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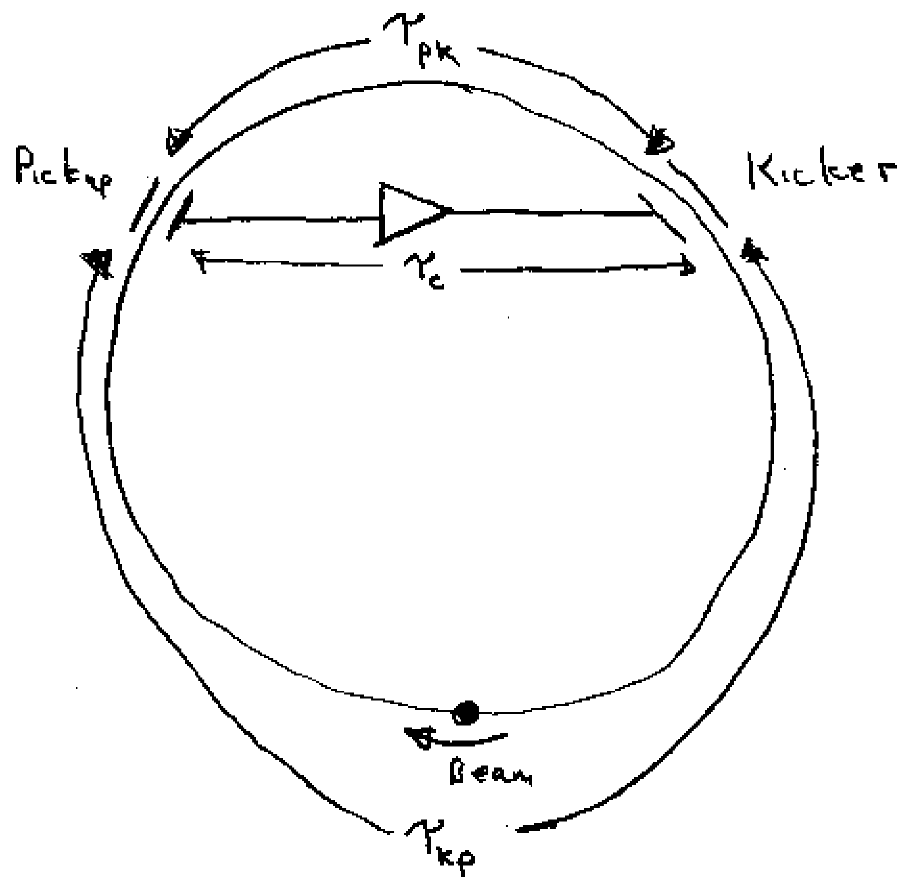
Purpose of Phasing

1) Time the systems.
2) Get the right phese for feedback

Timing of Cooling System



$$\tau_{pk} + \tau_{kp} \equiv T_{rev}$$

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We want

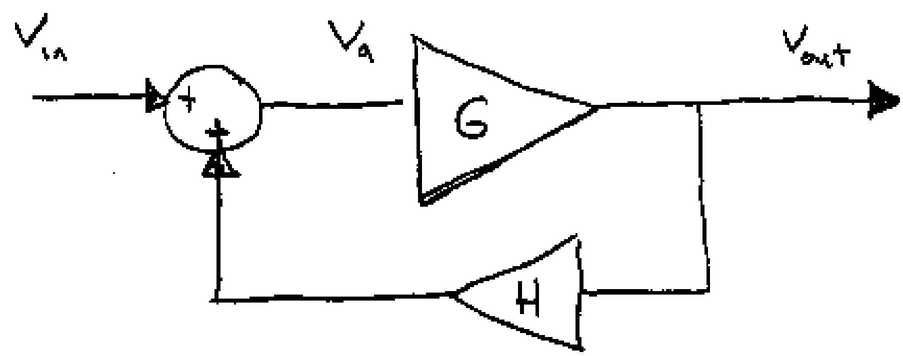
$$\tau_c = \tau_{pk}$$

We measure $\tau_c + \tau_{kp}$

If we make $\tau_c + \tau_{kp} = T_{rev}$

Then $\tau_c = \tau_{pk}$

Negative Feedback



$$V_{out} = G V_a$$

$$V_A = V_{in} + H V_{out}$$

$$V_{out} = G V_{in} + GH V_{out}$$

$$V_{out} = \frac{G}{1-GH} V_{in}$$

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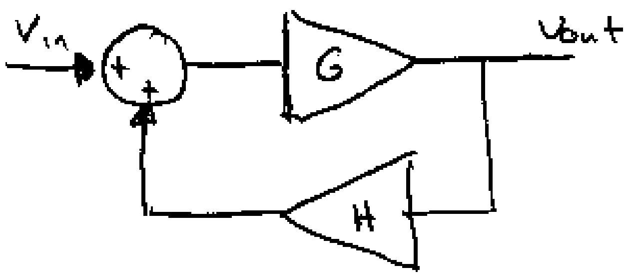
If $GH < 0$ negative feedback
Always stable.

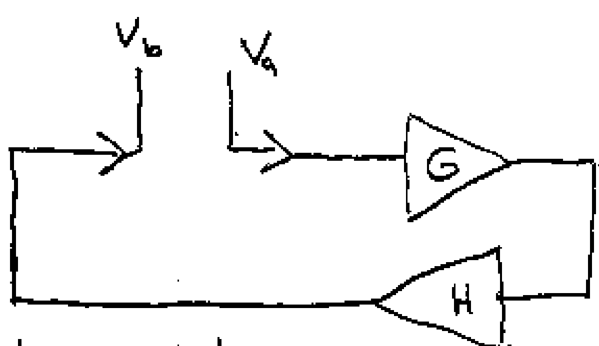
If $GH < 1$ sometimes stable

If $GH \geq 1$ positive feedback
Unstable.

GH is called the loop Gain.

Measuring the loop Gain





$$GH = \frac{V_b}{V_a}$$

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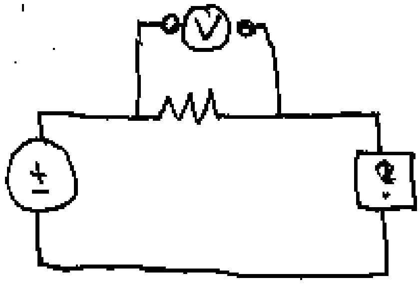
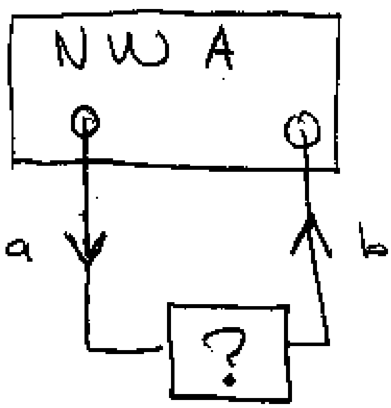
Network Analyzers

is a glorified Ohm meter.



Ohm meter has a source (a battery) and a detector (voltmeter across a resistor)

One measures the voltage drop across the known resistor and compares it to the source voltage



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A network analyzer sends out a sine wave at a single frequency out port (a)

$$a = V_a \cos(2\pi f t + \phi_a)$$

The network analyzer recieves the signal at port (b). Port (b) is a tuned reciever set to recieve signals only at the same frequency that port (a) is set to.

$$b = V_b \cos(2\pi f t + \phi_b)$$

The network analyzer displays:

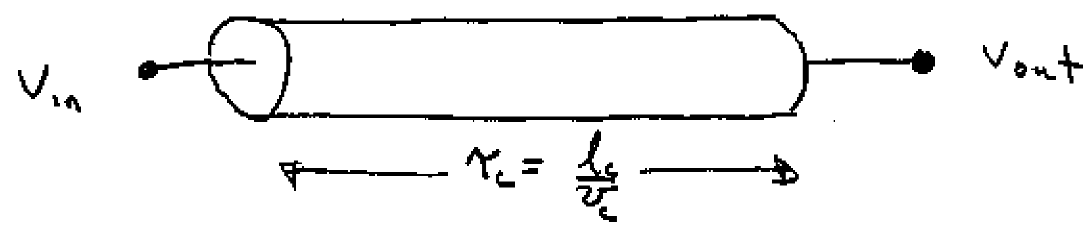
$$\text{Magnitude} = \frac{V_b}{V_a}$$

$$\text{Phase} = \phi_b - \phi_a$$

It measures the magnitude & phase at one frequency and steps over to the next frequency and makes the next measurement.

How the NWA measures delay.

Consider a co-axial cable of length τ_c



Let $V_{in} = V \cos(2\pi f t)$

Then V_{out} is the voltage at the input looking back τ_c seconds

$$V_{out} = V \cos(2\pi f (t - \tau_c))$$

$$= V \cos(2\pi f t - 2\pi f \tau_c)$$

$$\text{Magnitude} = \frac{V}{V} = 1$$

$$\text{Phase} = -2\pi f \tau_c$$

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Plot the phase versus frequency

The slope of the line is

$$\frac{\Delta \phi}{\Delta f} = -2\pi \tau_c$$

∴ The delay can be measured from the frequency slope of the phase

$$\tau_c = \frac{-1}{2\pi} \frac{\Delta \phi}{\Delta f} \qquad \Delta\phi \text{ in radians}$$

$$\tau_c = \frac{-1}{360°} \frac{\Delta \phi}{\Delta f} \qquad \Delta\phi \text{ in degrees.}$$

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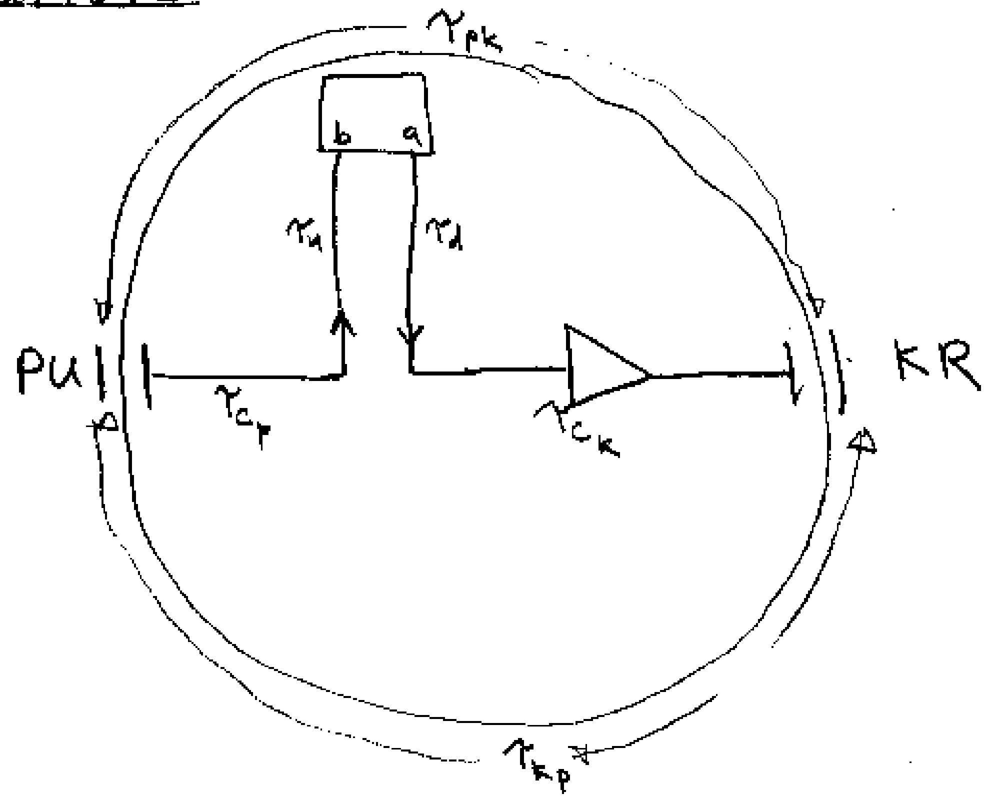
Calibrations



The NWA measures

$$-\frac{1}{2\pi}\frac{\Delta\phi}{\Delta f} = \tau_d + \tau_{ck} + \tau_{kp} + \tau_{cp} + \tau_u$$

We will have

$$\tau_{pk} = \tau_c = \tau_{cp} + \tau_{ck}$$

When

$$\tau_c + \tau_{kp} = T_{rev}$$

OR When

$$-\frac{1}{2\pi}\frac{\Delta\phi}{\Delta f} - (\tau_d + \tau_u) = T_{rev}$$

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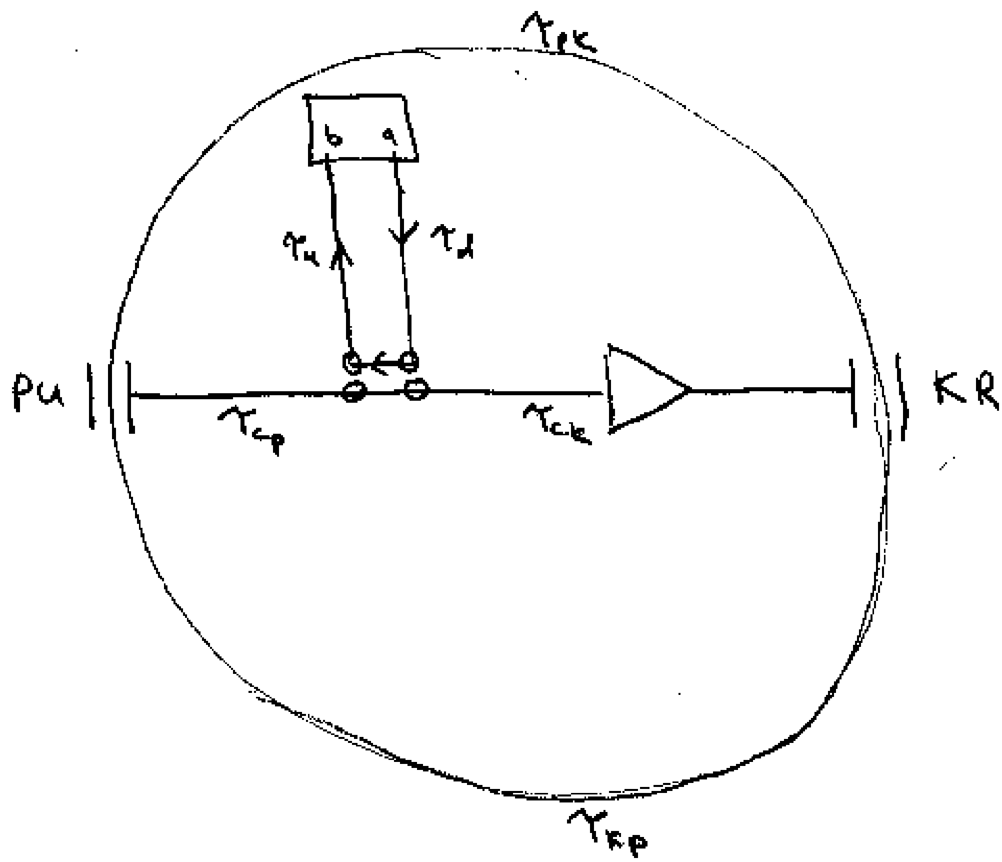
We need to know $\tau_d + \tau_u$



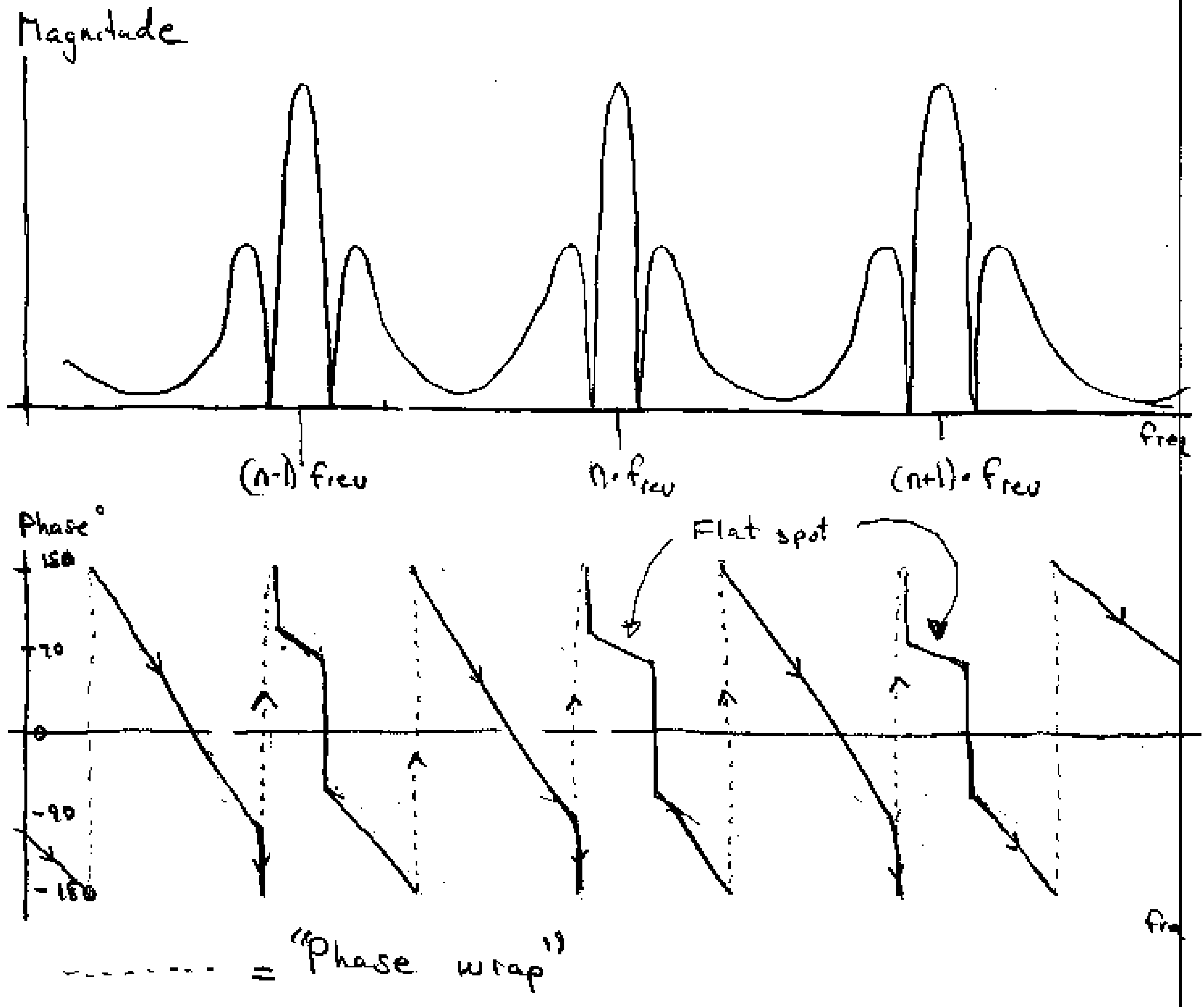
By connecting τ_d directly to τ_u and measuring the phase at each frequency we can determine $\tau_d + \tau_u$.

$$\phi_{cal} = -2\pi f\,(\tau_d + \tau_u)$$

The network analyzer will subtract this phase automatically from the measurement data when we <u>CALIBRATE</u> with τ_d connected directly to τ_u

Momentum Cooling Systems

The beam does not respond uniformly to all frequencies. For a momentum signal the beam has a strong response only near the revolution lines.



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At each revolution line, there are 3 humps in the response. Underneath the each hump there is a "flat spot" in phase. The center hump which is the largest is where we want to know the phase. For a "perfectly" timed sum mode signal, the central hump flat spot has a phase offset of 90°. One can think of this offset as the result of the pickup is AC coupled to the beam (kindof - sortof).

For a momentum measurement we will only measure the response at frequencies that are integer harmonics of the revolution frequency.

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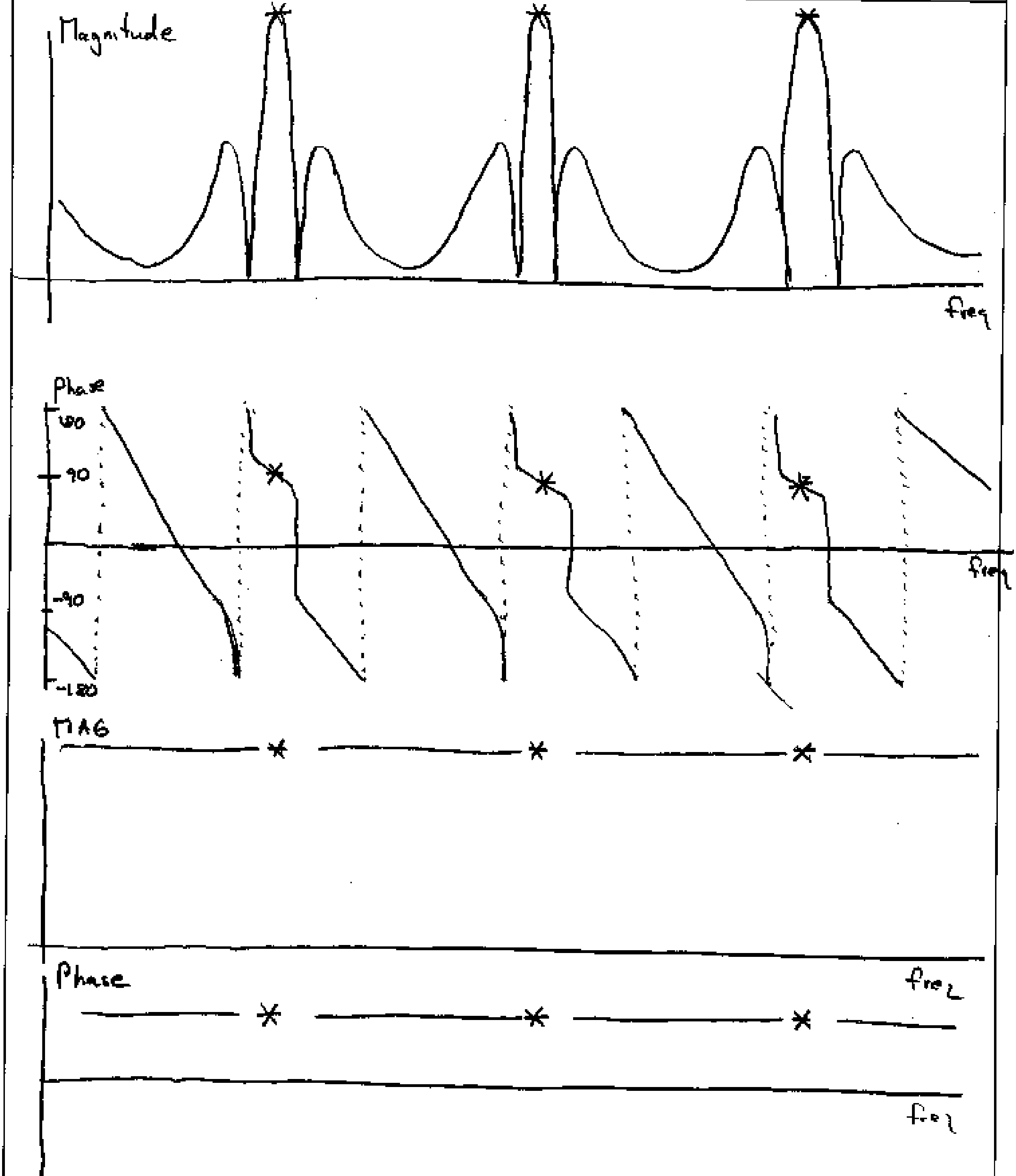

* = measured Points.

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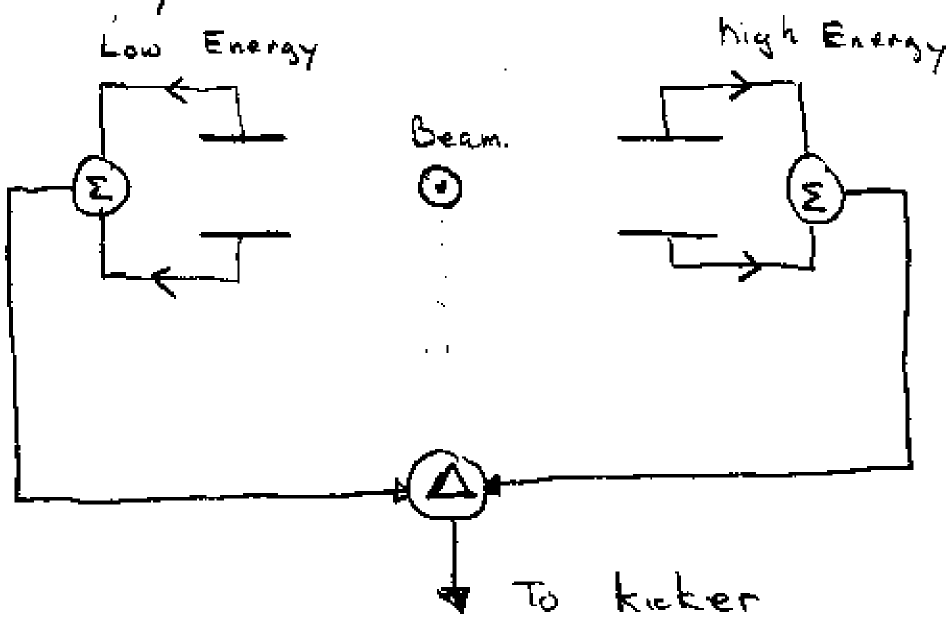
An Example: The Accumulator Core momentum System. This system is a Palmer type cooling system. It has its pickups in high dispersion.



Core located at ≈ 628,881 Hz

Low E PU located at ≈ 628,910 Hz

High E PU located at ≈ 628,881 Hz

To phase the system, one would not put beam at the core because the 2 sets of pickups would cancel each other and very little signal would be seen.

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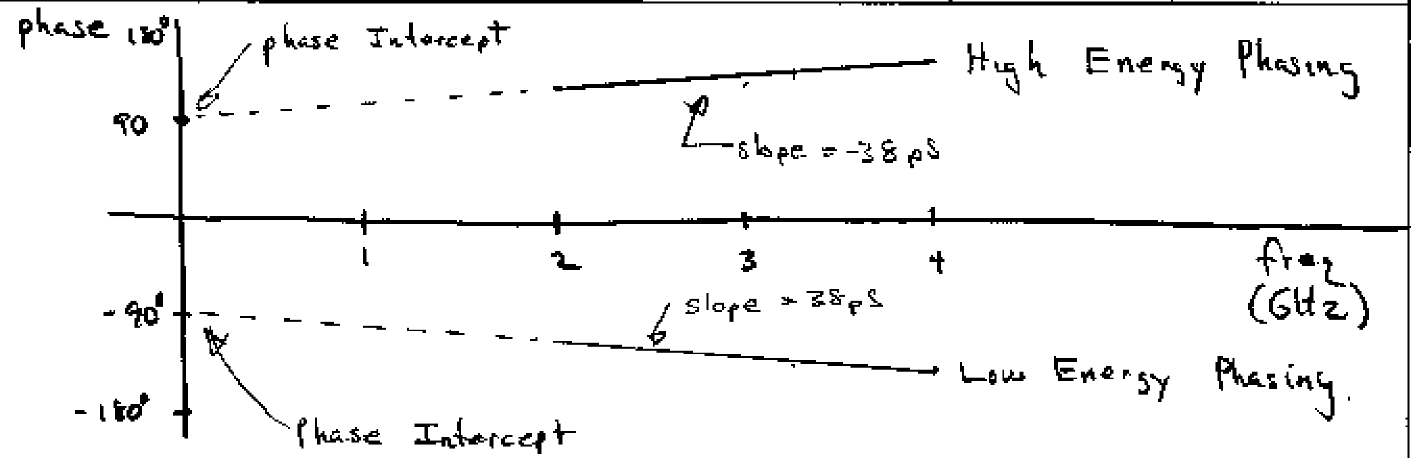
To phase the system, put the beam underneath the high energy set of pickups (or the low energy set of pickups.)

Measure the phase of the system at harmonics of the revolution frequency of the high energy (or low energy) beam.

The next step would be to adjust the trombone for the desired phase. Since the beam measurement was made on the high energy side where the beam takes a longer time to go around the machine, we want to make the delay shorter so that particles on the core orbit will have the right cooling delay

$$\Delta T = \frac{1}{2}\left(\frac{1}{628{,}881\,\text{Hz}} - \frac{1}{628{,}851\,\text{Hz}}\right) = -38\ \text{pS}$$

because going from A60 to A30 is 1/2 of machine



Likewise, if we had phased the system using Low Energy beam (underneath the Low energy PU), the low energy particles take a shorter time to go around (above transistion) than the core so we would want to add delay

The phase which is extrapolated to ZERO Hz is called the Phase Intercept One sees that the phase intercept of the High or Low energy pickups is ± 90° so that the core is centered at 180°.

NOTE: It is more than likely I got the sign of the phase intercepts wrong in this example.

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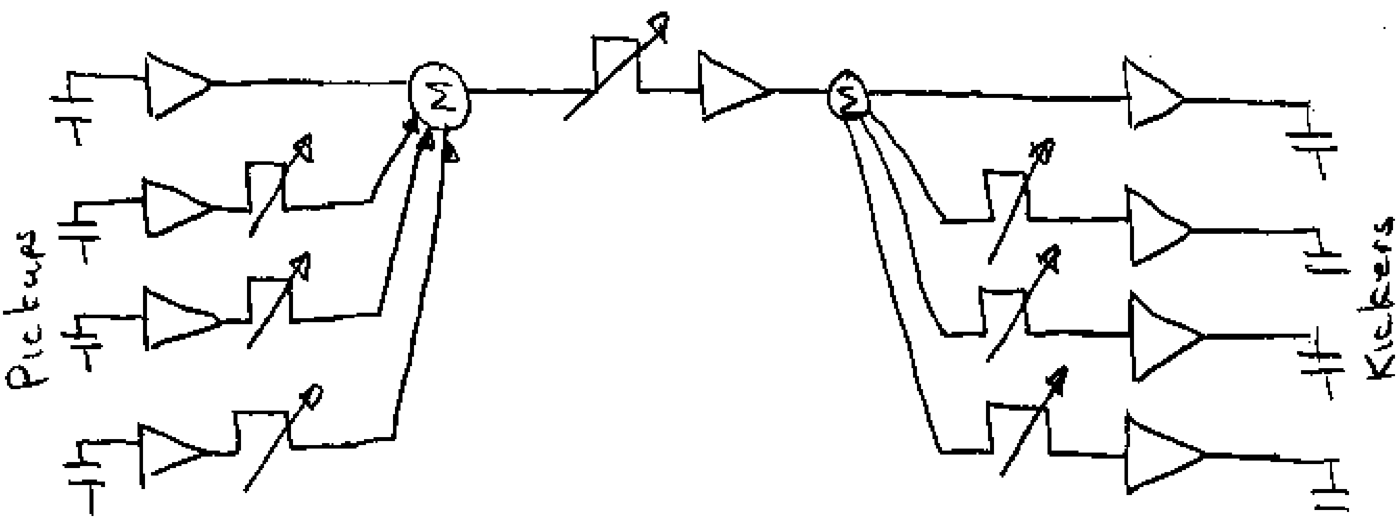
Phasing the Stacktail momentum system is similar to the Accumulator core system except there is no well defined "dead" spot as the core was for the Accumulator core system. Because of this, one needs "Magic" phase intercept & delay offset numbers from the design.

The Stack Tail system has a pickup Fan-in and a kicker Fan-out that must be phased as well.



X MeV leg of Stack Tail System

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The first step is to turn off all the pickup and kicker amplifiers except for the top set of pickup & kicker.

The overall system phase is set using the trombone in the middle of the picture.

Then using only the top kicker, the first pickup amp is turned off and the second pickup amp is turned on. The second pickup trombone is then set.

This procedure is done for each pickup trombone and a similar procedure is done for all the kickers using the top pickup amp and cycling thru each kicker.

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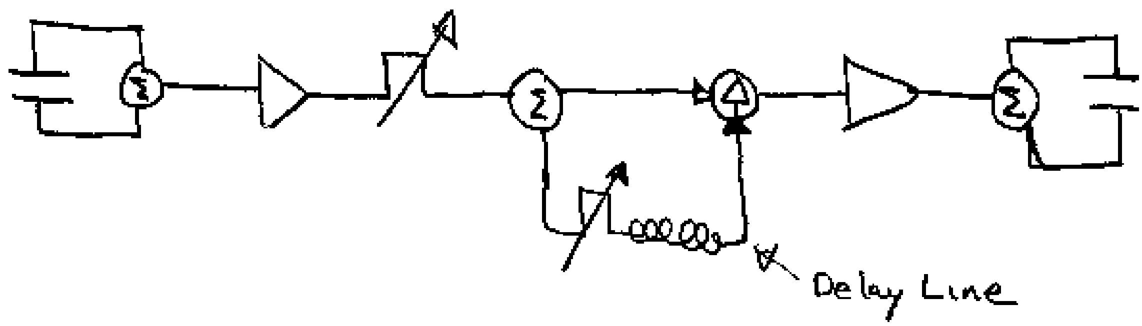
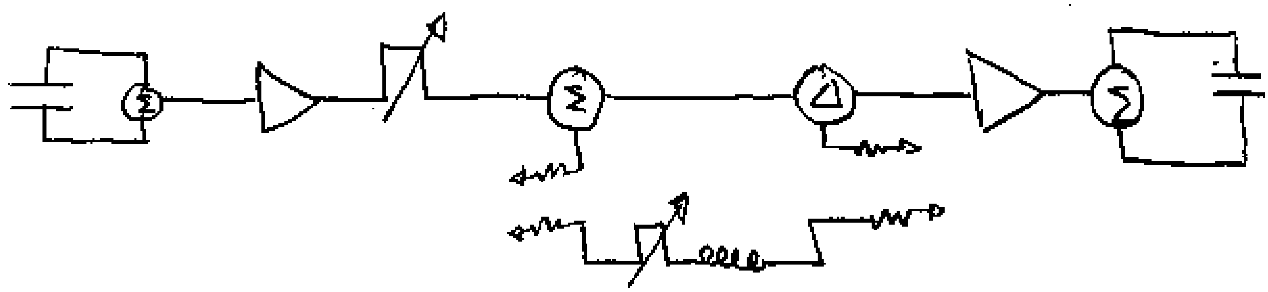
The Debuncher Momentum Systems

The Debuncher Momentum system is a notch filter system.



To see the beam signal, the notch filter must be turned off.



The system is phased at harmonics of the revolution frequency. The phase intercept should be ± 90°. Because the pickup is not in high dispersion, a delay offset is not needed

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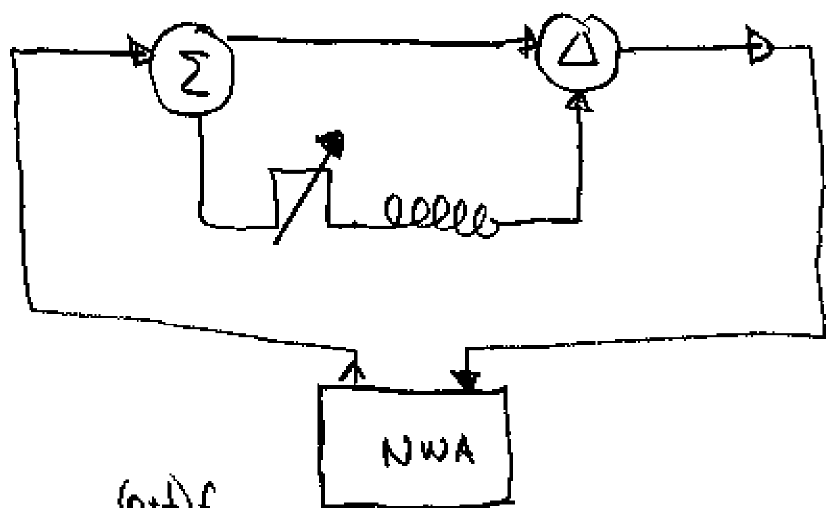
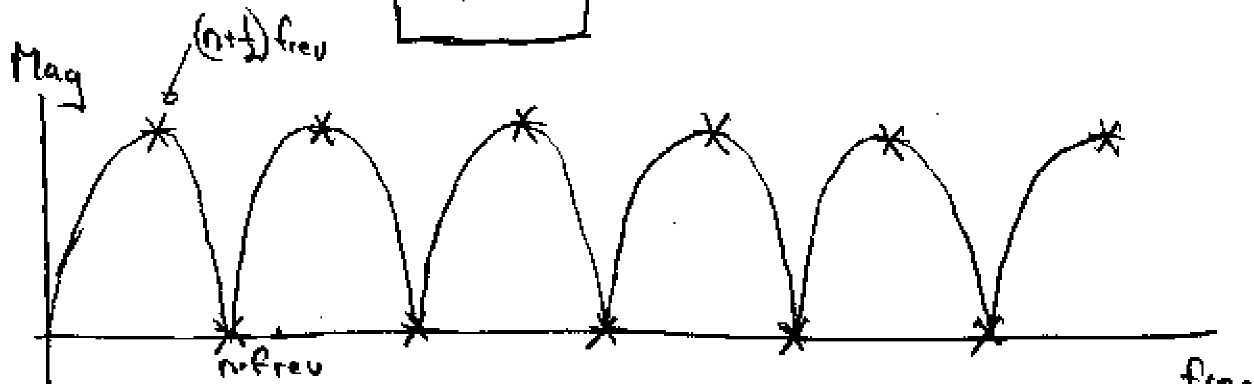
Debuncher Momentum System.

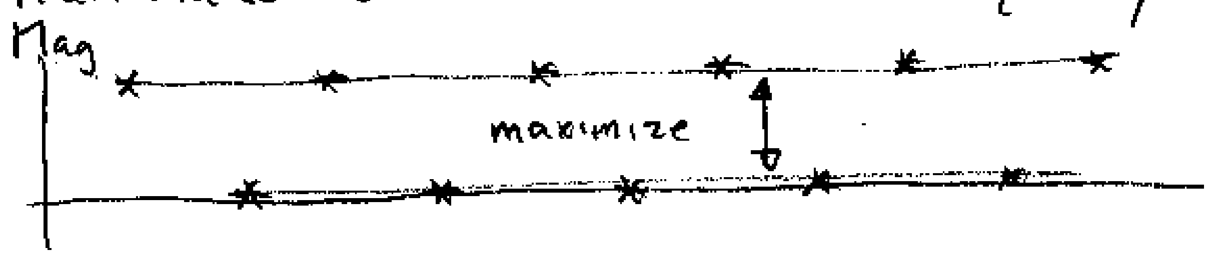
The notch filter is usually set with a comb signal or a network analyzer.





* = measurement points

The trombone is adjusted so that notchs fall on harmonics of the revolution frequency.



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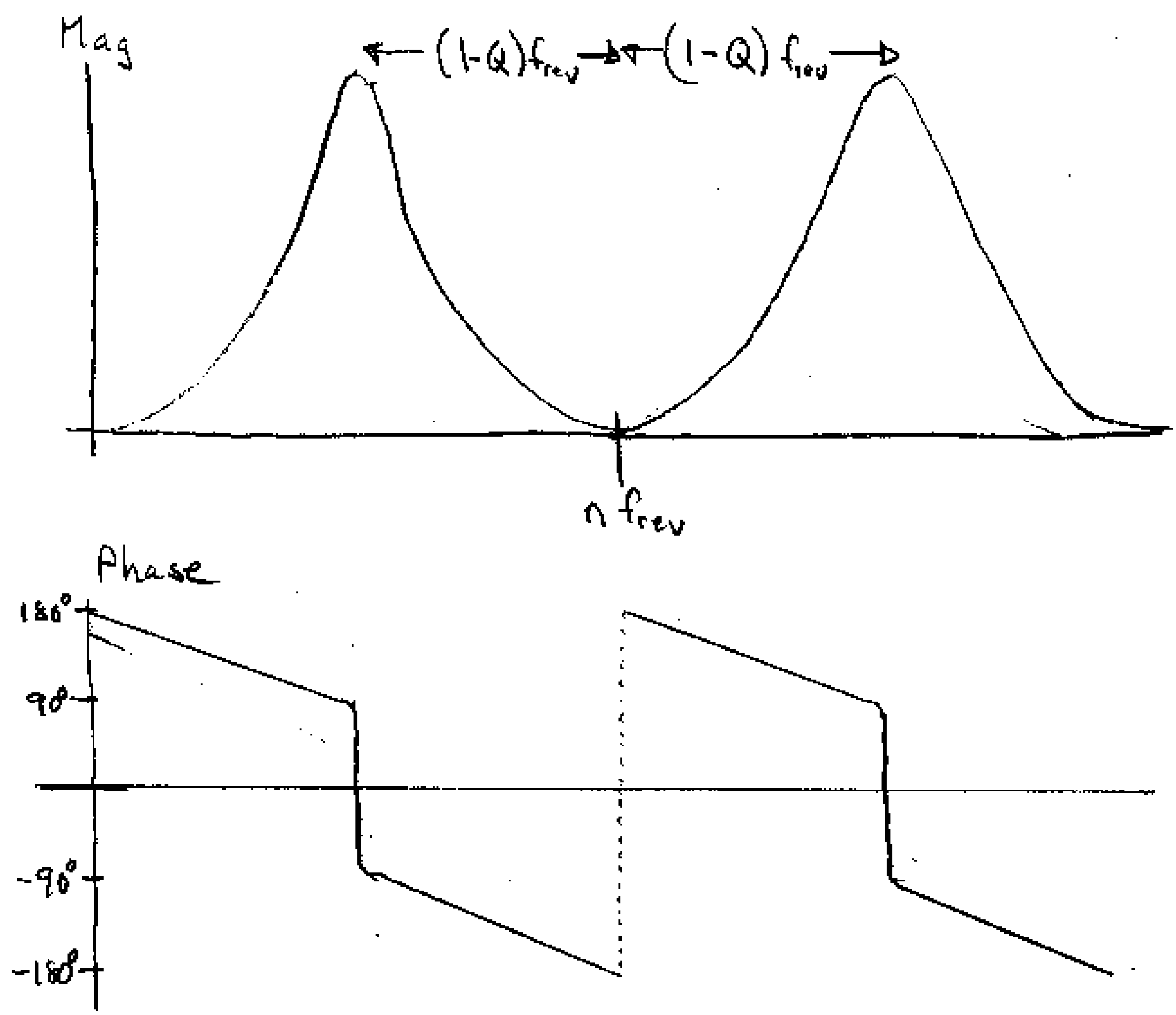
Betatron Systems

First Step is to measure over one revolution band.



Q = fractional tune

Note that at the peak of the response, the phase is changing rapidly.

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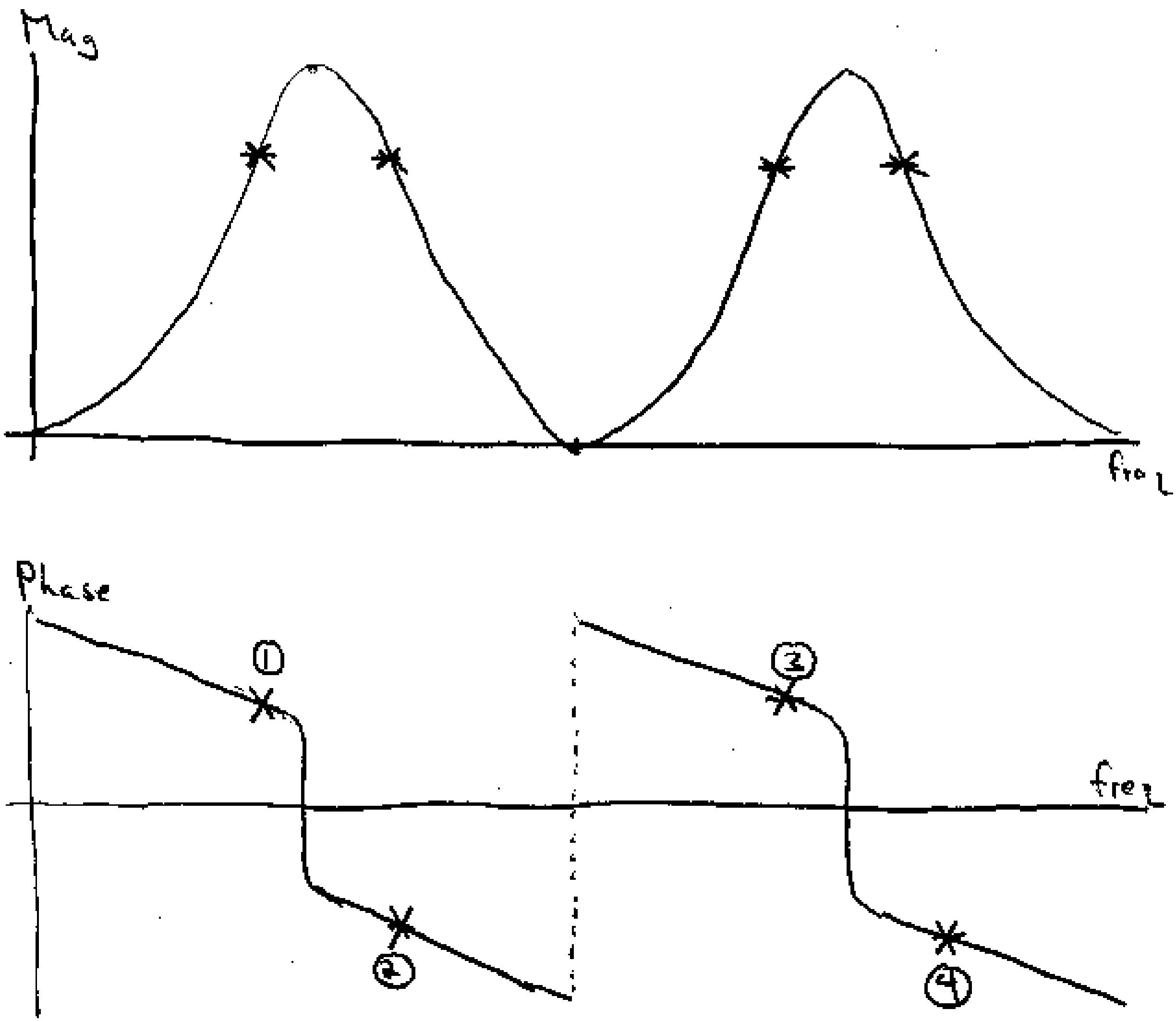
∴ The peaks would not be a good place to make the measurements.



* would be the best spot for measurements because the phase is flatter.

The average of ① & ② would give the upper sideband & the average of ③ & ④ give the lower sidebands. ∴ We need to make 4 measurements per revolution band.

These measurements can be defined by the following parameters.

$$F_{center} = \frac{m1 + m2 + m3 + m4}{4}$$

$$Harmonic = Integer\left(\frac{F_{center}}{F_{rev\_guess}}\right)$$

$$F_{rev} = \frac{F_{center}}{Harmonic}$$

$$Tune = 1 - \left(\frac{\frac{m4+m3}{2} - \frac{m2+m1}{2}}{2 \cdot F_{rev}}\right)$$

$$Beam\ Width = \frac{\frac{m4-m3}{2} + \frac{m2-m1}{2}}{Harmonic}$$

i.e. $\begin{pmatrix} m1 \\ m2 \\ m3 \\ m4 \end{pmatrix} \Rightarrow \begin{pmatrix} Harmonic \\ F_{rev} \\ Tune \\ Beam\ Width \end{pmatrix}$

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For any harmonic N

$$P1 = N \cdot F_{rev} - (1-Q)F_{rev} - \frac{BeamWidth \cdot N}{2}$$

Schottky bands get wider

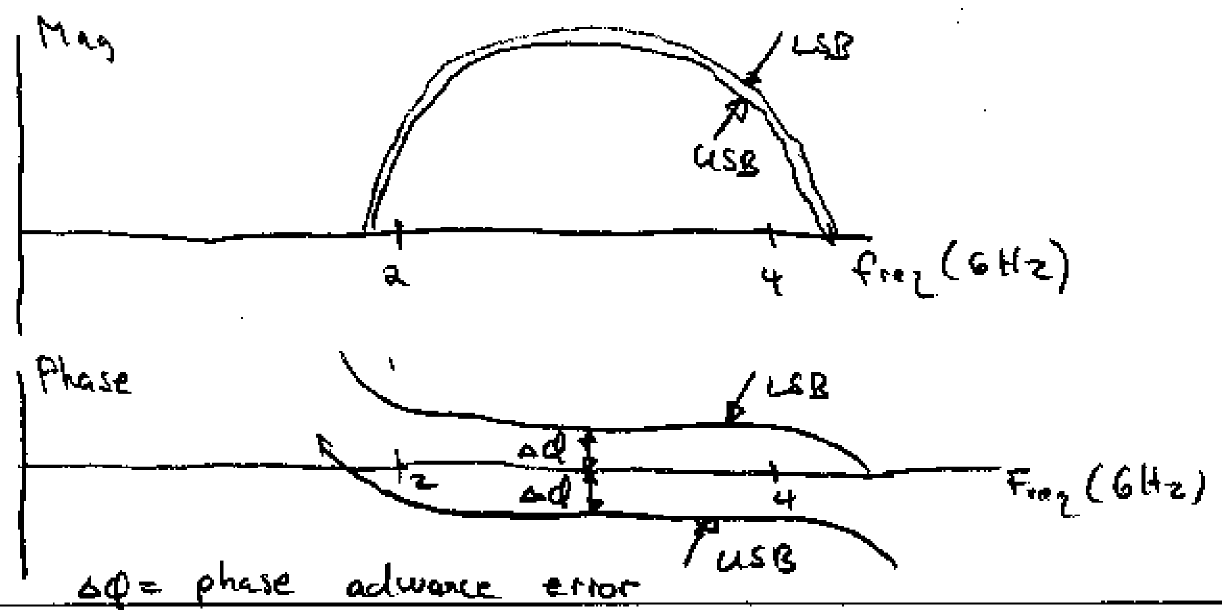
$$P2 = N \cdot F_{rev} - (1-Q)F_{rev} + \frac{BeamWidth \cdot N}{2}$$

$$P3 = N \cdot F_{rev} + (1-Q)F_{rev} - \frac{BeamWidth \cdot N}{2}$$

$$P4 = N \cdot F_{rev} + (1-Q)F_{rev} + \frac{BeamWidth \cdot N}{2}$$

$$\text{Upper Sideband} = \frac{P1 + P2}{2}$$

$$\text{Lower Sideband} = \frac{P3 + P4}{2}$$



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If the phase advance between pickup and kicker is an odd multiple of 90° then the phase of the upper sideband is the same as the phase of the lower sideband.

If the phase advance between pu & kicker is:

$$\text{Phase advance} = (2n+1)90^\circ + \Delta\phi$$

then the phase between upper & lower sideband is $2\Delta\phi$