Beam Position Monitor
Design Note #16

BPM R.F. MODULE DESCRIPTION

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1.0 INTRODUCTION

The R.F. modules are part of the Fermilab energy doubler beam position system (BPM) that are designed to convert the 53.1 MHZ R.F. signals from the beam detectors into D.C. levels representing beam position and intensity. The normalized difference between the two input signal amplitudes is converted into beam position, and the sum of the two input signal amplitudes is converted into beam intensity. The modules have also been described in AN RF BEAM POSITION MEASUREMENT MODULE FOR THE FERMILAB ENERGY DOUBLER , S.P. Jachim, R.C. Webber, R.E. Shafer, IEEE Transactions On Nuclear Science VOL. NS-28, No. 3, June 1981.

This description is divided into two parts: a general block diagram and operational overview, and a more detailed circuit operation description. For a general description of the BPM system see Operations Bulletin #888, FERMILAB ENERGY DOUBLER BEAM POSITION MONITOR SYSTEM ,Rod Gerig, 7/82

2.0 BLOCK DIAGRAM

The R.F. module may be divided into four major circuits: the front-end filters, an amplitude to phase converter, a phase detector, and a coherent detector. The two front-end filters each consist of a bandpass and a lowpass section. They serve to limit the bandwidth of signals accepted by the module. Additionally, the bandpass section, using a half-wave resonant coaxial transmission line, "rings" when a single beam bunch is detected, effectively stretching out the signal to last long enough to process. The amplitude-to-phase converter is a passive network with outputs which are equal in amplitude but vary in phase relationship from 0 to 180 degrees depending on the normalized difference between the two input signal amplitudes. The phase detector limits the converter outputs to remove variations caused by differing beam intensities, then detects the phase difference and amplifies the output to produce a D.C. voltage level between +2.5 volts and -2.5 volts corresponding to the beam position. The coherent detector uses a portion of each input signal to produce a D.C. voltage level between 0 and -2.5 volts corresponding to beam intensity.

3.0 DETAILED CIRCUIT DESCRIPTION

Pertinent drawing numbers are as follows:

1. 1680.00-EE-107660 SCHEMATIC DRAWING
2. 1680.00-BD-158117 COMPONENT LAYOUT

The four major circuits described earlier and the internally regulated power circuit will be described separately.

3.1 FRONT-END FILTERS

In addition to the two main inputs (J1 and J3) there are two test inputs accessible from the 8-pin Burndy connector. These test inputs provide a D.C. path to the beam pickup and termination, and provide a means of injecting R.F. signals into the module. Resistors R1 and R5 in series with the R.F. detector cables and terminations form part of a voltage divider used to test cable integrity when a D.C. voltage is applied to the test inputs. R.F. from the test inputs is coupled through C2 and C9 and through R3 and R7 to the main inputs for R.F. module functional testing. Resistors R2 and R6 are used to terminate the test inputs in 50 ohms, and chokes L1 and L4 prevent R.F. from passing through R1 and R5.

Transformers T1 and T2 in combination with transmission line assemblies W1 and W2 form the two bandpass filters, with bandwidths of about 5 MHZ centered at 53.1 MHZ. The lowpass filters are enclosed in grounded aluminum boxes providing shielding and mechanical stability, and are constructed as plug-in modules to facilitate matching measurements.

Both sets of filters are phase and amplitude matched to within 3 degrees and 0.1db. The bandpass filter resonant frequencies are matched to within .08% in order to meet the 3 degree tracking requirement after about ten cycles of oscillation following excitement by a single beam bunch signal.

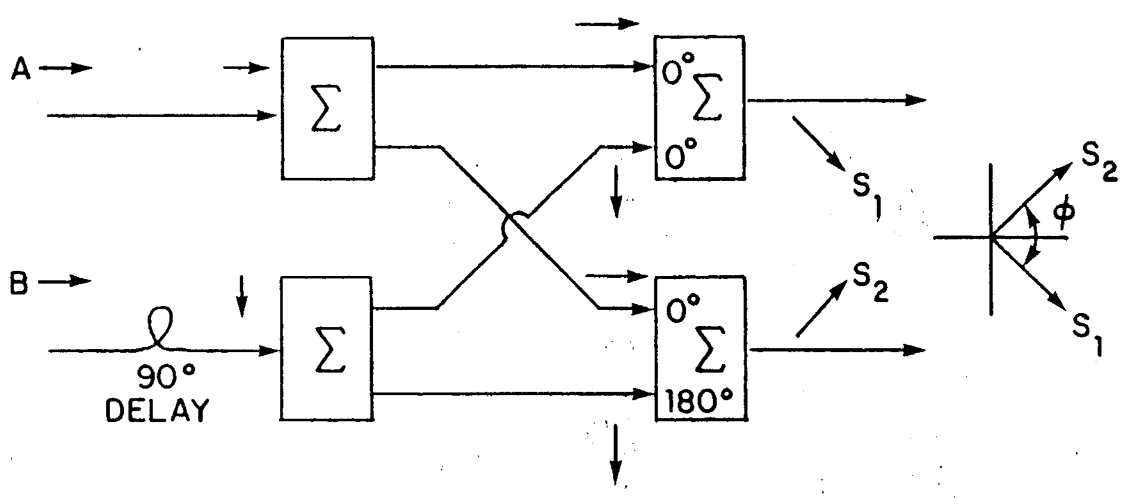
3.2 AMPLITUDE-TO-PHASE CONVERTER

The filtered inputs are each split by an MCL PSC2-1 power splitter into signals for the position circuit and for the intensity circuit. Two signals go to the inputs of the AM-PM converter. The other two signals, for the intensity circuit, are combined in another MCL PSC2-1 and fed to the coherent detector to be discussed later.

The amplitude-to-phase converter consists of a delay cable, (90 degrees at 53 MHZ) three MCL PSC2-1 in-phase power splitters, and an MCL PSCJ2-1 180 degree power splitter. The "A" input signal is split into two in-phase signals. The "B" input is first delayed by 90 degrees, then split in a like manner. One "A" and one "B" signal are then combined by vector summing to obtain the first output. When the "A" and "B" inputs are equal in amplitude, the vector sum will be phase-shifted exactly -45 degrees relative to the inputs. As the "A" input increases the phase shift will move toward 0 degrees, and as the "B" input increases the phase shift will move toward -90 degrees.

The other "A" and "B" signals are combined by vector summing into the second output by the MCL PSCJ2-1, which has a 180 degree phase shift built into the "B" side. Thus when the "A" and "B" inputs are equal in amplitude this output will be phase-shifted by +45 degrees relative to the inputs. In this case as the "A" input increases the the phase shift still moves toward 0 degrees, but as the "B" input increases the phase shift moves toward +90 degrees.

One may now see that the two outputs of the amplitude-to-phase converter are equal in amplitude because they are each the vector sum of the two inputs. They will both move toward 0 degree phase shift as the "A" input amplitude becomes larger than "B". They will in fact be in phase with each other when there is no "B" input at all. As the "B" input becomes larger one output moves toward 90 degrees while the other moves toward -90 degrees, resulting in a full 180 degree phase difference if there is no "A" input.



3.3 PHASE DETECTOR

The two outputs of the amplitude-to-phase converter are amplified by a matched pair of MWA130 amplifiers U1 and U2, then fed to the limiters. Diodes D1, D2, D3, and D4 are used to protect the amplifier inputs from large transients, and chokes L2, L3, L5, and L6 form part of an extensive decoupling network to insure that there will be no crosstalk between the amplifiers. Capacitors C4 and C11 may be used to make small adjustments in the phase shift of the outputs.

The limiters are each enclosed in a grounded aluminum box, and are constructed as plug-in modules. They have been carefully matched for phase-shift characteristics over an input level range of 60db using a computerized measuring technique. At the heart of each limiter is an AM685 comparator powered by voltage regulators which are internal to the R.F. module. The offset voltage inputs are adjusted to provide a 50% duty cycle at the limiter outputs.

The limiter outputs are fed through 2db pads to an MCL SRA-1 double-balanced mixer used as a phase detector. The detector output is filtered by L7, C16, and L8 then amplified and buffered by U3, Q1, and Q2. R15 provides a 50 ohm termination for the detector through C15, and R16 and R17 provide an output amplifier gain adjustment. Thermistor R101 provides output amplifier gain compensation to offset the effects of ambient temperature variations. The position output is impedance matched to 50 ohms by R29, and sampled for observation at the front panel through R28.

3.4 COHERENT DETECTOR

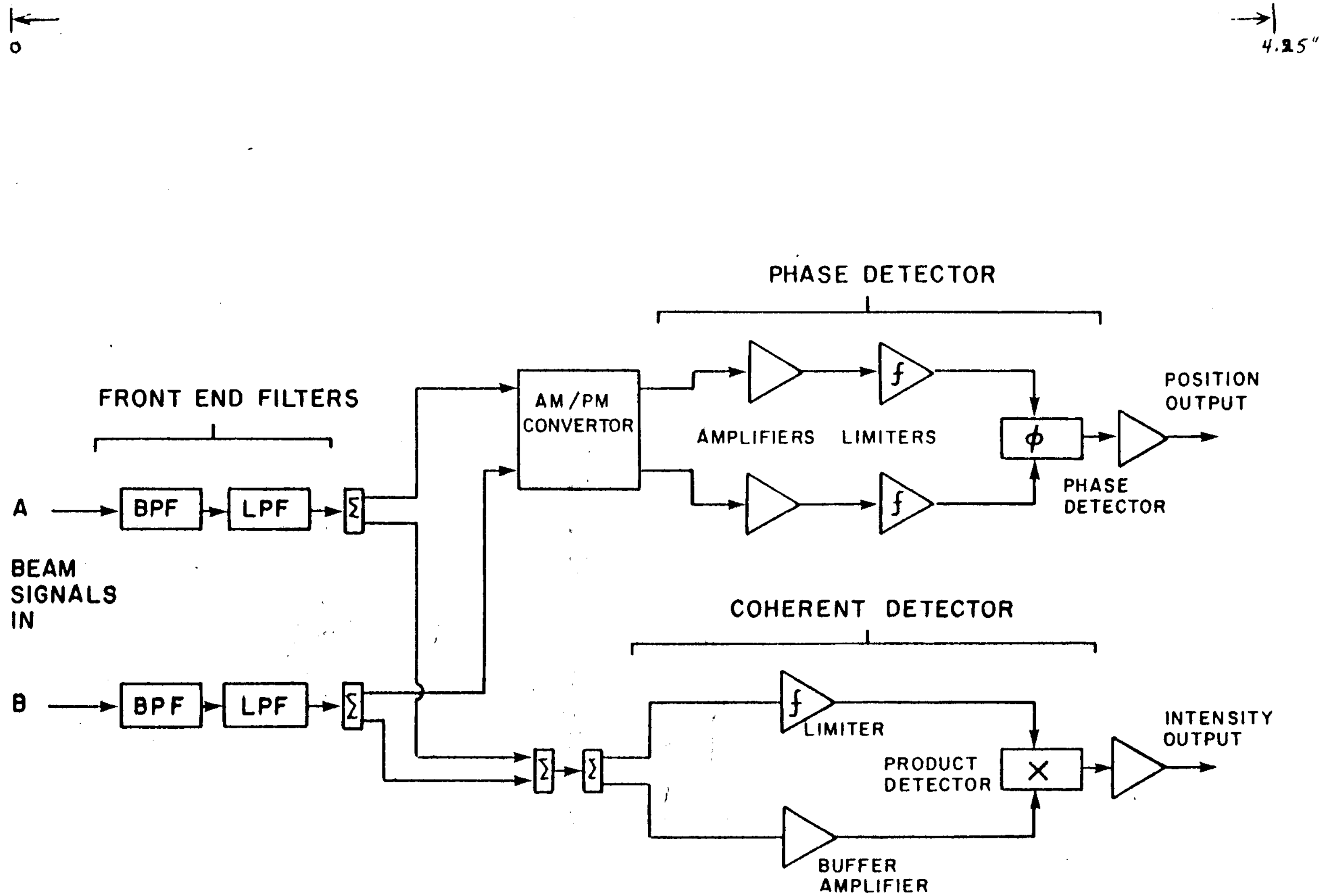
The input signal to the coherent detector, the sum of the filtered "A" and "B" inputs, is proportional to beam intensity. This signal is split by an MCL PSC2-1, one output going to the cascaded MC1590 limiter U4 and U5, and the other output going to linear isolation amplifier Q5. U4 and U5 form a limiter circuit with an output signal level of -3 dbm at the output of transformer T6. This signal is then amplified to +6 dbm by transistors Q3 and Q4 and used as the LO input to the MCL SRA-1H-42 double-balanced mixer.

The series-resonant circuit L16 and C33 provide a phase delay to compensate for the inherent delay in the limiter circuit. The linear amplifier Q5 buffers the signal to be used as the RF input to the mixer. The two inputs to the mixer are adjusted to be in phase so the detected output of the mixer is simply proportional to the amplitude of the RF input. This mixer's output as connected here is in the positive-going direction, and the mixer has been specially selected by the manufacturer to have a small positive residual output when there is a LO but no RF input signal. This allows adjustment of the output amplifier's offset so that there is a small positive residual output with no RF or LO inputs to the mixer.

The detector output is filtered by L19, C41, and L20 then amplified and buffered by U6, Q6, and Q7. R47 provides a 50 ohm termination for the detector output, and R48, R49, and R50 provide an output amplifier gain adjustment. The intensity output is impedance matched to 50 ohms by R63, and sampled for observation at the front panel through R62.

3.5 LIMITER POWER VOLTAGE REGULATORS

There are three voltage regulators in the R.F. module, U11, U10, and U9, supplying +6, -6, and +2.2 volts to the limiters. These voltages may be measured at the front panel and are also available at the 8-pin Burndy connector for monitoring by the TIM. In addition, a quad 741 op-amp U8 supplies an offset voltage to each limiter. An LM113 precision reference diode D9 provides a 1.2 volt reference and is buffered by one of the 741 op-amps. The reference is voltage-divided to 0.77 volts by the resistors R70 and R72, or R79 and R78, and used as one input to the offset voltage op-amps. The other input of each op-amp is adjustable by R69 and R75 to obtain offset voltage outputs in the range of +.22 to -.35 volts. The fourth 741 op-amp uses the reference voltage to provide -2.8 volts as the common input to the 5 volt regulator U9. This regulator's output is thus -2.8 plus 5 or +2.2 volts.



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PHASE DETECTOR
FRONT END FILTERS
AM/PM CONVERTOR
AMPLIFIERS
LIMITERS
POSITION OUTPUT
PHASE DETECTOR
A
BPF
LPF
BEAM SIGNALS IN
B
BPF
LPF
COHERENT DETECTOR
LIMITER
PRODUCT DETECTOR
INTENSITY OUTPUT
BUFFER AMPLIFIER