A BEAM CURRENT MONITOR FOR THE VECC ACCELERATOR

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Abstract

TRIUMF is building VECC, the first stage of a 50 MeV electron linac. Beam diagnostic devices will be inserted radially into 8-port vacuum boxes. RF shields, 6.3 cm diameter tubes perforated by pump out slots, can be inserted to reduce wakefields. They will also serve as capacitive probes picking up harmonics of the 650 MHz bunch rate. 100 mV P/P was measured for 3 mA at 100 keV. A SC cavity will accelerate the beam to 10 MeV. The main dump current is limited by the shielding to 300 W. The e-gun will deliver up to 10 mA with a variable pulse rate and duty cycle. Two RF shields will monitor the current. A circuit will produce dc outputs proportional to the average beam current and either the peak beam current or the duty cycle. It uses a log detector with a range of 70 dB for 1 dB of error and a rise and fall time of ~20 ns. Terasic development boards process the log signals. Each signal is digitized by a 14-bit ADC at a 50 MHz rate and passed to a FPGA programmed in Verilog. Altera Megafunctions offset, scale, convert to floating point, antilog and filter the signal in pipeline architecture. Two 14-bit DACs provide the outputs. Digital processing maintains the wide dynamic range. Beam pulses can be <120 ns and the sample rate insures accuracy at low duty cycle.

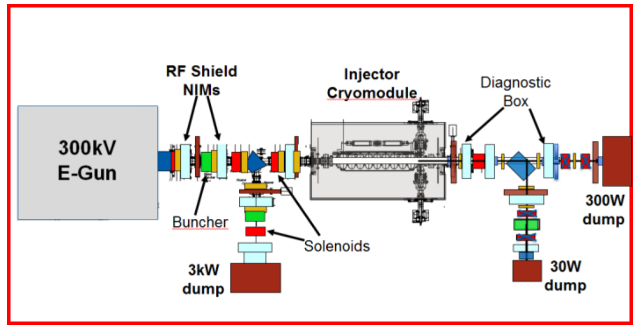

Figure 1: The VECC test stand.

INTRODUCTION

TRIUMF is preparing to install a 50 MeV 10 mA electron linac for ARIEL to be used as an injector to produce radioactive ion beams. In collaboration with the Variable Energy Cyclotron Centre (VECC) in Kolkata TRIUMF is installing a small facility to allow construction and testing of a 10 MeV linear accelerator which will serve as an injector to the ARIEL e-linac. This VECC test area will host a 300 kV thermionic emission electron gun with a RF modulated grid in front of the cathode to produce 650 MHz beam bunches, a Low Energy Beam Transport (LEBT) diagnostic section, an Injector Cryomodule (ICM) with a single nine-cell

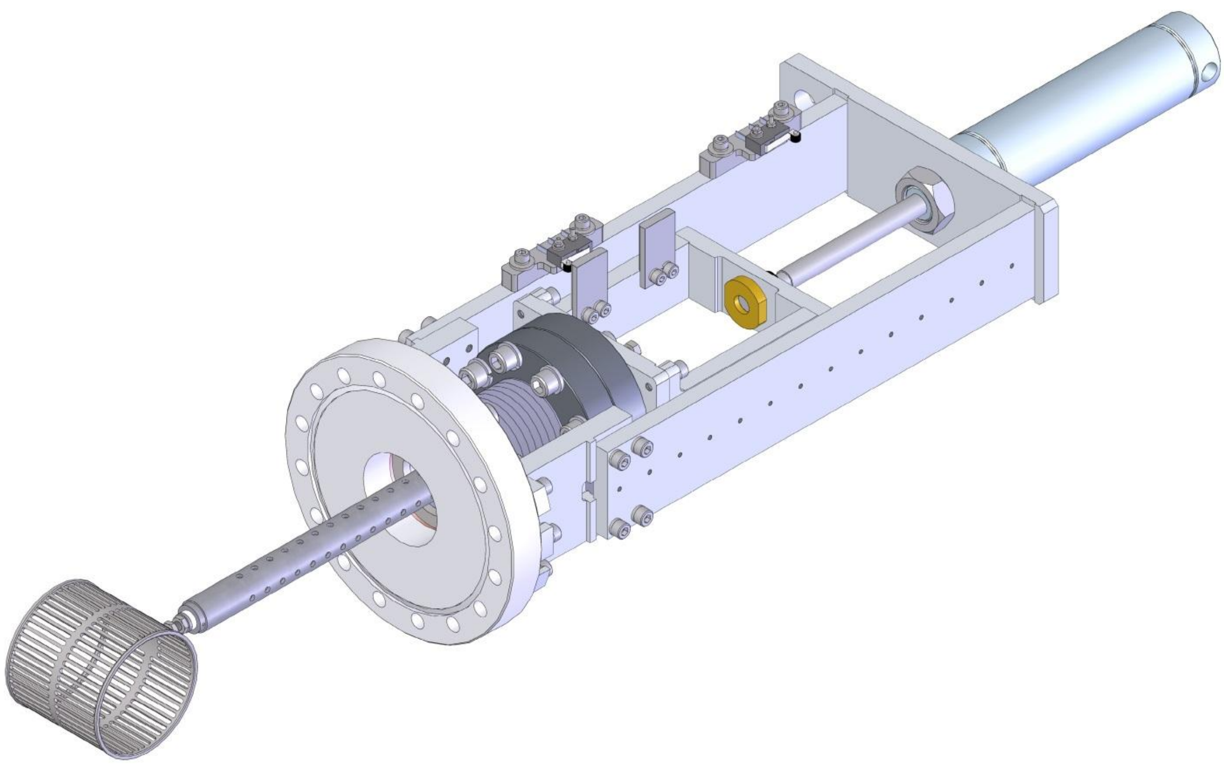

Figure 2: A SolidWorks model of a VECC RF shield.

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superconducting RF cavity for beam acceleration and a Medium Energy Beam Transport (MEBT) line and diagnostic section leading to a beam dump. The LEBT has a 90° analysing leg leading to a 3 kW beam dump while the MEBT has a 30 W beam dump on an analysing leg plus a 300 W dump on the straight ahead section. Shielding is in place to suppress radiation fields to permissible levels up to the design beam powers. The layout of the VECC linac is shown in Fig. 1.

There will be 41 diagnostics boxes distributed throughout the VECC linac installation and in the e-linac. When no other diagnostic devices are inserted, RF shields will be inserted to reduce beam energy spread due to single bunch Wakefields. At the start-up of the e-linac, they will be installed only in boxes close to the e-gun and accelerator cryomodules. Provision will be made to allow for installation of shields in the rest of the e-linac boxes though they will not be necessary for RIB operation. They may be installed later for energy recovery FEL operation to insure a 50 MeV beam energy spread of less than 0.1% rms [1].

The RF shields may also serve as capacitive probes. The supporting structure consists of a rod inside a cylinder which forms a 50Ω coaxial signal transmission line. Though the accelerator cavity RF is 1.3 GHz, only every second bucket will be populated giving a beam induced signal of 650 MHz plus higher harmonics. There will be a macro pulse structure with a usual rate of up to 1 kHz and a duty cycle of down to 0.01%. Peak beam current will be 10 mA. In the 300 keV LEBT section, the dump will accept the full 10 mA average beam current. In order to protect the MEBT beam dumps and limit radiation the first two RF shields close to the e-gun will be used to trip the beam if the average current or duty or duty cycle becomes too high at the energy in use.

SIGNAL STRENGTH

The expected signal strength from the RF shields can be calculated using an equation from reference [2].

$$V_T = \frac{2\, i_{ave}\, l\, Q_0}{C_T \beta_c} \cdot \frac{\sin(N\pi f T)}{N\pi f T} \cdot \frac{\sin(\frac{N\pi f l}{\beta_c})}{\frac{N\pi f l}{\beta_c}} \qquad (1)$$

V_T = peak induced signal	(V)
i_{ave} = average bunched beam current	(3 mA)
l = the pickup electrode length	(6 cm)
C_T = the total capacitance	(15 pF)
β_c = particle velocity	(m/s)
Q_0 = lightly loaded Q of system	(1)
N = bunching harmonic number	(1)
T = bunch width, typ. 16° at 650 MHz	(0.068 ns)
f = bunch repetition rate	(650 MHz)

Table 1: Expected Signal Strength

Energy (MeV)	β_c (m/s)	V_T (mV peak)
0.1	1.64e8	130
0.3	2.33e8	96.5
10	2.996e8	76.5
30	2.9996e8	76.4
50	2.9998e8	76.4

Table 1 indicates that we lose less than half of our signal strength in going from 100 keV to 50 MeV. The bunch width may vary at most from 10° to 60° at 650 MHz. The second term in eqn. 1 varies from 0.999 to 0.955 over this range, a difference of 4.4%.

MEASUREMENTS

Figure 3 shows the signals from the two RF shields closest to the VECC e-gun. The beam energy was 100 keV, the current 2.8 mA peak and the pulse width 520 ns. (The e-gun energy will be increased to 300 keV). The signal carrier is primarily a 650 MHz sine wave though some second harmonic has also been seen. Oscillations apparent in the signal envelopes may be due to fluctuations in the e-gun power supply voltage.

To compare the predicted and measured signal levels the lumped element capacity of the tube to ground and cable losses were taken into account. Also, a 1 dB attenuator is always left in place at the monitor to insure that the pickup can never charge up accidently. We measured 100 mV P/P for 3 mA beam current while the predicted value was ~50% higher.

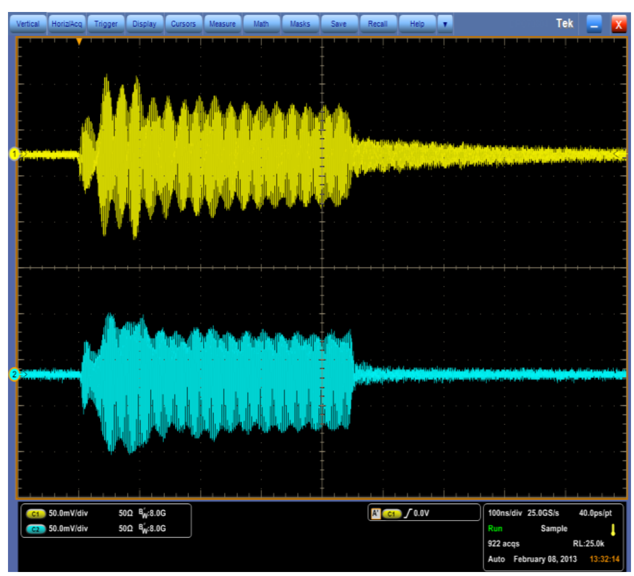

Figure 3: Signals from the two the RF Shields closest to the VECC e-gun. The beam current is 2.8 mA peak and the pulse width is 520 ns.

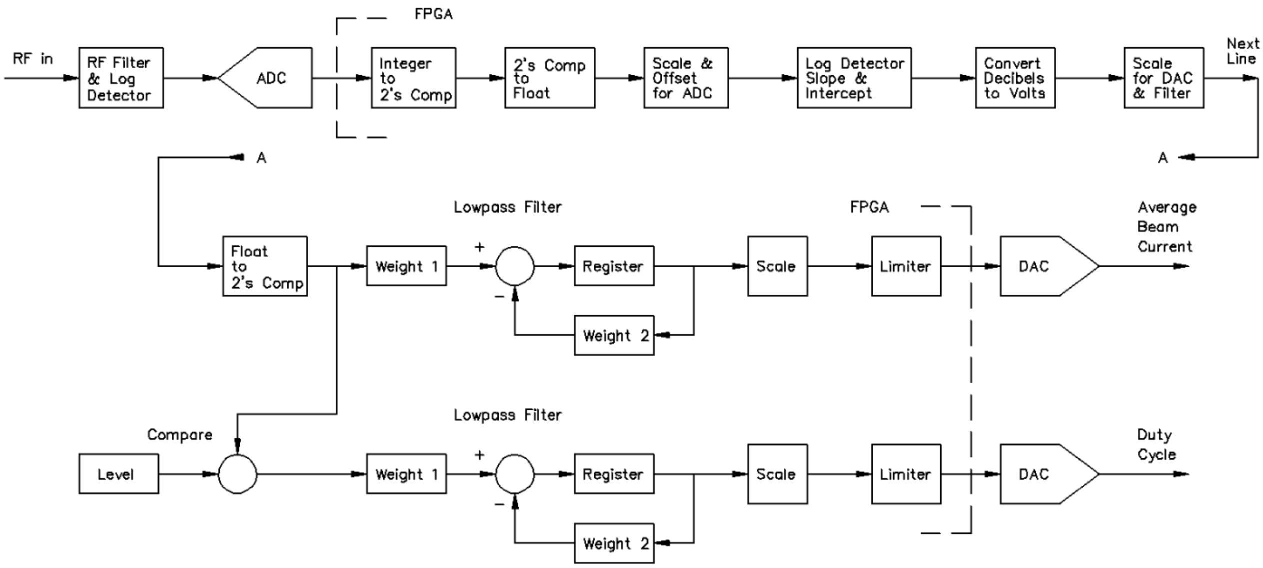

Figure 4: The data flow through the log detector, ADC, DACs and 50 MHz signal processing pipeline.

MECHANICS

VECC

A model of a shield assembly is shown in Fig. 2. An air cylinder is used to insert the device. Edge welded bellows and an SMA feed through contain the vacuum. The shield has slots for pump out. The coaxial structure uses Macor insulators. A THK linear bearing maintains the shield to wall spacing at 1 mm. Grounding fingers cannot be used between the tube and walls as rubbing could generate particulate. A Vespel pin through the rod and cylinder insures that there will be no rotation of the tube. Five shields will be installed in the VECC test stand.

E-linac

For the e-linac, the air cylinder will be mounted on the side to reduce the size. The beam pipe reduces from 2.5 in in VECC to 2 in. The geometry of the pump slots will be modified to reduce the Wakefields for a 0.3 mm long beam bunch while still allowing sufficient pumping speed. Thirty six rows of pairs of slots, each slot 1 mm wide and 2.5 cm long, will be made in a 3 mm thick stainless steel tube. Using a formula for the molecular conductance of short channels 8e-9 Torr should be readily attainable [3]. A high precision linear bearing was specified as the tube to wall spacing will be reduced to 0.5 mm. The tripod alignment table at the base of the support cylinder was improved. The radiation field will be up to 1 mSv/h at the beamline and bakeout may go to 150°C so plastic parts were eliminated from the bearing blocks. Eight shields will be installed at start up.

ELECTRONICS

The signals from the RF shields are brought to the electronics area on 21 m of Andrew 1/4 in Heliax cable. They pass through a 650 MHz bandpass filter to a circuit that will give dc outputs proportional to the average current and either the peak current or duty cycle. It uses a log detector with range of 70 dB for 1 dB of error and a rise and fall time of ~20 ns. Terasic development boards process the log signal. It is digitized by a 14-bit ADC at a 50 MHz rate and passed to a FPGA programmed in Verilog. Altera Megafunctions offset, scale, convert to floating point, antilog and filter the signal in pipeline architecture, see Fig. 4. Two 14-bit DACs provide the outputs. Digital processing maintains the wide dynamic range of the log detector and allows processing of short pulses without loss of accuracy. Beam pulses can be <120 ns and the sample rate insures accuracy at low duty cycle. A previous project used a DSP chip and a table lookup to perform similar functions, but required more programming effort and processed samples at a 100 kHz rate [4].

Figure 5 compares the response of the circuit using two different log detectors with a CW signal from a synthesizer. The Mini-Circuits ZX47-60LN uses an AD8318 with a 5 dB pad in front of it. The response of the ZX47-60LN in the plot has been decreased by 10 dB for clarity. Figure 6 shows the response to a pulsed signal. In these setups, the dynamic range was limited by the resolution of the output DAC. The prototype units were built into double width NIM modules, Fig. 7.

Capacitive probes do not provide absolute measurement of the beam current. Instead, at the start of a run, an EPICS program will calculate the allowable average current and duty cycle for the beam energy and dump in use. The RF shield signals will be calibrated using a downstream Faraday cup and the trip levels will be locked. This method has proven practical in our ISAC-II operation [5, 6, 7].

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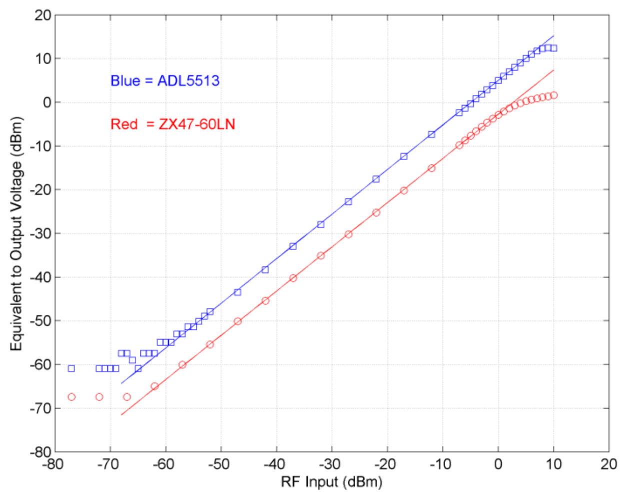

Figure 5: The response of the electronics for two different log detectors. The response of the ZX47-60LN has been decreased by 10 dB for clarity.

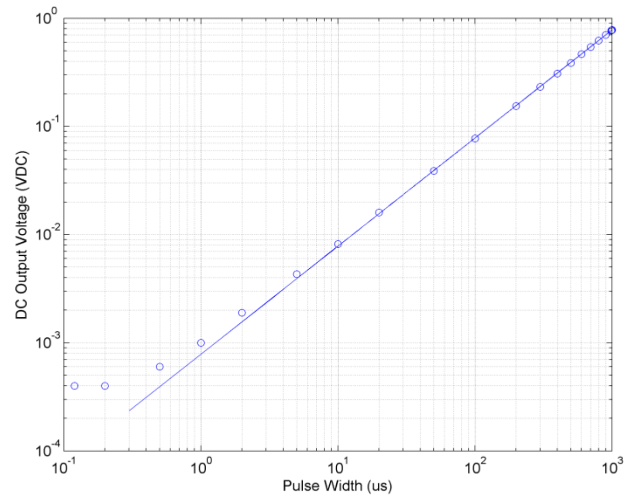

Figure 6: The response of the electronics to a pulsed signal.

CONCLUSIONS

It has been found that the RF shields can provide useful diagnostics signals. Electronics with wide dynamic range and fast response have been developed. The FPGA can provide accurate signal processing while being very straight forward to program.

ACKNOWLEDGEMENTS

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Figure 7: The prototype module is built into a double width NIM module.

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