim \text{OK}$$

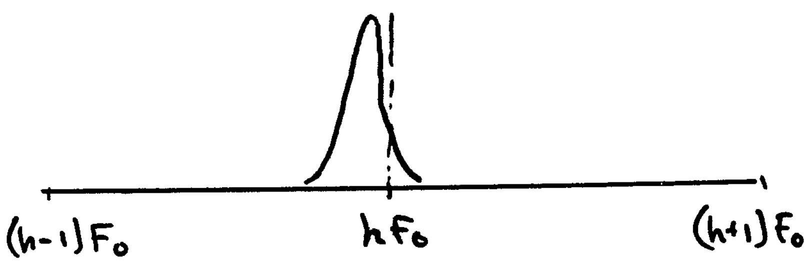
$$\text{also } \tan\Theta = 2Q\frac{\Delta\omega}{\omega} \quad \text{or} \quad 2Q\frac{\Delta f}{f} = 2$$

$$\Delta f = \frac{2f}{2Q} = \frac{160.4 \text{ MHz}}{22500} = \underline{7.1 \text{ kHz}} \qquad \text{OK}$$

about 0.1 rotation band.

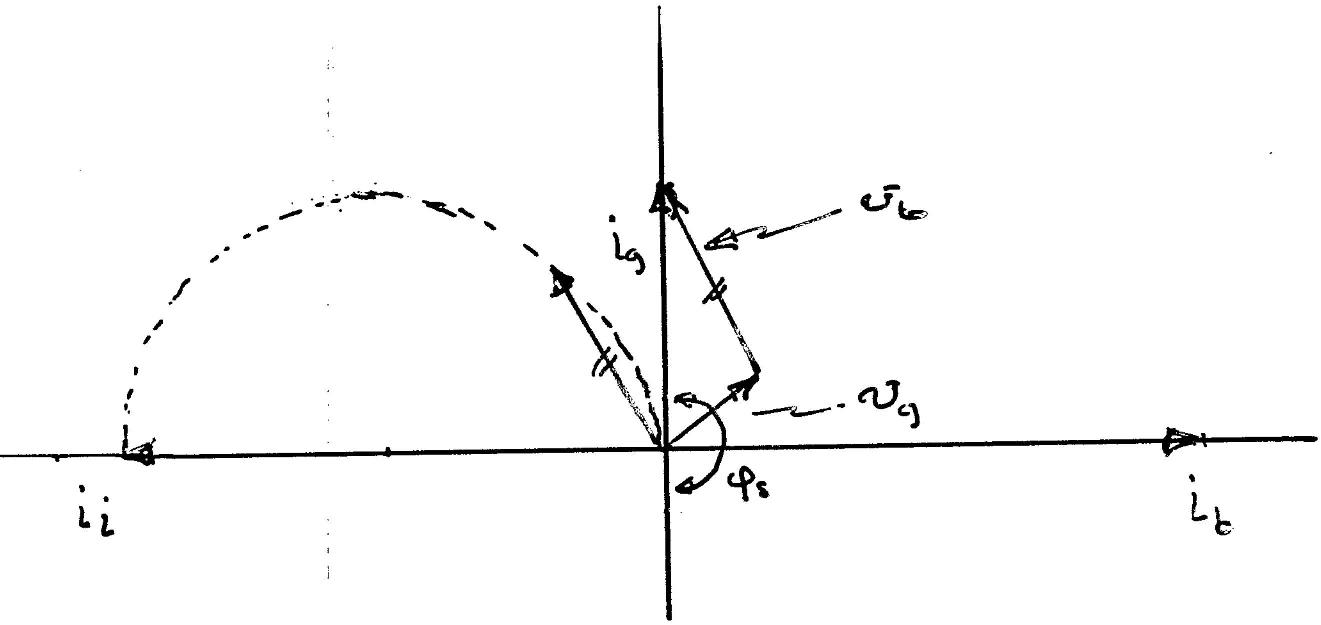
Cavity half-power bandwidth

$$\Delta f_{\frac{1}{2}} = \frac{f}{Q} \text{ also}$$



So: During store, steady state beam loading can easily be accounted for by a local cavity tuning feedback system.

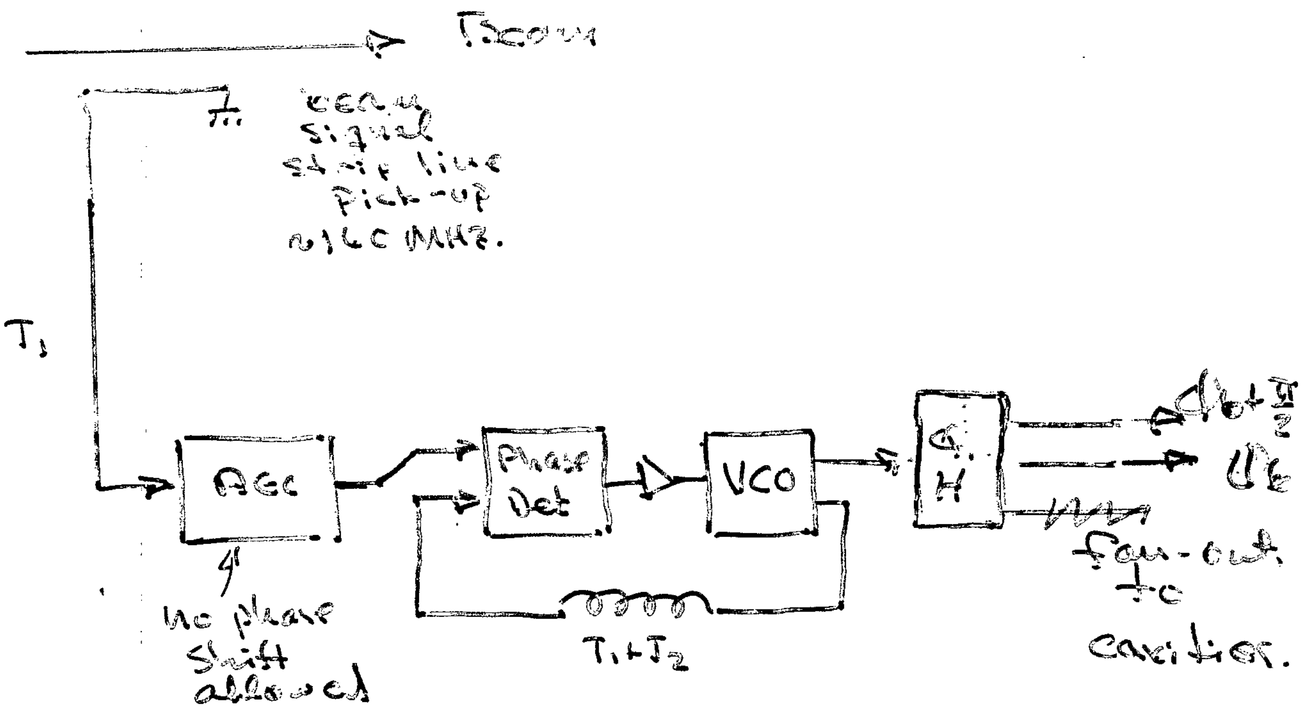
Note - Detuning is correct sign to establish Robinson stability.



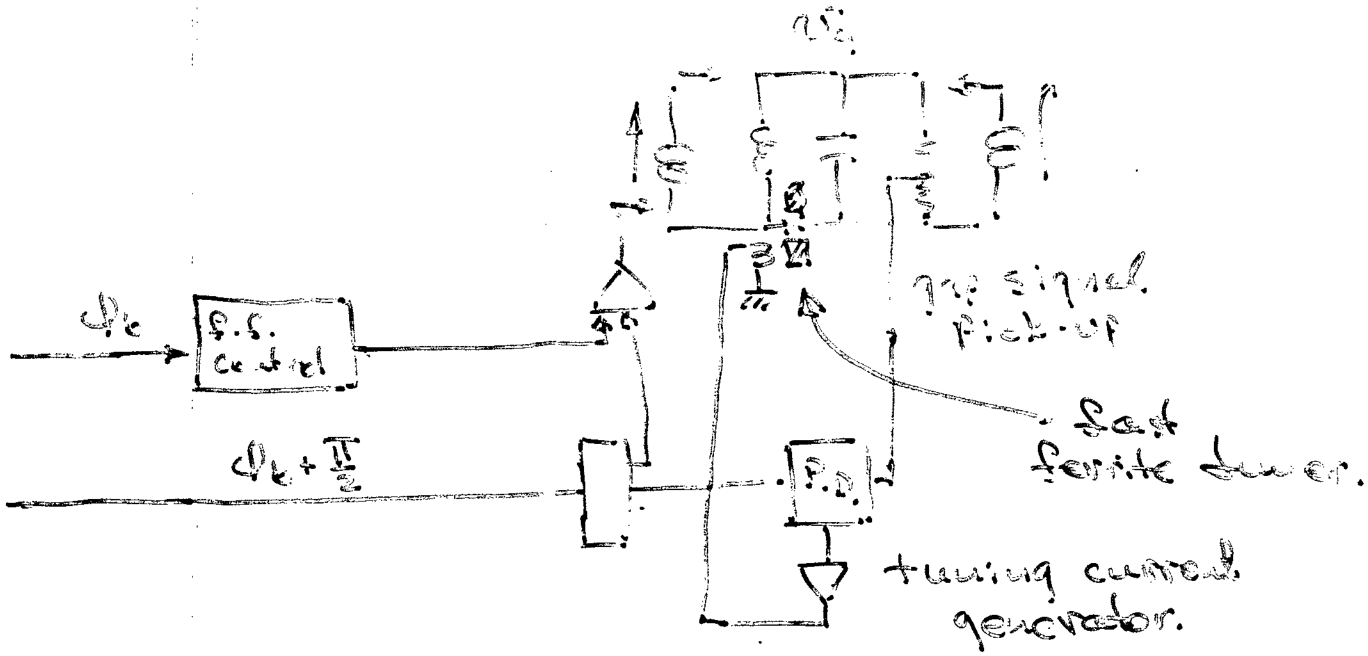
The net gap voltage is in quadrature with the beam current, as required for stationary bucket, and it is in phase with the generator current, so the load looks real to the generator (rf power source).

It is important to note here that if a bit of feed-forward current is introduced ~~at~~ the beam current phase, the detuning angle will be decreased just as if the beam current had been reduced. This would allow a decrease in the generator current and the net gap voltage, accompanied by a return back to the maximum value (~60°) of the detuning angle.

Low level of signal source required.



This system makes signals available at each of station at the beam phase and at the beam phase + $\pi/2$, as required to create a stationary bucket above transition.



A phase detector compares the gap voltage phase with ~~the~~ a representative of the generator current phase $\phi_t + \frac{\pi}{2}$ and detunes the cavity so that for that component of generator current the load looks real.

Tuning. We need about ± 10 kHz.

Tuner stored energy $\frac{\Delta W}{W} = 2\frac{\Delta f}{f} = 2.5 \times 10^{-4}$

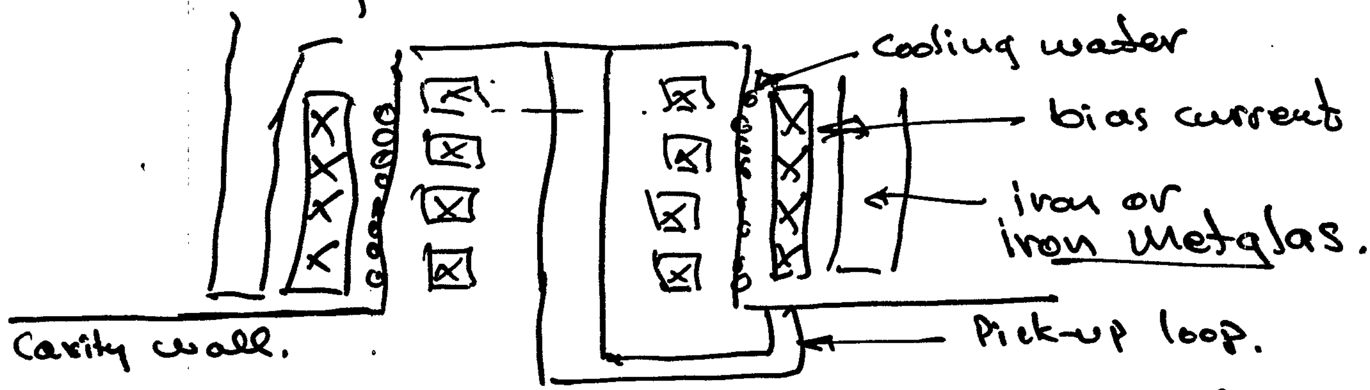
$\Delta W = (2.5 \times 10^{-4})(2.6) = 6 \times 10^{-4}$ Joules

Since one cannot bias all of the stored energy out of ferrite, better store about 10^{-3} Joules

Using Yt Ga microwave ferrite $Q \sim 3000$

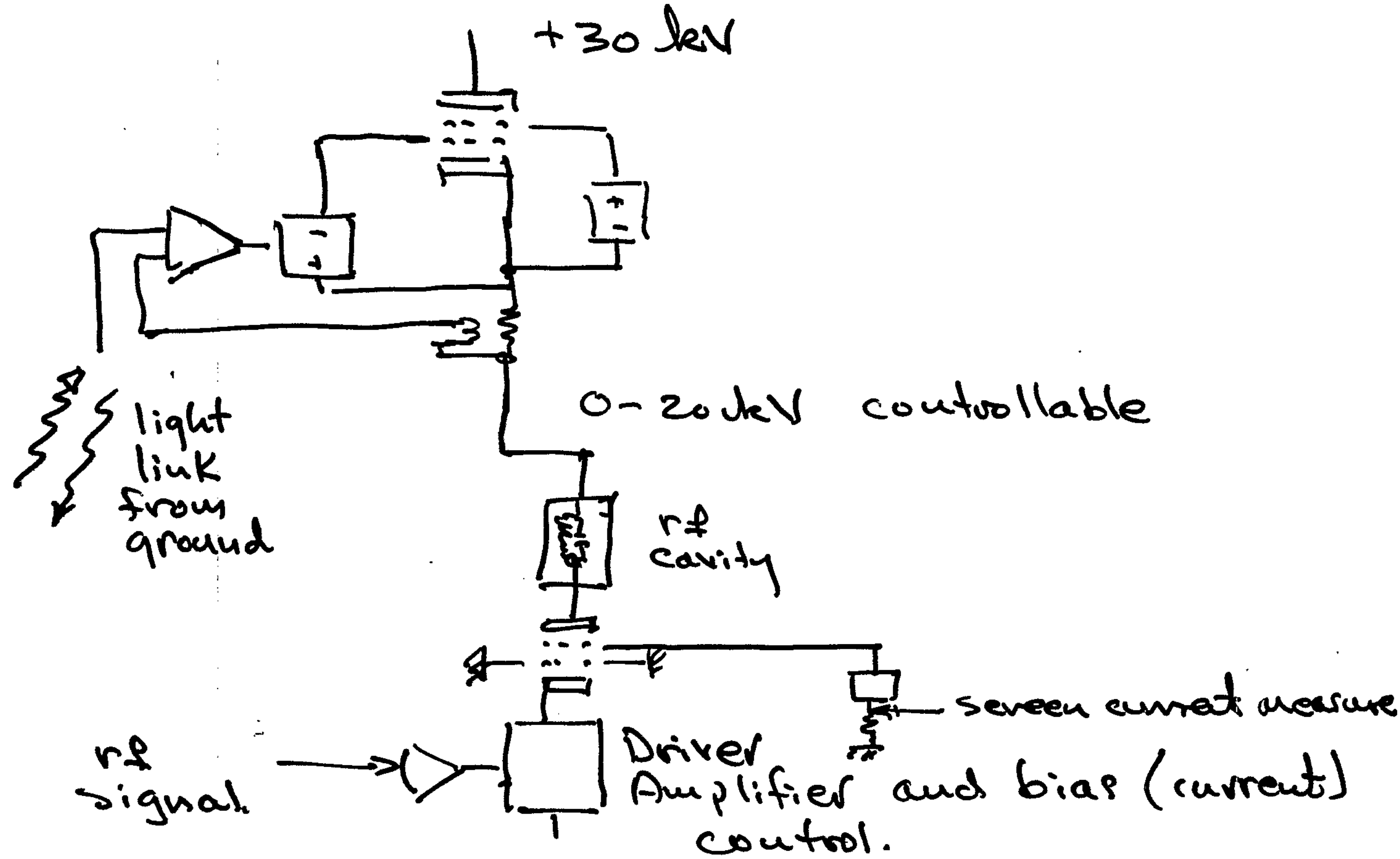
$$P = \frac{\omega W_{st}}{Q} = \frac{(10^9)(10^{-3})}{3 \times 10^3} \doteq 300 \text{ Watts.}$$

At 1 ws/cc one needs 300 cc ferrite, not much. Contained in cylindrical can on cavity wall. Evacuated ??



the can should be slotted longitudinally to allow rapid entry of bias flux to ferrite.

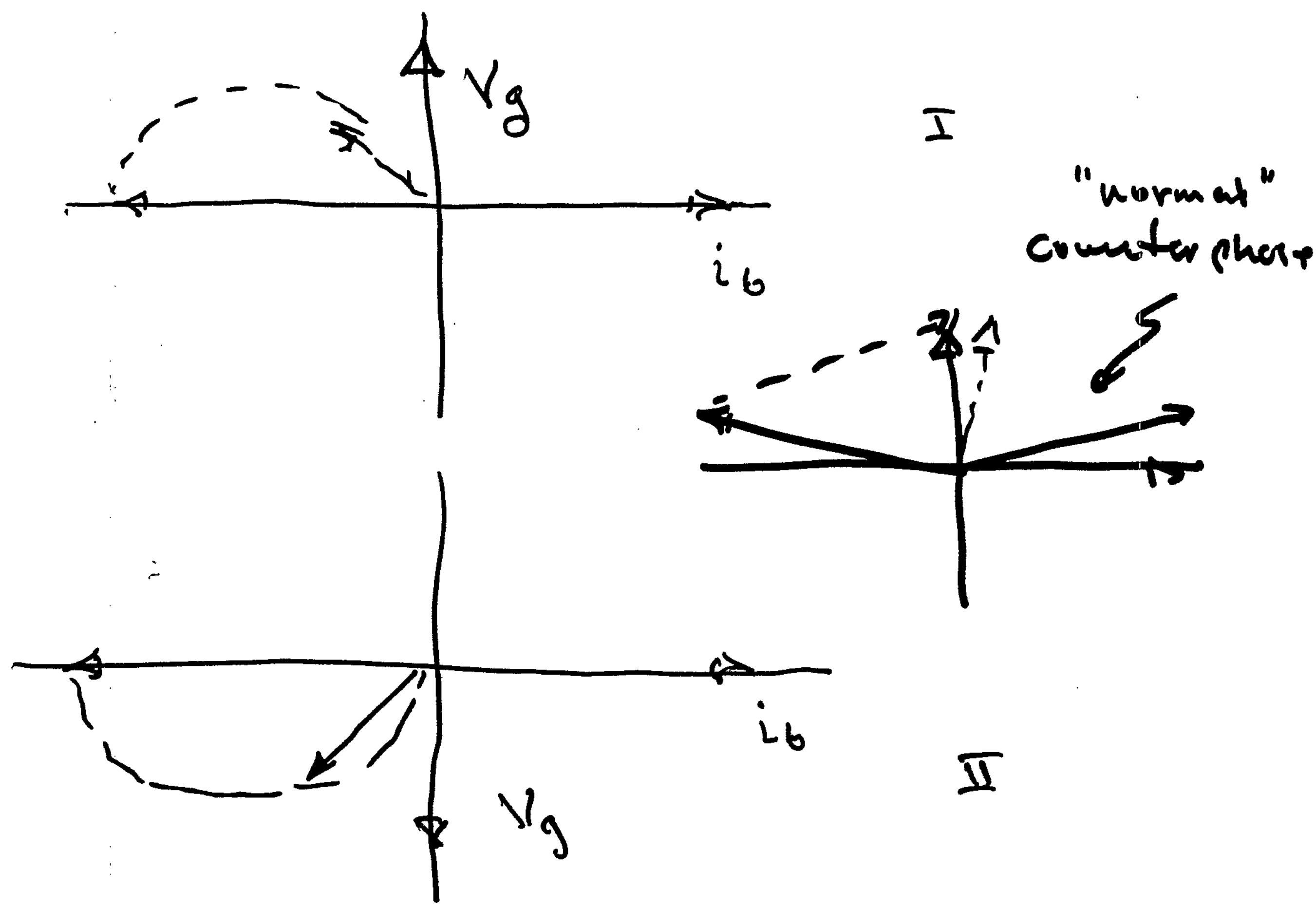
Each power amplifier should have a controllable series tube modulator so that its anode voltage can be adjusted quickly and precisely between zero and maximum (say 20 kV).



A feedback loop, sensing the sreen current of the PA tubes feeds a signal to the driver amplifier which adjusts the P.A. current so that the anode rf voltage swing is from Va to below the screen voltage (~ 400 V) (and, of course up to 2Va also). When the anode voltage swings below the screen, a sharp rise in Isg can be detected easily.

Now we have precise control of the phase and amplitude of the cavity, how do we control the total voltage?

By operating pairs of cavities 180° out of phase, i.e.



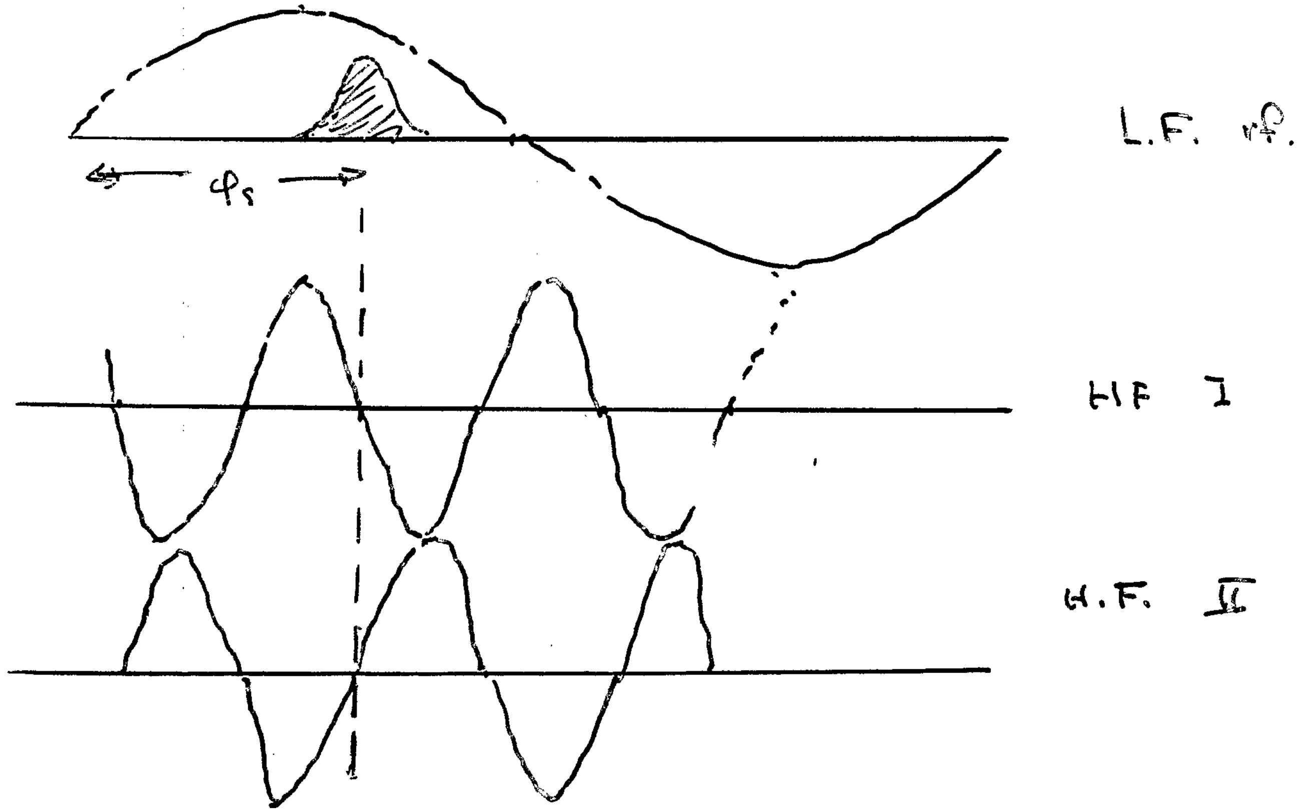
If I and II are each operating at, say 400 kV (requiring some feed-forward if full beam intensity) and I is raised to 800 kV - net stationary bucket voltage goes to 400 kV.

subsequently II can be lowered to ~ 200 kV then jumped in phase by 180 degrees so that it <u>adds</u> to I. At this time I is dropped by 200 kV (800 → 600 using series tube modulator program) Then each can be raised as needed. Finally all cavities are <u>in</u> phase at, say, half voltage, and all raised to maximum as needed.

Note that since there is always <u>some</u> net stationary bucket, the result of all + and − detuning will be Robinson <u>stable</u>.

During acceleration <u>all</u> high frequency cavities are op<u>erat</u>ed at about the 300 kV level and all counterphased as above, providing no net voltage save for error level which will generate only a focussing or defocussing s<u>lop</u>e. Since bunches are much longer, I_{rf} is smaller and lower generator current can be used with adequate detuning angle.

During acceleration:



There may be substantial beam induced voltage in H.F. system anyway, so this is a means of controlling it.

Note – at Fermilab protons and antiprotons pass in opposite directions through the same cavities. (8 cavities, 4 for each) The cavities are phased and located so that protons see only 4 cavities and antiprotons the other 4. The phases, (i.e. azimuthal position) of p's can be adjusted w.r.t. $\bar{p}$s.

The H.F. system must now be tunable over the entire β range. This can be done with a slow mechanical tuner so long as the fast ferrite tuner has the range to correct small errors enroute. Ferrite tuner range might have to be increased by ~ x 2 over earlier suggestion.

During acceleration the H.F. system is supposed to be "Robinson neutral". The low frequency system should be detuned to compensate for beam loading and provide Robinson stability.

This means that the phases and amplitudes of the cavities can be maintained sufficiently well so that one specie sees negligible interferance from the cavities directed at the other.

Using series tube modulator amplitude control one should be able to control the amplitude to a few hundred volts in a few hundred kV. ~ 1%.

So far I have invoked "local" amplitude and detuning feedback, but no local rf feedback. I <u>did</u> require some measure of controlled feed forward.

<u>CONCLUSION</u>

I have not yet encountered any insurmountable obstacles. Everything looks manageable in a fairly straightforward manner.

Suggestions

- Get a summer student (or etc.) to build a full scale cavity out of wood (or something). Two half-shells. Cover with thin copper foil (or Al.). Measure everything - transfer ratio, tuning range, spurious modes - etc. Make photographs -

- Since both cavities (or systems) are to operate simultaneously, look into possibility of making a cavity to do both jobs simultaneously. (i.e. low freq now ~ 50 MHz)

- Simulate acceleration with small amount of properly phased sixth harmonic of either sign.

[illegible signature]

Rough Cost Estimate -

Per rf station -

RF cavity	35 K
Power Amp. w/ driver	40 K
series tube modulator	120 K
Tuning bias supply	40 K
Ferrite tuner	15 K
control electronics	30 K
	280 K

Does not include anode power supplies -
one for each eight stations
2 x 30 kV 100 A - ?!

Global low level rf and
computer interface etc -