
SC cavity used as beam phase detector

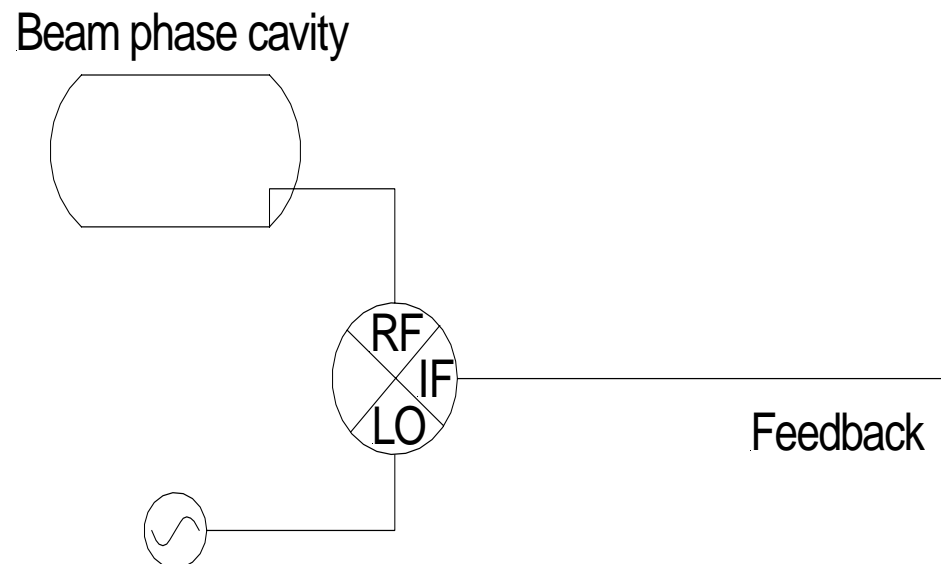
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Beam phase detector overview

In order to achieve good quality beam, it is important to detect the phase difference between beam and RF and give a phase correction signal to either the beam source or the RF oscillator.



Beam phase cavity

*The function of the cavity in phase detecting mode is to couple beam energy into RF energy.
A cavity that is efficient at coupling rf energy into the beam is also, not surprisingly,
efficient at coupling rf energy out of the beam.*

Basic requirements:

- 1. Stabilized temperature*
- 2. Stabilized humidity*

Cavities

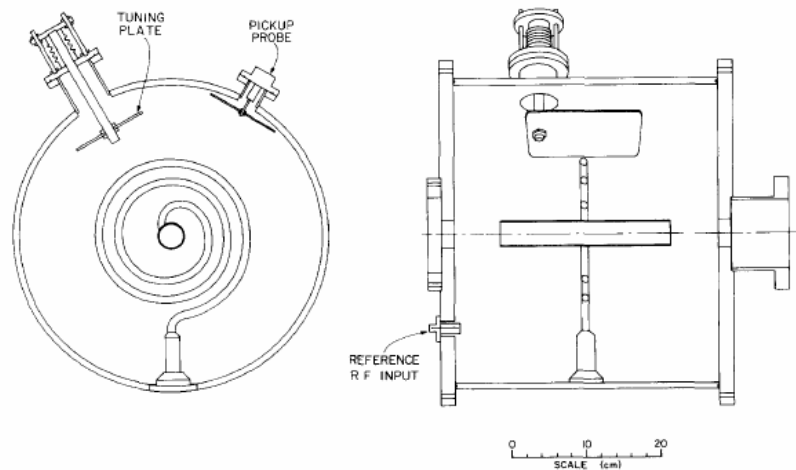


Fig 1 A 48.5 MHz, spiral-loaded resonant cavity for beam detecting beam bunches. Also shown are the rf input and output coupling, and a movable tuning mechanism. The ends of the cavity are demountably joined to the cylindrical portion of the housing with an indium-gasket high-vacuum seal.

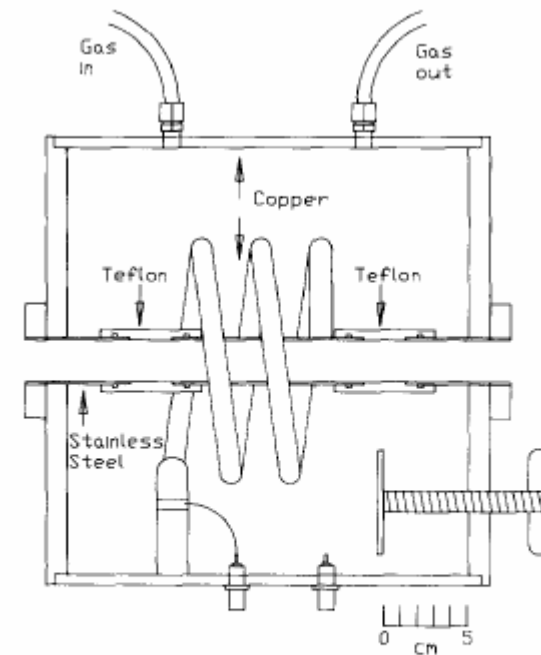


Fig 1. The 49.6 MHz resonant cavity used for beam-phase detection. Shown are the signal coupling loop, test signal input, tuner and temperature-stabilizing gas lines. Conflat flanges are on the drift tube ends.

Pickups

Two ways of coupling:

- 1. Capacitively (plate, button)*
- 2. Inductively (wire, loop)*

Sensitivity

The energy gain the particle get from RF when passing accelerating cavity
 Is the same as the work the particle will do when it passing detecting cavity
 And exciting RF field:

$$\Delta W = q \int E(z) \cos(\omega t + \phi) dz$$

$$\Delta W = q \cos \phi * \Theta * T(\beta) * V$$

$$T(\beta) = \frac{\int_{-\infty}^{+\infty} E(z) \cos\left(\frac{\omega z}{\beta c}\right) dz}{\text{Max} \int_{-\infty}^{+\infty} E(z) \cos\left(\frac{\omega z}{\beta c}\right) dz} \quad \text{Velocity Acceptance}$$

$$\Theta = \frac{\text{Max} \int_{-\infty}^{+\infty} E(z) \cos\left(\frac{\omega z}{\beta c}\right) dz}{\int_{-\infty}^{+\infty} |E(z)| dz} \quad \text{Transit Time Factor}$$

The total power the beam give out will be

$$W_b = N f_0 k q \Theta T(\beta) V = I_b \Theta T(\beta) V$$

At steady state,

$$W_b - W_o - W = dU / dt = 0$$

$$W_b = (1 + \beta) W$$

$$R_0 = \frac{V^2}{W}$$

Outcoupled power:

$$W_o = \frac{I_b^2 \Theta^2 T^2(\beta) R_{sh} \beta}{1 + \beta}$$

Voltage on the external load R_0

$$V_o = \sqrt{W_o R_0}$$

Sensitivity, the rf voltage per unit beam current:

$$S = \Theta T(\beta) \sqrt{R_{sh} R_0} \sqrt{\frac{\beta}{1 + \beta}}$$

SC cavity as phase detector

The reason for choosing SC cavity is the shunt impedance is high so the sensitivity is high, it can detect very low current beam.

A fundamental control problem with SCRs is microphonic fluctuations of the resonator's resonant frequency. It prevent direct use of the induced rf signal in the SCR for beam phase detection.

some initial level of rf field inside the resonator is required for locking the cavity

Summarizing, using an SCR as a beam phase pickup, the following three conditions are required:

(i) Both amplitude and phase feedback loops have to be locked—some rf is required.

(ii) Reference rf level has to be low.

(iii) Resonator rf field is a superposition of a reference rf field and beam-induced field.

Principles

The resultant resonator rf vector can be written as

$$A_{\Sigma}(t) \exp[i\phi_{\Sigma}(t)] = A_{\text{rf}} \exp[i\phi_{\text{rf}}(t)] + A_b \exp(i\phi_b),$$

Amplitude and phase

$$A_{\Sigma}(t) = A_{\text{rf}} \sqrt{1 + p^2 + 2p \cos(\phi_{\text{rf}} - \phi_b)},$$
$$\phi_{\Sigma}(t) = \arctan \frac{\sin\phi_{\text{rf}} + p \sin\phi_b}{\cos\phi_{\text{rf}} + p \cos\phi_b},$$

For small p , the amplitude of the resultant field is

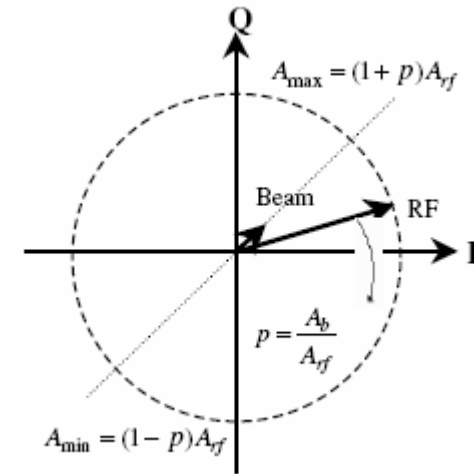
$$A_{\Sigma}(t) \approx A_{\text{rf}} [1 + p \cos(\phi_{\text{rf}} - \phi_b)].$$

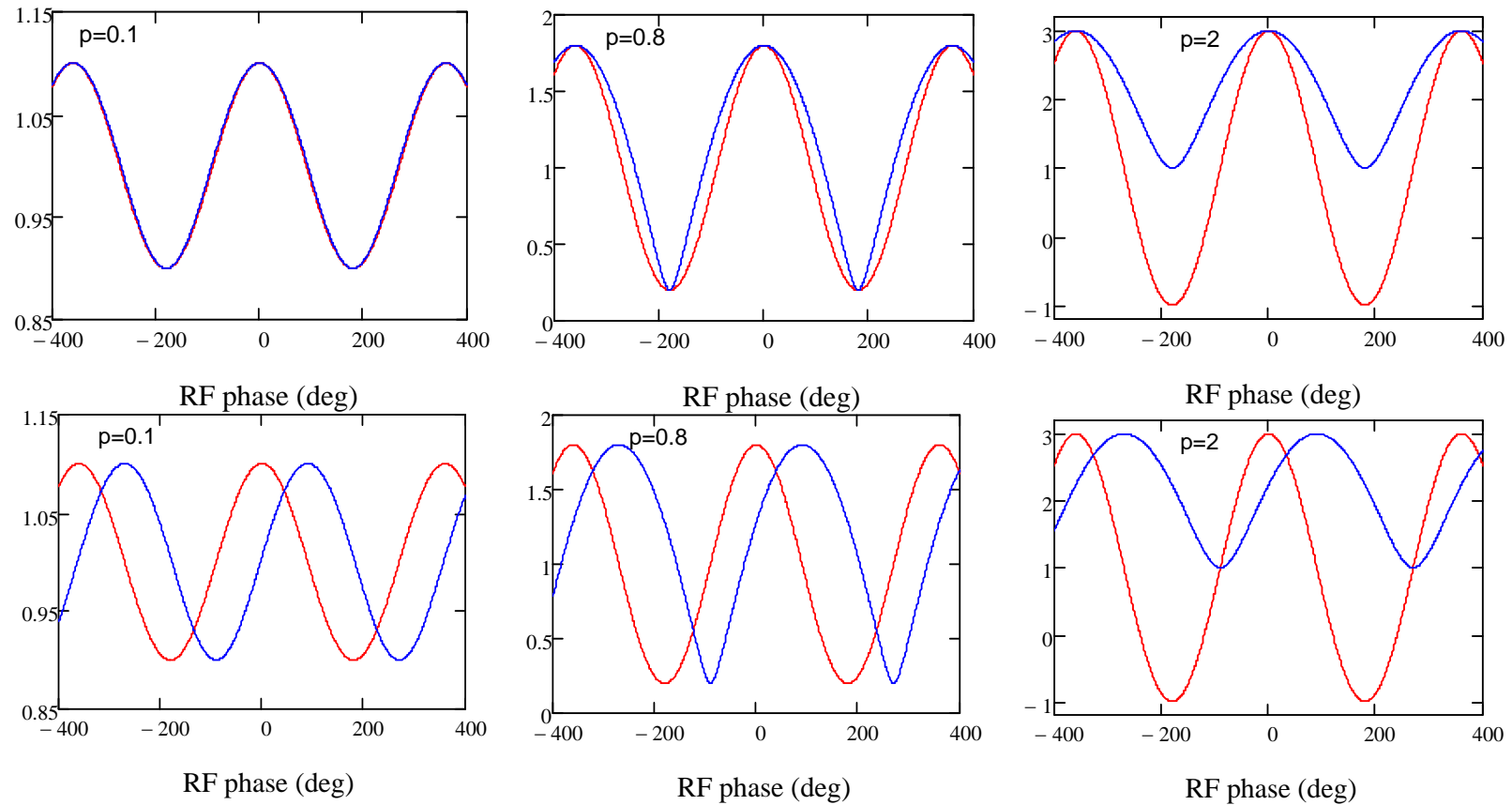
Suppose we apply a linear circular phase modulation to the reference rf field:

$$\phi_{\text{rf}}(t) = \omega_r t = 2\pi F_r t,$$

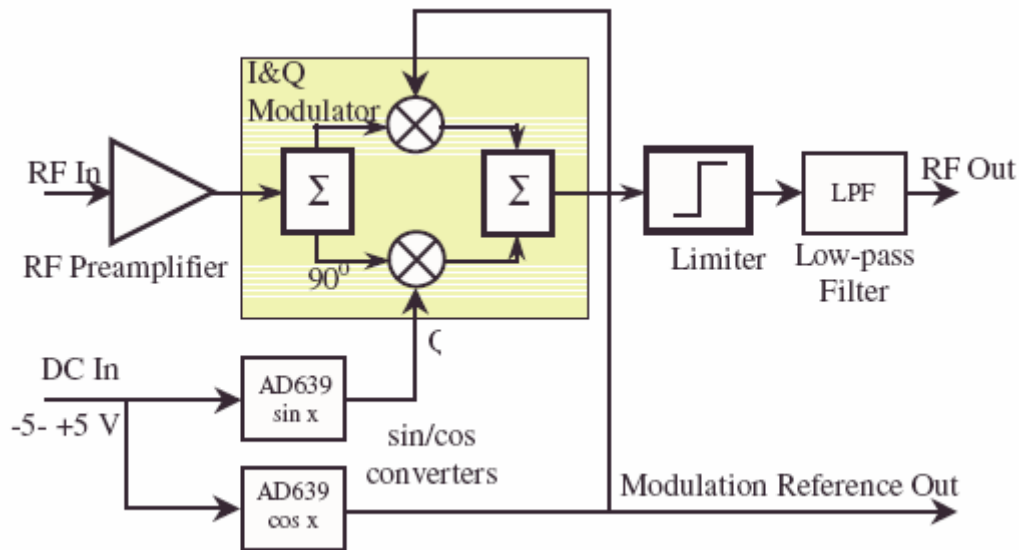
Thus, by applying a linear circular phase rotation to the reference rf field, and measuring the phase shift between the resonator's resultant signal magnitude and modulation signal, one can measure the beam-induced signal phase.

$$A_{\Sigma}(t) = A_{\text{rf}} [1 + p \cos(\omega_r t - \phi_b)],$$

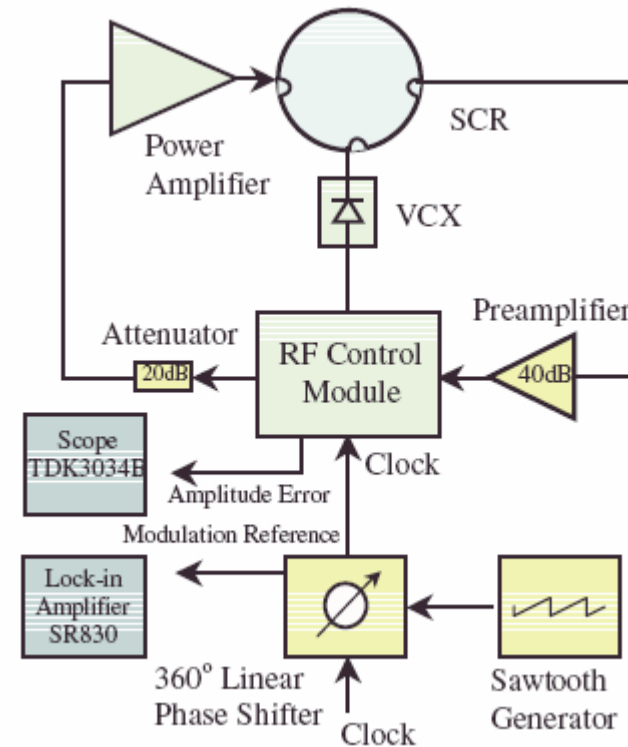




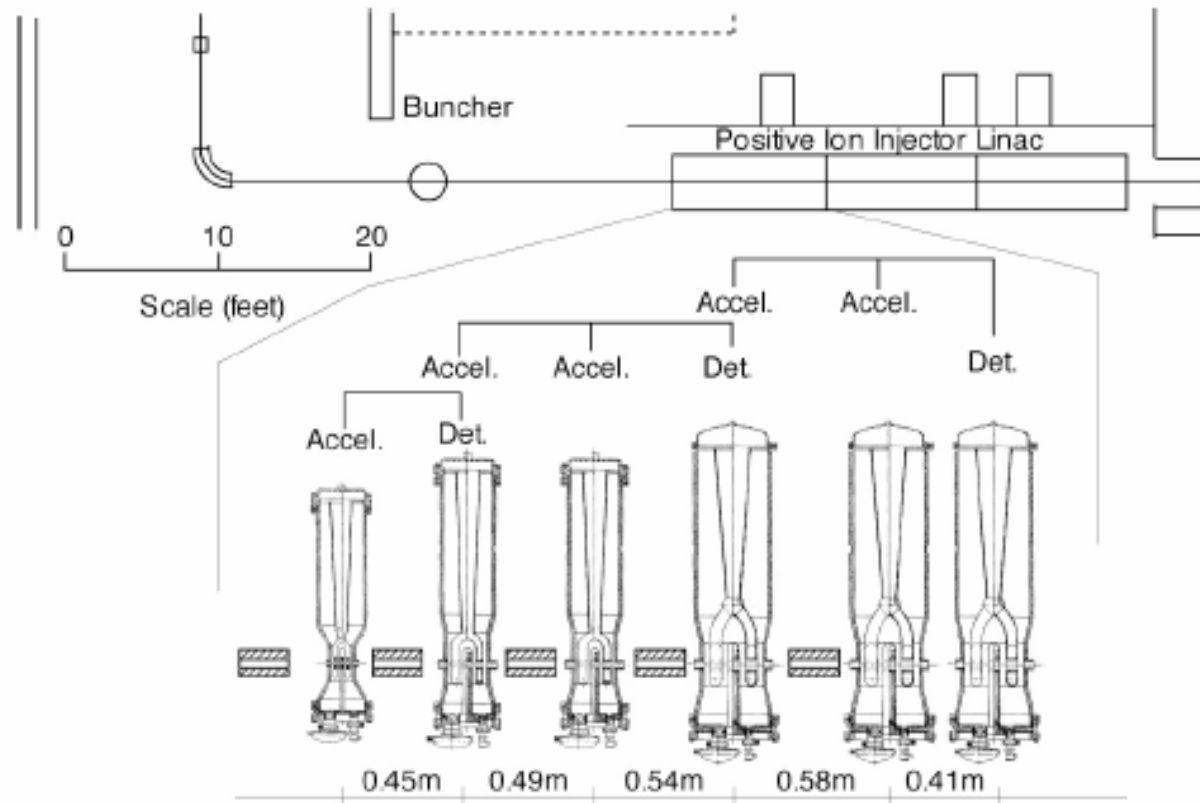
*Envelope of resonator resultant field for different beam amplitude and phase;
Red curve: reference signal*



Block diagram of a 360 linear phase shifter.



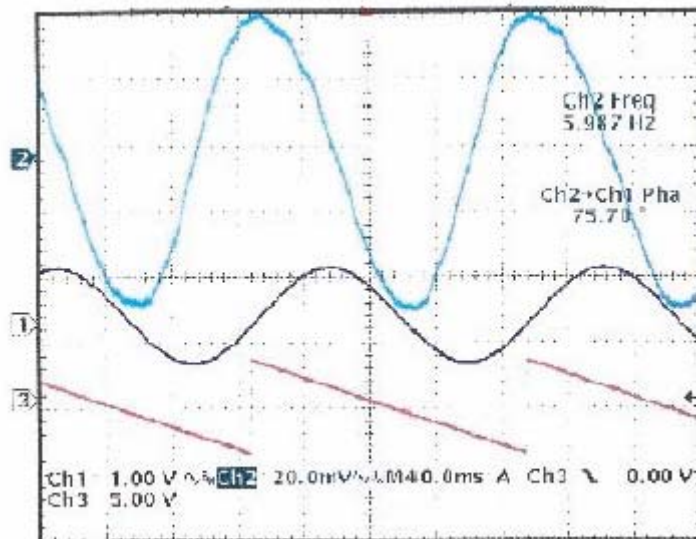
Complete experimental setup for using SCR as a beam phase detector.



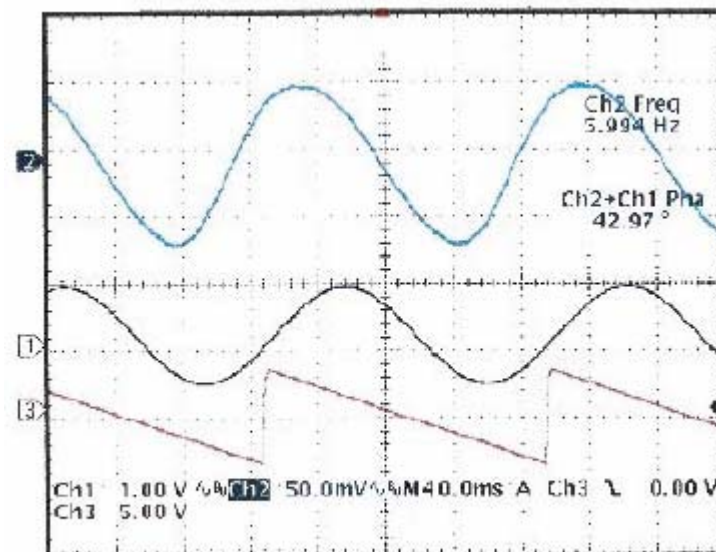
Floor plan of the ATLAS Positive Ion Injector and a blowup of the resonator configuration in the first cryostat used to develop the techniques

Measurement

*The system is now in regular use at the ATLAS facility
48.5MHz SC cavities*



(a)



(b)

Top traces: amplitude feedback loop error signal; middle traces: modulation reference signal; bottom traces: sawtooth control voltage. Time scale is 40 ms=div.

conclusion

1. *Overview of beam phase detector*
2. *The principles of a SC phase detector for low current beam is introduced*
3. *If two cavity are used, the difference in phase can be used to obtain the beam energy.*