

# AN RF SIGNAL PROCESSING MODULE FOR THE SPS ORBIT OBSERVATION SYSTEM UPGRADE

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## Abstract

CERN will replace the 200 MHz electronic calibrator and filter modules used in the SPS Orbit Observation System as part of an ongoing upgrade. TRIUMF is designing the new modules and will supervise the manufacture of 300 modules as part of Canada's contribution to the LHC. Six prototype modules were also provided for additional diagnostics with injected long ion bunches in Fall 1996. The SPS accelerated fully stripped Pb ions and the modules operated at 47.5 MHz, the fifth harmonic of the bunch spacing. The beam position was measured during the first few turns following injection before the beam was captured by the 200 MHz RF. The modules process the RF sum and difference signals from the beam position monitors. They allow for compensation of phase drift in the cables from the monitors, provide for calibration of the electronics system and house pairs of bandpass filters.

## 1 SYSTEM DESCRIPTION

Fig. 1 is a block diagram of a SPS beam position monitor and its front end electronics. A beam of charged particles, which can be electrons, positrons, protons or lead ions, induces signals in the monitor electrodes by its passage.  $50 \Omega$  cable matching networks on the air side of the vacuum feedthroughs were designed for 200 MHz and are not ideal for 47.5 MHz. For 200 MHz operation, each monitor has a ring hybrid constructed of lengths of coaxial cable near the monitor to form the sum and difference of the electrode signals. Anzac H9 wideband hybrids are used for the 47.5 MHz monitors. The beam position is determined by the ratio of the amplitudes of the sum and difference signals.

The signals are carried by coaxial cables from the beamline area to the electronics area. The losses in these cables are equalized to 25 dB. Each segment of the ring also has 6 long cables with 32 dB attenuation but these particular monitors are not used at 47.5 MHz. Pre-amps with a gain of 30 dB are switched into the signal path when accelerating lead ions or switched out for other species.

A manually adjustable phase shifter in the difference path allows for compensation of drift in the cables from the beamline. It is anticipated that this adjustment will only be made about once a year. A phase shifter in the sum channel has a fixed value at the midrange of the variable phase shifter. This combination allows for positive or negative phase compensation. A splitter and RF switches facilitate compensation for errors in the gain and phase matching of the system. The signals pass through the bandpass filters to remove all but the 47.5 or 200 MHz component.

The gains of the variable amplifiers which follow the calibrator module may be set from 0 to 60 dB in 10 dB steps. The amplified sum signal is passed through a limiter and used to homodyne itself and the difference signal via a pair of mixers. The outputs from the mixers pass through low pass filters finally yielding the envelopes of the two signals. These signals are sampled for continuous beams or peak detected for single bunches and then digitized.

## 2 CALIBRATOR MODULE COMPONENTS

The description that follows refers mainly to the 47.5 MHz modules [1][2]. Many modifications in the design will be incorporated in the 200 MHz units.

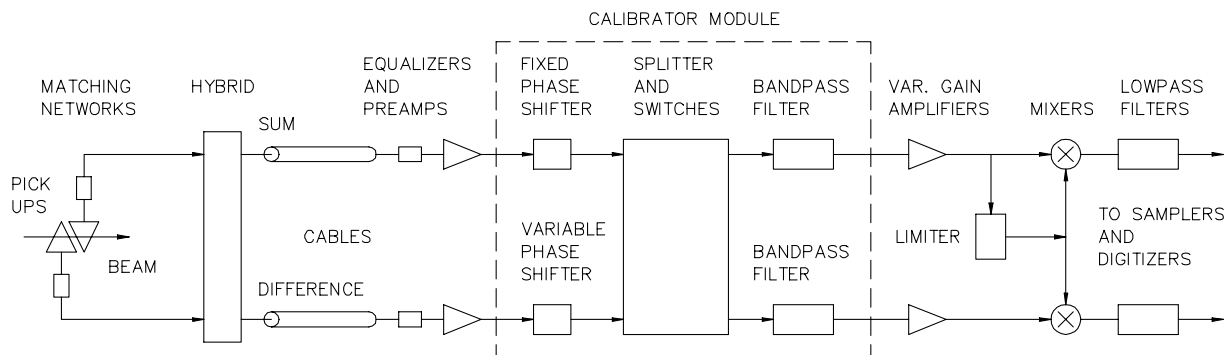


Figure 1. A block diagram of the system.

## 2.1 Module Layout

The module is a double height Eurocard (VME) 233.35 mm high, 39.2 mm wide and 220 mm deep. Ten modules fit in a Eurocrate. Signals enter the module via SMA jacks which project through the front panel. Coplanar microstrip carries the signals to OCX connectors on the motherboard. These connectors mate with a daughter board which supports the surface mount phase shifters and RF switching network. The control signals and power are carried to the daughter board by pin headers. Coaxial cables with Teflon dielectric take the signals to the bandpass filters. The outputs from the filters are available on N connectors which project through the front panel. The daughter card is contained inside an RF shield and can be unplugged from the main card for service.

## 2.2 Phase Shifters

The variable phase shifter consists of a quadrature hybrid with its  $0^\circ$  and  $-90^\circ$  ports terminated by variable capacitance diodes (varicaps). The output is taken from the normally isolated port. The phase shift through the network is  $\phi = \arctan((1 - \omega^2 C^2 Z_C^2) / (2 \omega C Z_C)) - 180^\circ$  where  $\omega$  is the angular frequency,  $C$  is the capacitance of the varicaps (assumed equal) and  $Z_C$  is the characteristic impedance of the hybrid,  $50\Omega$ . The capacitance of the Motorola MMBV109LT1 varicap diodes as a function of their reverse bias voltage can be approximated as  $C = C_0 / (1 + V/V_0)^{\text{GAMMA}}$  where  $C_0 = 52.8$ ,  $V_0 = 10.2$  and  $\text{GAMMA} = 2.36$  at 1 MHz. In fig. 2 the measured phase shift at 47.5 MHz is shown as a function of the varicap reverse bias voltage using a test fixture incorporating a M/A-Com JHS-115 quadrature hybrid.

The diode reverse bias available in the module is variable from 3 to 13 V corresponding to a measured phase shift from  $-131.44^\circ$  to  $-100.27^\circ$ , a range of  $31.17^\circ$ . This is a little less than the calculated range of  $32.7^\circ$ . The smallest range measured for the actual modules as delivered was  $31.1^\circ$ . The worst input VSWR of the phase shifter over its range and over the 7 modules delivered was 1.18. To maintain equal delays the phase shifter in

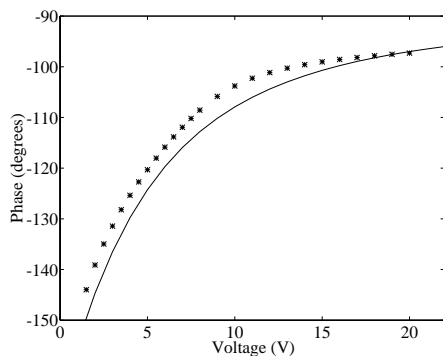


Figure 2. The measured (points) and calculated phase shift versus the varicap reverse bias voltage.

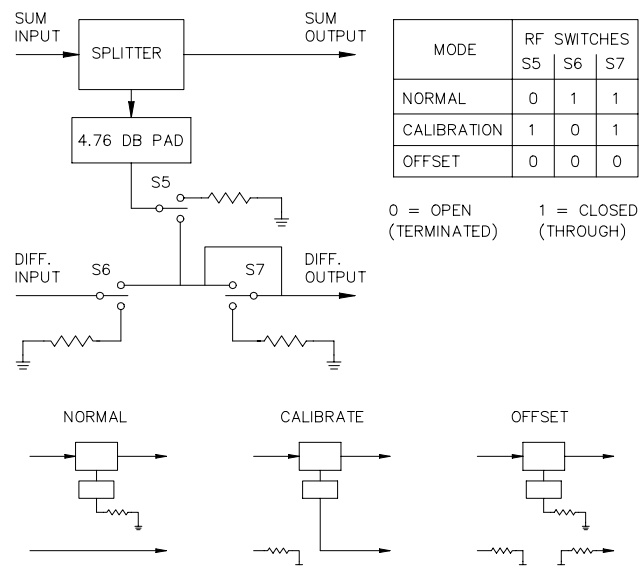


Figure 3. Calibration modes.

the sum channel uses a similar quadrature hybrid circuit but with fixed capacitors.

## 2.3 RF Switching

The calibrators have three operating modes which are illustrated in fig. 3. Beam position measurement occurs in the Normal mode. The Calibrate mode is used to measure the gain balance of the amplifiers that follow the module. In this mode, the sum input is split between the sum and difference outputs. The 4.76 dB pad following the splitter insures that the sum channel output will be 6 dB greater than the difference channel output. The splitter is a wideband transformer and provides lower loss, 3.75 dB, and better isolation, 25 dB, between its outputs than a simple resistive splitter. The Offset mode is used to measure the position offset error of the system by zeroing the difference channel output.

The mode switches will be operated frequently, once each cycle (16 s) or few cycles, to measure the offset. Calibration mode will be used less frequently. Solid state switches were chosen for reliability. CERN has had problems with mechanical switches and limited their use to occasional calibrations done by experts. GaAs FET switches allow the 60 dB isolation specification for the module to be met. The M/A-Com SW-221 switches have built in  $50\Omega$  termination resistors. Their guaranteed isolation at 500 MHz is 60 dB and is typically 75 dB at 47.5 MHz. Their guaranteed insertion loss is 0.9 dB but is typically 0.7 dB. A 16L8 Programmable Array Logic (PAL) chip is used to convert the control signals to the patterns required by the RF switches. The TTL level signals from the PAL control Harris CMOS dual switches which act as level converters. These devices pass ground to one of the controls lines of a GaAs switch and  $-8\text{ V}$  to the other. The control line voltages are reversed to change the state of the GaAs switch.

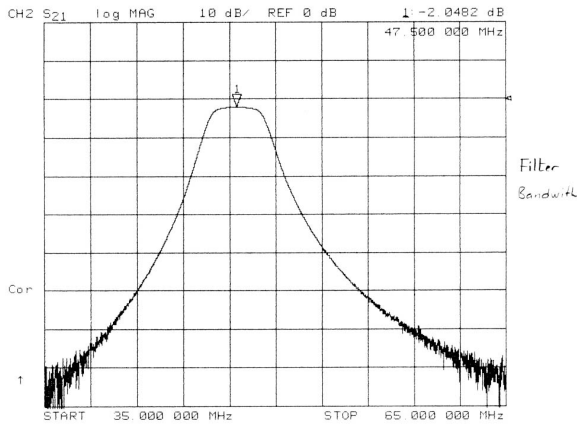


Figure 4. The frequency response of a 47.5 MHz filter.

### 2.4 Filters

The 47.5 MHz filters are Bessel type and were made at CERN. They are an adaptation of the 200 MHz filters developed by the LTT company and are housed in the same type of aluminum cases. They are constructed using hand wound inductors, air trimmers, and ceramic capacitors. The bandwidth is 4 MHz and the insertion loss is 2 dB, fig. 4. The beam position can be measured in two modes. In continuous mode the filters remove all but the 47.5 MHz component of the signals. In single bunch mode the filters ring at 47.5 MHz. The envelope of the ringing response builds quickly to a well defined peak at 250 ns whose amplitude is measured by a peak detector. The ringing duration is about 600 ns, fig. 5.

200 MHz combine filters, with 4.4 MHz bandwidth, will be purchased from the Microwave Filter Co. A filter consists of 4 copper rods shorted to the case at one end and loaded by paralleled porcelain capacitors and piston tuning capacitors at the other ends. The input and output coupling loops are adjustable. It is a 4 pole, 0.1 dB ripple Chebychev design with 2.7 dB insertion loss. The  $\lambda/26$  resonators give  $\geq 80$  dB harmonic rejection to 2.5 GHz.

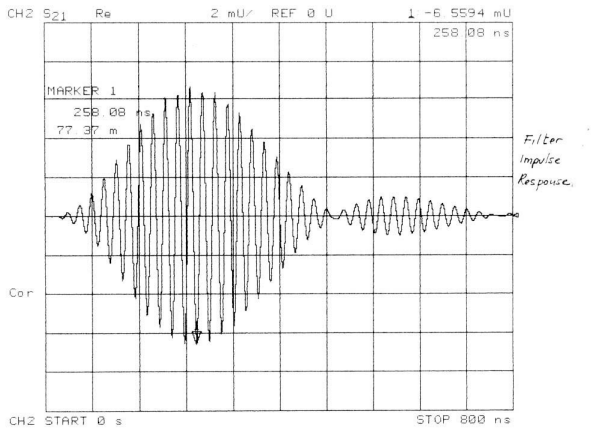


Figure 5. The time response of a 47.5 MHz filter to an impulse.

The phase shifts through the sum and difference channels of a module, of which the filters are the major contributors, should track within  $3^\circ$  over a temperature range of  $15^\circ\text{C}$  to  $30^\circ\text{C}$ . The error in the amplitude measurement of the signals in the synchronous detection system is  $1 - \cos\phi$  where  $\phi$  is the phase error between the sum and difference signals. A phase error of  $3^\circ$  gives an amplitude error of 0.14%. The requirement that the phase shift through a filter pair track within  $3^\circ$  at 200 MHz is equivalent to their centre frequencies tracking within 33 kHz. The requirement that their ringing responses track within  $3^\circ$  at the peak of the envelope is equivalent to their centre frequencies tracking within 39 kHz.

## 3 BEAM TESTS

The six modules installed for the Fall run operated satisfactorily. Fig. 6 shows the growth of 200 MHz on a pair of bunches of Pb ions injected 105 ns apart. A spare module was also supplied and four more modules for additional monitors have been built.

## 4 ACKNOWLEDGEMENTS

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## REFERENCES

- [1] 'A 47.5 MHz Calibrator Module for the CERN SPS Orbit Observation System', W.R. Rawsley, S. Fang, K. Fong, J-P Papis, TRIUMF Design Note TRI-DN-97-9
- [2] 'Documentation for 47.5 MHz Calibrator Module of CERN SPS Orbit System', S. Fang, TRIUMF, 1997

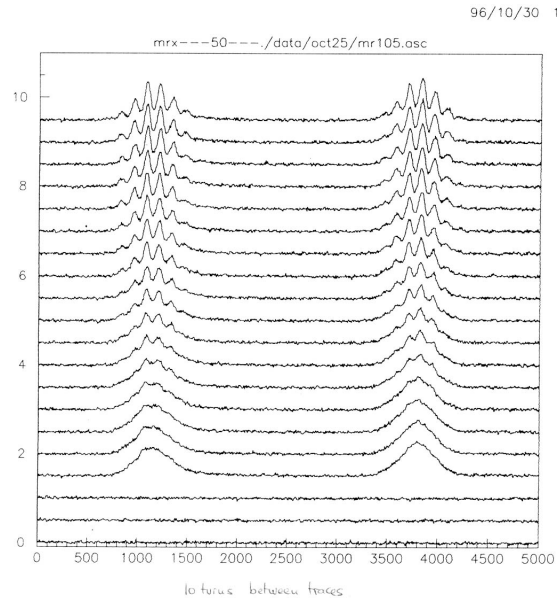


Figure 6. The growth of the 200 MHz component on a pair of bunches spaced by 105 ns. The horizontal scale is in arbitrary units. The traces were taken 10 turns apart.