Fermi National Accelerator Laboratory

BOOSTER HIGH LEVEL RF SYSTEM
WIDE BAND PHASE DETECTOR
9520-ED-309974
OPERATION AND SERVICE

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October 11, 2002

Operated by Universities Research Association, Inc., under contract with the United States Department of Energy

Introduction

It is important to understand how a phase detector works in order to troubleshoot and fix it. It is even better to also understand the system it will be operating in. With this said, before talking about the phase detector, let's talk a little about the system it will be operating in, the Booster RF Cavity tuning loop. See Figure 1.

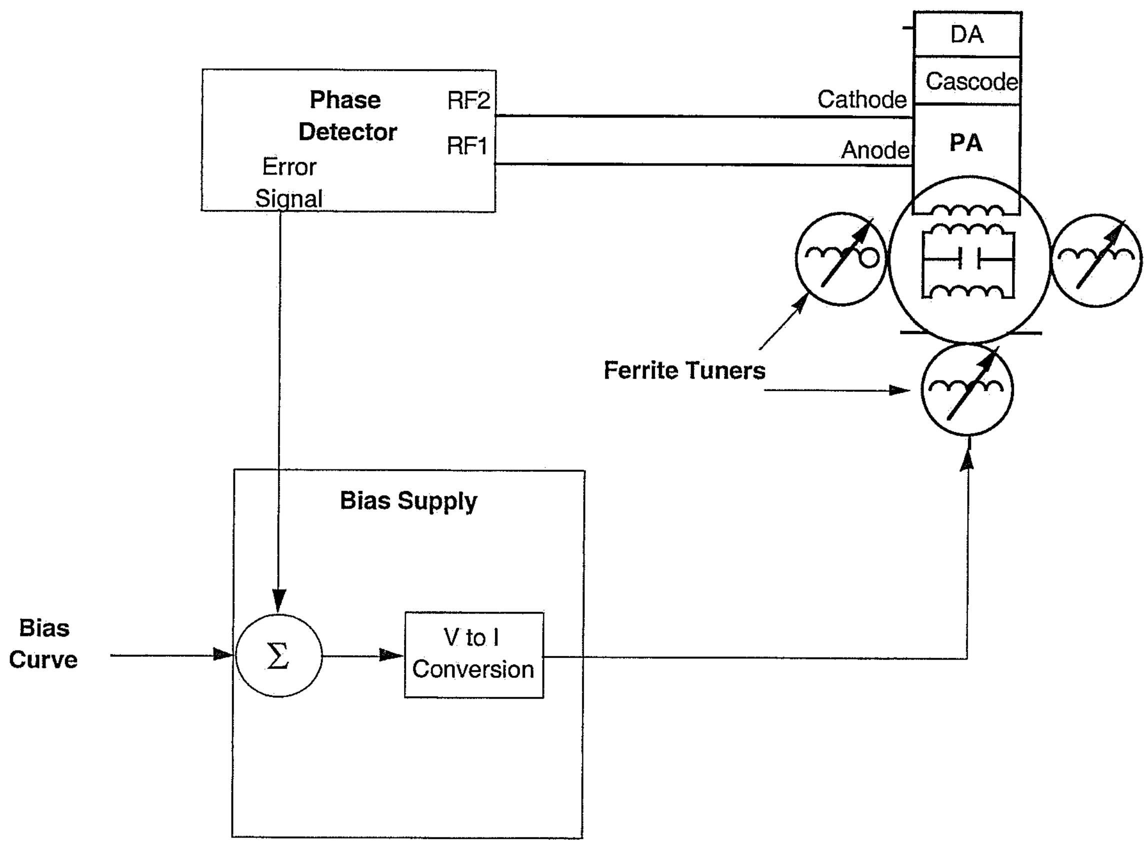

Figure 1. Booster RF Cavity Tuning Loop

The Booster RF Cavity is a dynamic cavity in the sense that its resonant frequency must change and stay in tune with the sweeping RF Signal which sweeps from 37MHz to 53MHz in about 35.5ms.

The resonant frequency of the cavity is controlled via three ferrite tuners that are located on the sides and bottom of the cavity. Injecting a certain amount of current through the ferrite tuners changes the inductance of the cavity, the more current the less inductance. The resonant frequency is given giving by $w_r=1/\sqrt{LC}$. You can see from this equation that as the inductance decreases the resonant frequency increases.

A programmable Ferrite Bias Supply (Bias Supply) is used to inject current into the ferrite tuners. The Bias Supply is a voltage controlled current source. A predetermined voltage program (bias curve) is generated at the control room and fed to the Bias Supply. In theory the Bias Supply then produces the right amount of current to the ferrite tuners to keep the cavity tuned to the sweeping frequency of the RF signal.

What does this all mean? It means that if the cavity is tuned correctly, then, the RF signal in the cavity will be in Phase with the RF signal being fed to it via the RF Power Amplifier (PA). The RF signal fed to the PA is monitored at the Cathode of the PA and the RF signal to the cavity is monitored at the Anode of the PA. If the cavity is not tuned correctly the RF voltage in the cavity will have a resistive and reactive component to it resulting in a RF voltage vector that is at a phase angle Ø with respect to the applied RF signal. How do we bring the signals back in phase? The Anode signal is brought back in phase with the Cathode signal by the use of a phase detector.

The phase detector will generate an error signal when it detects a phase difference between the Anode and Cathode RF signals. This error signal is then fed back to the Bias Supply and summed in with the Bias Curve. The Bias supply will supply more or less current to the ferrite tuners until the phase angle between the Anode and Cathode signal goes to zero.

Description

The 9520-ED-309974 Wide Band Phase Detector measures the amplitude and phase relationship of two RF signals. It has two input ports, RF1 and RF2. There is a pair of monitors on both the front and back panels ~~were~~ where the amplitudes at RF1 and RF2 can be measured. These monitors are labeled RF1 LOG Monitor and RF2 LOG Monitor. There are two monitors to measure the phase relationship between RF1 and RF2. These monitors are DIRECT OUT and Eout and can be monitored from both the front and rear panels.

DIRECT OUT is always active and gives a phase error signal of 1V/45°. Eout is activated with a TTL level trigger input at TRIG 1 and gives a phase error signal of 1V/9°. Eout is deactivated when a TTL level trigger is applied to TRIG 2.

The phase detector also has other features like TRIG1, TRIG2 and INHIBIT which can be used or bypassed internally by changing a shorting connector. It also provides a loop filter, ERROR FILTER, which is used in the Booster HLRF feedback system. This loop filter should not be used in the TEV or Main Injector.

Theory of Operation

Two RF signals of equal frequency are applied to RF1 and RF2 inputs on the back panel. Each of the RF signals passes through a two-way 90°-power splitter, which are U1 and U3. The power splitters are PSCQ-2-60. RF1 is kept at 0° and RF2 is shifted 90°.

The signals are then fed into a pair of AD8306 Limiting-Logarithmic Amplifiers, U2 and U4. The output VLOG of the Amplifiers provide an accurate logarithmic measure of the RF signals and can be monitored on the back or front panel labeled RF 1 Log Monitor and RF 2 Log Monitor. The Amplifier also provides a limiter output, LMHI and LMLO where the incoming sine wave RF signal is converted into a square wave of fixed amplitude. This removes the amplitude difference between the two signals while retaining their phase difference Ø.

Since the limiter output of the AD8306 has a dc component it must be coupled out before going into the mixer. Impedance matching transformers T1 and T2 eliminates the dc component.

The Phase Detector is designed around the SRA-1 mixer from Mini-Circuits, U5. The mixer has two inputs, LO and RF, and an output IF. The output IF will be of the form $A_1\cos[(W_{LO}-W_{RF})t - (Ø_{LO}-Ø_{RF})]$ + $A_2\cos[(W_{LO}-W_{RF})t - (Ø_{LO}-Ø_{RF})]$ + [higher order terms]. Where A_1 and A_2 are the peak amplitude of the RF signals, W_{LO} and W_{RF} are the signal frequencies and $Ø_{LO}$ and $Ø_{RF}$ are the signals phase

If the two signals have the same frequency, $W_{LO} = W_{RF}$, the term $W_{LO} - W_{RF}$ will disappear and IF will only be a function of $A_1 \cos(Ø_{LO}-Ø_{RF})$ + $A_2 \cos(2Wt)$ + higher frequency terms. The LC filter following the mixer will eliminate the 2Wt and higher terms so that IF has the form **$IF = k_d \cos(Ø_{LO}-Ø_{RF})$.**

The amplitudes of the two signals must remain constant for they can add dc errors on the IF output. Also, one of the signals must be shifted 90° so when the signals are in phase the output IF will be 0-volts because cos 90 =0.