Dynamic Emittance Monitor for the Recycler

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Abstract

A real time horizontal and vertical emittance monitor has been built for the recycler. The emittance monitor is an electronic circuit that measures emittance using the 1.75 GHz waveguide schottky detectors. The circuit uses the delta signals from both the horizontal and vertical detectors to measure emittance. The circuit is designed to measure the total integrated power in one schottky band. There are a total of four emittance monitors, one for each delta signal in the schottky system. There is the horizontal proton, horizontal pbar, vertical proton, and vertical pbar. A simplified block diagram of the emittance monitor circuit is shown in fig. 1. It consists of a down converter, a band-pass filter, and a RMS-to-DC converter. The function and design of each component will be discussed in this paper. Details of the 1.75 GHz schottky detector can be found in [1].

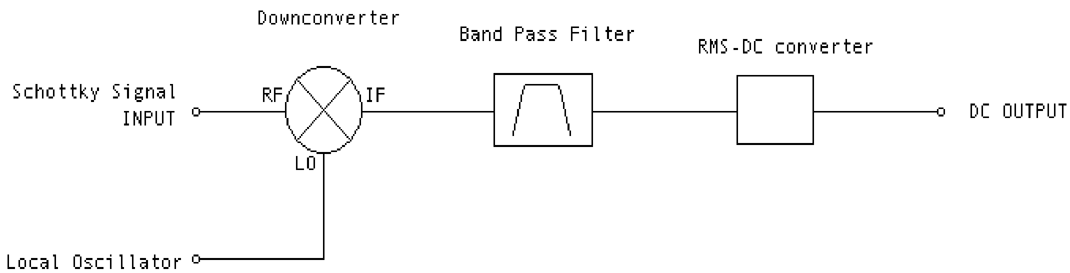


Fig. 1. Emittance monitor block diagram

Down Conversion

The function of the down converter is to bring the schottky signal to DC. A Mini-Circuits LRMS-1J frequency mixer is used in this circuit. The schottky signal before and after down conversion is shown in fig. 2. To properly center to schottky signal at DC, the local oscillator signal must be a harmonic of the revolution frequency of 89.813 kHz. The frequency should also be between 2 and 8 MHz, which is the frequency band of the schottky signal coming from the detector. The 25th harmonic of the revolution frequency is shown in fig. 2. The local oscillator signal is remotely programmable through a web page, and there are two output frequencies that can be programmed. A picture of the web page can be seen in fig. 3. The way the system is configured, the horizontal emittance monitors are programmed with frequency 1, and the vertical emittance monitors are programmed with frequency 2. The web address for this local oscillator is: (www.rclr-sch-lo.fnal.gov)

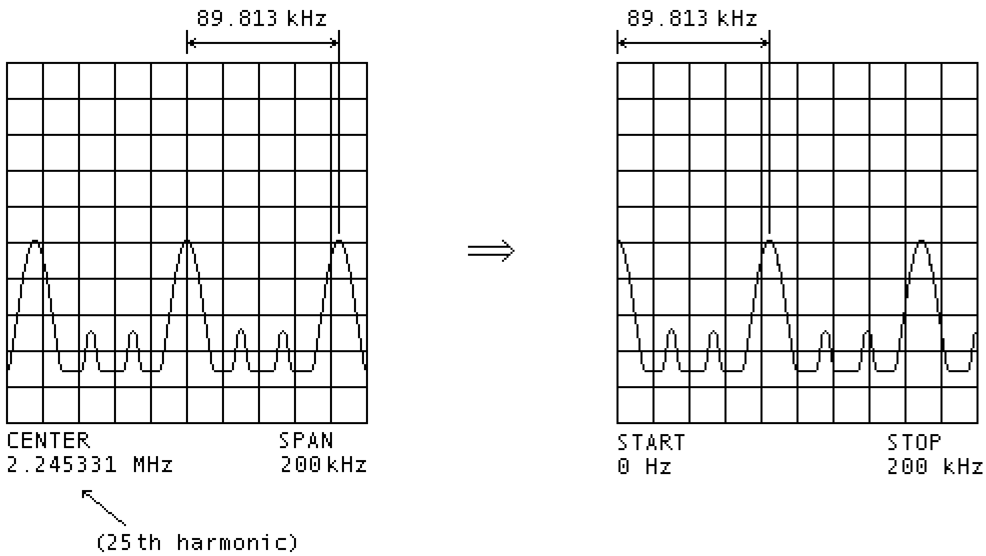
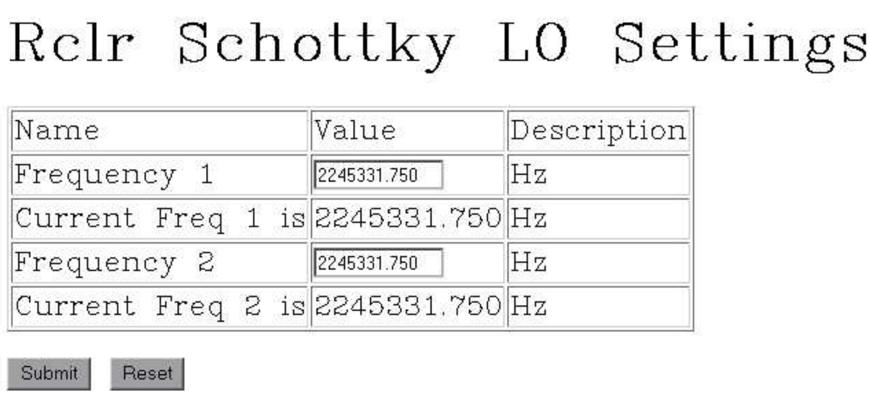


Fig. 2. Schottky signal down conversion



Rclr Schottky LO Settings

Name	Value	Description
Frequency 1	2245331.750	Hz
Current Freq 1 is	2245331.750	Hz
Frequency 2	2245331.750	Hz
Current Freq 2 is	2245331.750	Hz

Submit Reset

Fig. 3. Local oscillator web page

Band-pass Filter

The band-pass filter is needed to select one schottky band from the rest of the signal. This is done because the emittance is proportional to the power in one schottky band. A diagram of the band-pass filter response over the down converted schottky signal is shown in fig. 4. The band-pass filter is a 4-pole Butterworth op-amp filter designed using the Geffe Algorithm. A Butterworth filter is used to keep the band-pass region as flat as possible. A schematic of the op-amp filter is shown in fig. 5. All op-amps used in this circuit are wide bandwidth TL082. The gain of the op-amp filter is 250, and the measured response of the filter is shown in fig. 6 and fig. 7. The gain of the filter is important for the dynamic range of the system, and the calculation of the band-pass filter gain will be explained in the following section

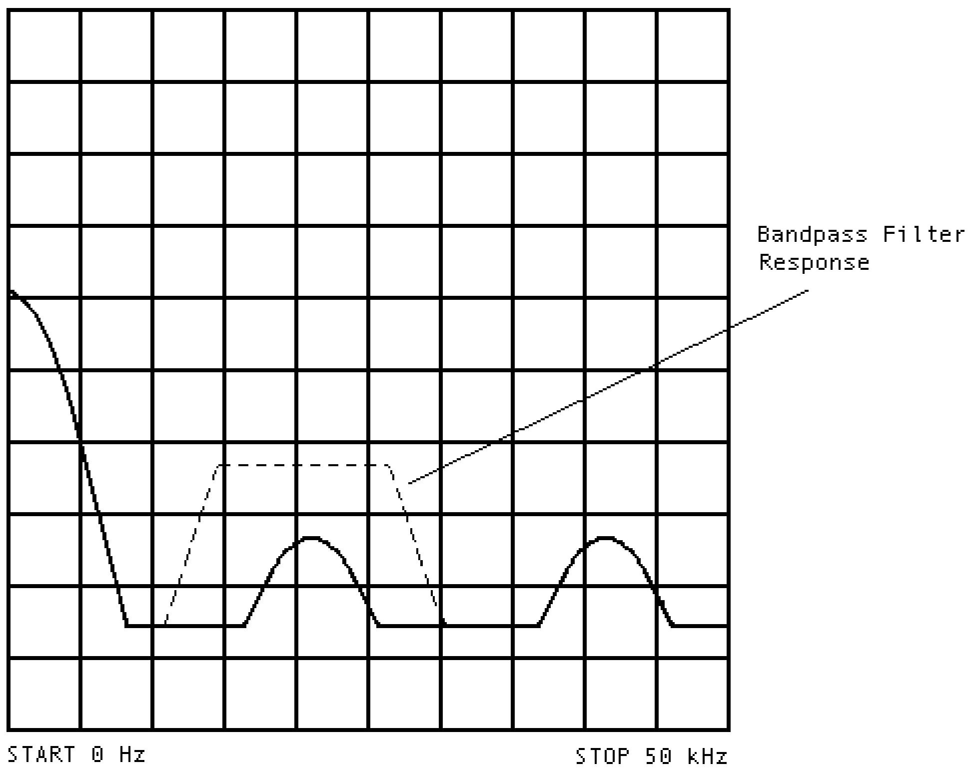


Fig. 4. Band pass filter response

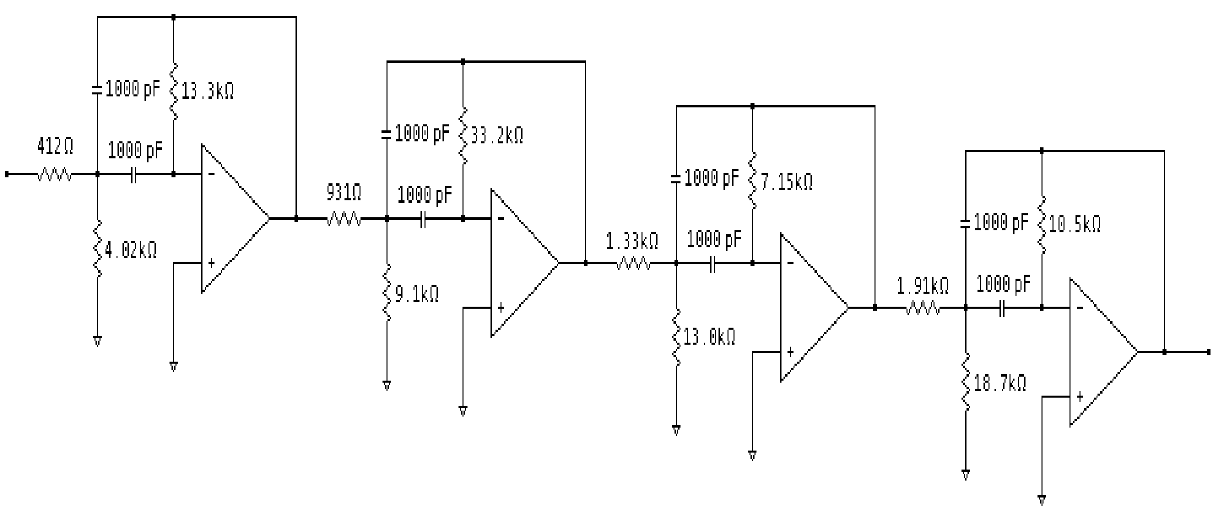


Fig. 5. Four-Pole Butterworth band-pass filter

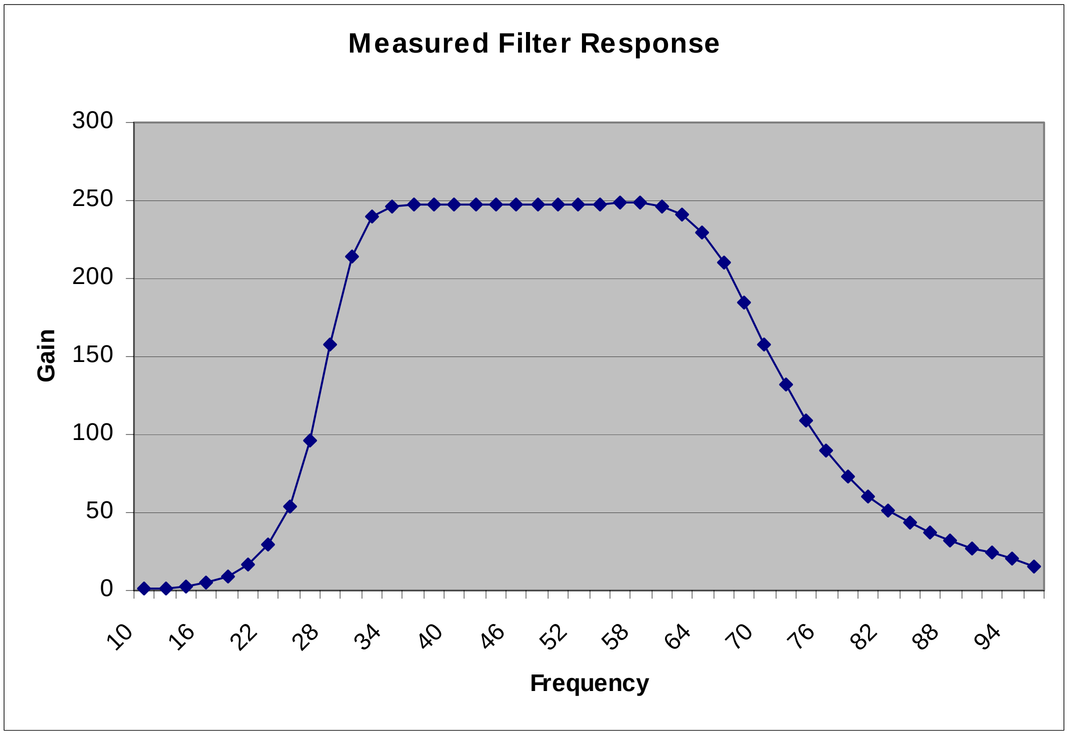


Fig. 6. Measured band-pass filter response

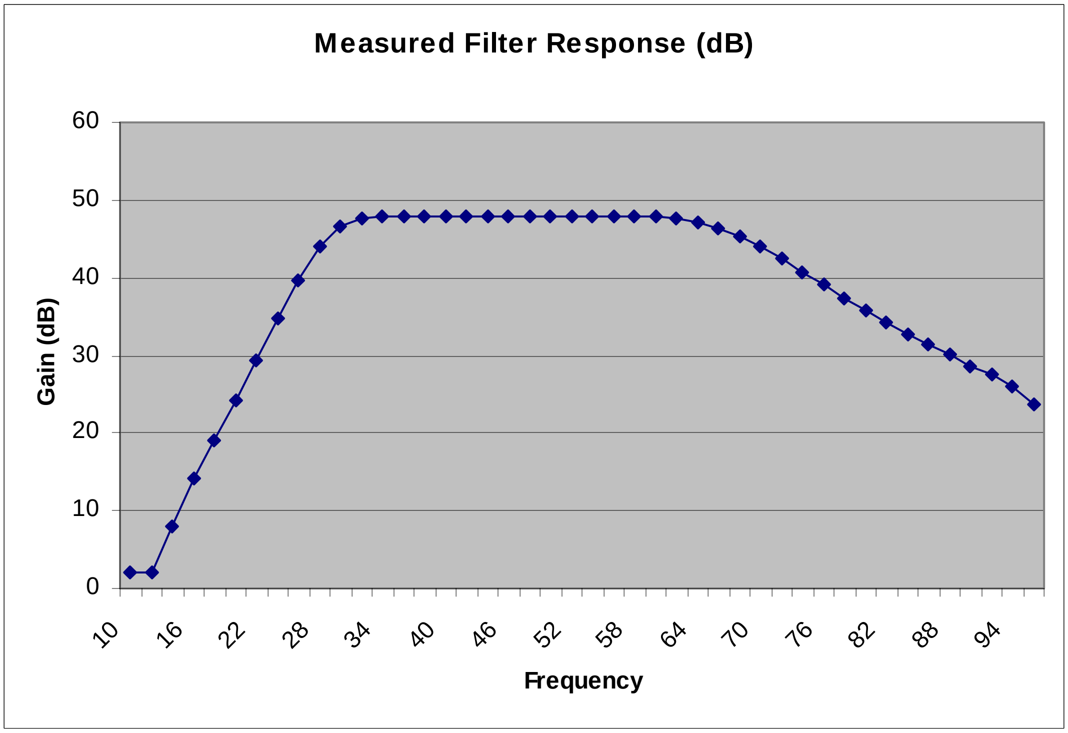


Fig. 7. Measured band-pass filter response in dB

RMS-to-DC Converter

The chip used in this circuit is the Analog Devices AD637 high-precision, wideband RMS-to-DC converter. The chip can handle 8 MHz of bandwidth with an input of 2V RMS for accurate linear operation (.02% linearity). The chip can go up to 7V RMS with an accuracy of 0.05% linearity. For this circuit, a maximum of 2V RMS is used. The connection of the chip is the two pole Sallen-Key filter shown in the manufacturer's data sheet. This configuration uses a filter to reduce the output ripple that could lead to measurement uncertainty. The complete emittance monitor circuit is shown in fig. 8.

Calculation of Bandpass Filter Gain

Measurements and calculations show that the total power in one schottky band, when the beam current is 4e12, should be about -29 dBm at the input of the band-pass filter. (–29 dBm into 50 Ohms) This is based on measurements taken in the field and extrapolating the data to a beam current of 4e12. 4e12 is taken to be a nominal value of beam current that could be in the Recycler. Using a power of -29 dBm at the input to the band-pass filter, the gain of the band-pass filter is calculated to be 250 to achieve 2V RMS at the input to the RMS-to-DC converter.

Complete Circuit and Installation

All four emittance monitors are mounted in one 19'' NIS chassis installed at MI-60. Details of the chassis are in drawing #0880.00-LB-417024. The local oscillator is also in a 19" NIS chassis installed at MI-60. The chassis' are located on the bottom half of rack MI60007. There are two test points in the circuit that lead to the front panel of the chassis. One test point is directly after the down converter, and the other test point is after the band-pass filter. Other additions were made to the circuit to make it work properly. There is an MWA-130 amplifier at the LO input to boost the power of the LO signal. The incoming LO signal is about –11 dBm, and the amplifier provides about 15 dB of gain, so the LO signal going into the down converter is about +4 dBm. There is also a 50 Ohm termination directly after the down converter, and a buffer amplifier is placed in front of the band-pass filter. The circuit includes a BNC twinax output on the rear panel that is sent to the MADC channels, and a BNC coax output that can be used for test on the front panel. MADC channels 49,50,51,and 52 located above rack MI60006 are used. The drawing number for the emittance monitor circuit is #0880.00-EB-417024. A photograph of the emittance monitor chassis installed at MI-60 is shown in fig. 9

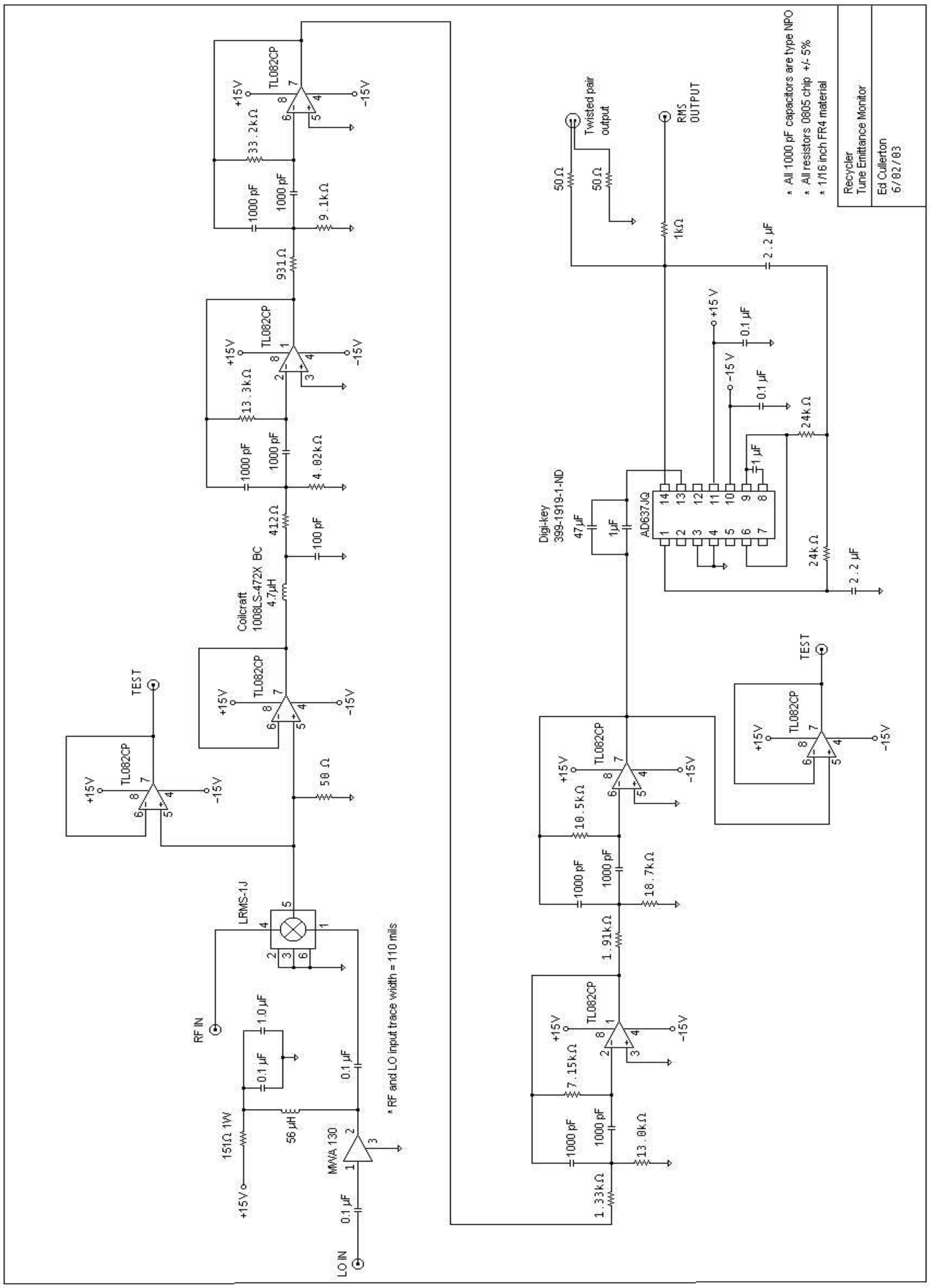


Fig. 8. Complete emittance monitor circuit.

Fig. 9. Photograph of the emittance monitor chassis installed in MI-60.

Measured Data

To verify that the circuit is measuring emittance properly, the data was compared to emittance data collected from ACNET page R37. The emittance measurement on R37 is calculated from the schottky system's vector network analyzer data. The emittance measured on this page is not real time, hence the need for this circuit. Once the plot is taken from the VSA, the power in one schottky side band is integrated and an emittance can be determined. The data taken from the circuit described in this paper is compared to the emittance data taken from R37. A linear relationship between the emittance monitors and R37 emittance measurements is seen and is plotted in fig. 10. The emittance must be normalized by subtracting the noise power, dividing by the beam current, and multiplying by some constant to give corrects units for emittance. The range of the monitor can also be examined from the beam current and emittance monitor voltages plotted in fig. 11. The maximum beam current plotted is about 3.5e11, and the vertical emittance reads about 0.8 Volts. Using a very rough calculation, if both of these values are increased by a factor of ten, which is close to the beam current of 4e12, the output voltage of the emittance monitor would be about 2.5 Volts. This is slightly past the predicted value of 2 Volts. The database names for the emittance monitors are:

R:EMHP	Horizontal proton emittance
R:EMVP	Vertical proton emittance
R:EMHA	Horizontal anti-proton emittance
R:EMVA	Vertical anti-proton emittance

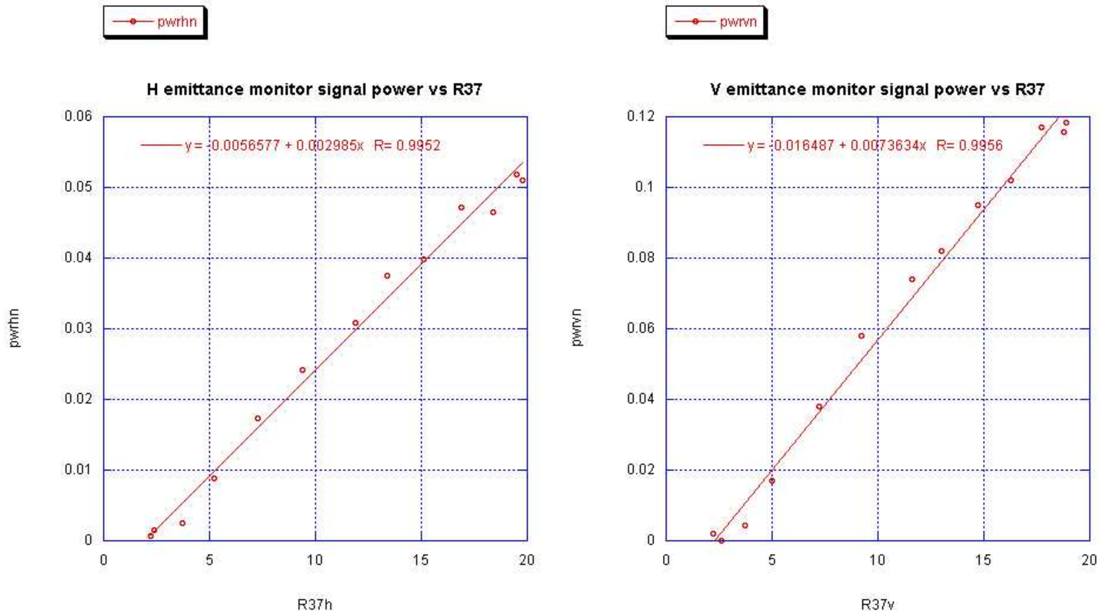


Fig. 10. Emittance comparison to R37.

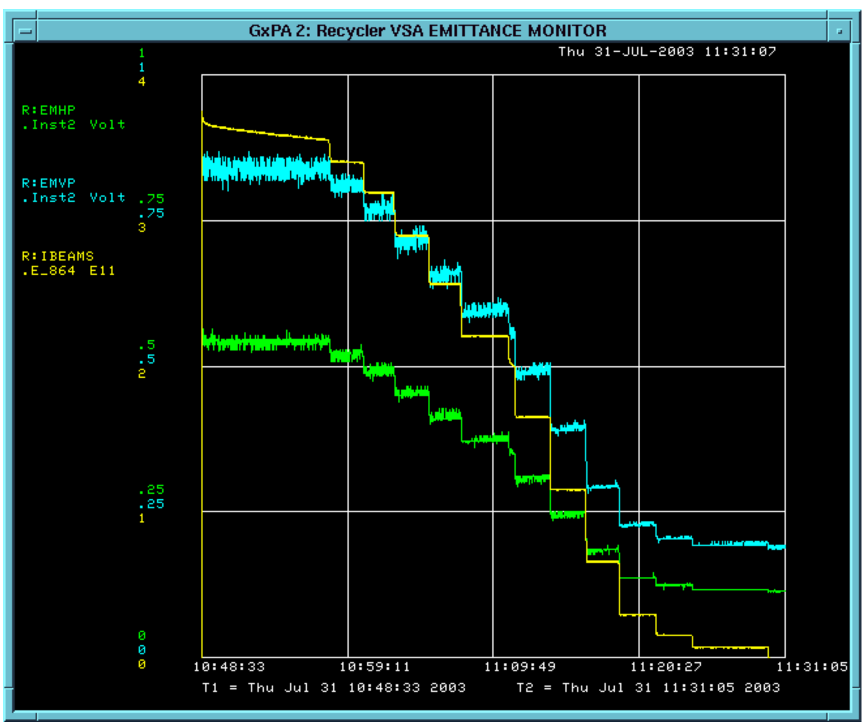


Fig. 11. Beam current and emittance monitor voltages.

References

[1] E. Cullerton, R. Pasquinelli, "A 1.75 GHz Waveguide Schottky Detector for the Recycler," Fermilab RF Department Note 63