THE SPALLATION NEUTRON SOURCE EIGHT-CHANNEL PULSED POWER METER *

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Abstract

The Spallation Neutron Source (SNS) Low Level Radio Frequency (LLRF) Control System currently utilizes the High-Power Protection Module (HPM) to monitor RF power levels, arc faults, and associated signals for the protection of the RF systems and accelerating cavities. The HPM is limited to seven RF channels for monitoring signals, which in some instances leaves some signals of interest unmonitored. In addition, the HPM does not support monitoring of RF frequencies below 100 MHz which makes it unusable for our Ring and Ion Source systems that operate at 1 and 2 MHz respectively. To alleviate this problem, we have developed a microprocessor based eight-channel pulsed RF power meter that allows us to monitor additional channels between the frequency range of 1 MHz to 2.5 GHz. This meter has been field tested in several locations with good results and plans are in place for a wider deployment.

INTRODUCTION

The Spallation Neutron Source (SNS) has been operational for over five years and routinely delivers 1 MW of beam power to the target at approximately 85 percent availability. During this time the RF systems have performed well but it has been noticed that it would be helpful to have additional RF monitoring capabilities. The current Low Level Radio Frequency (LLRF) system provides monitoring for up to seven RF channels, which is adequate for our system protection needs, but leaves some signals of interest unmonitored [1]. The system also is limited to frequency responses above 100 MHz due to the bandwidth of the detectors used. This leaves the ring and ion source RF systems that operate at 1 and 2 MHz respectively below the usable range of the system.

Due to the modularity of the LLRF system, it is possible to add one additional High-Power Protection Module (HPM) to the control system. This would allow for additional RF monitoring capabilities but will not solve the low-frequency response issue for the ring and ion source systems. The HPM solution will also limit where these extra channels could be utilized to existing LLRF locations. To solve these issues, a stand-alone solution was implemented that allows for greater frequency range, simple network communication, and the ability to locate it wherever needed.

SYSTEM OVERVIEW

The SNS eight-channel pulsed power meter is shown in Figure 1. The system supports simultaneous monitoring of 8 RF channels and 4 DC or analog channels. It can be locally controlled via the front panel or by remote communications. Remote communication is supported with 10/100 Ethernet and RS-232. Interlocks were added to support a simple protection scheme based on over-power detection. Two monitor ports are available to the user so that any of the ADC channels can be routed to the front panel via two 16 channel analog multiplexers.

Figure 1: Eight Channel Power Meter

A block diagram is presented in Figure 2 and provides an overview of the system. The design is based around a Microchip 16-bit microcontroller used to poll the analog to digital converters (ADC) and provide the user interface to the system. Two 2X16 character displays and two shaft encoders are provided to allow local users to scroll though and set all power meter functions.

Analog/RF Channels

The design of the analog and RF channels is based on the HPM design that is used for the LLRF systems. The analog and RF channels have been kept as similar as possible to limit layout errors with the printed circuit card (PCB). Twelve bit, 1.25 MSPS ADC converters are used for each of the input channels which provide enough resolution to recreate the pulsed waveforms when needed.

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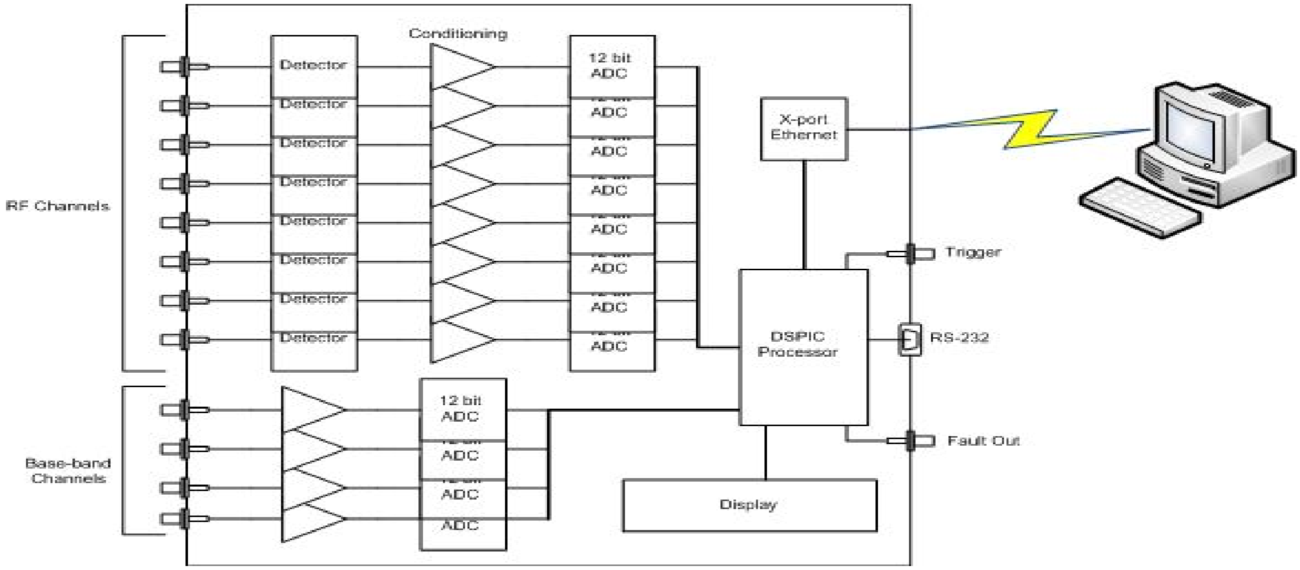


Figure 2: System Block Diagram

To solve the problem with the frequency range of the detectors, the power meter may be constructed with 1 of 2 possible detector choices. One detector covers the frequency range from DC to 440 MHz and the second detector covers 100 MHz to 2.5 GHz. The low frequency detector is limited to a lower frequency of approximately 500 kHz so that DC signals are blocked. Conditioning circuits have been added to remove the detector offset, set the channel gain, and optimize the range for the ADC. The RF channels are calibrated using the same two point calibration that is used for the HPM, this provides for a 50 dB usable dynamic range [1].

Four analog channels are provided for the measurement of baseband signals. At the SNS, these channels are used to measure the klystron voltage and current. This allows for the perveance of the klystron to be calculated so that the health of the klystron can be tracked.

Processor and Interlocks

The initial prototype single channel power meter used a simple 8-bit processor to perform all calculations and display features. When the system expanded to eight channels, a Microchip 16-bit microcontroller was chosen due to the built-in 12–bit ADCs, reasonable I/O count, and C compiler optimized instruction set [2]. The use of the built in ADCs were quickly abandoned due to their lack of sample and hold capabilities and were replaced with better performing stand-alone ADCs.

The Microchip digital signal processor provides adequate computing power to support all of the required functionality. The processor is responsible for reading all ADC channels, processing the input data, and displaying the information on the local 2 X 16 displays. All required calculations are done locally to support power readout in either dBm or Watts. Klystron voltage and current measurements have been added to the power meter to support perveance calculations.

With the use of a microprocessor, communications are simplified with the use of either the RS-232 port or 10/100 Ethernet. To keep the Ethernet functionality simple, an Xport Ethernet module was chosen that allows for either a simple web based application or terminal emulation based communication. Our current implementation utilizes a simple command set that allows for polling of the processor to provide data to EPICS for display remotely.

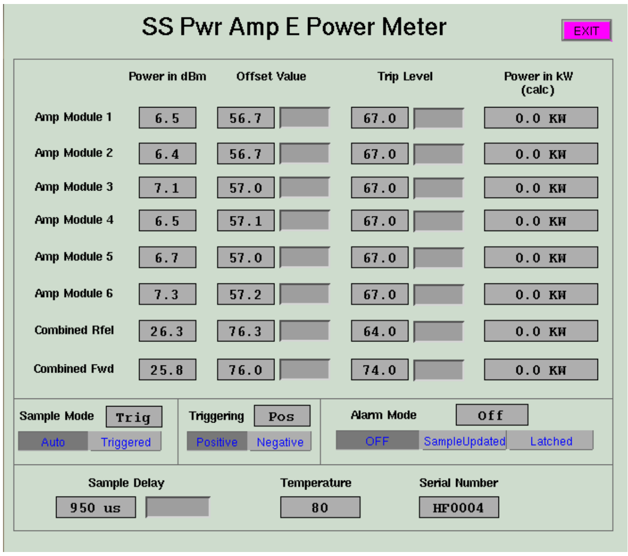
The implementation of interlock functions allows the power meter to provide device protection when required. The interlocks are implemented as a simple power level based measurement that is compared with a user settable trip point. Each RF channel has an independently settable trip level to allow for maximum flexibility. The system provides a single HPM style output connector that can be interfaced with the accelerators machine protection system (MPS) system.

User Interface

Two user interfaces are provided for the power meter, one for local control and one for remote control. The local control is accomplished with the use of the two shaft encoders and the two local display panels. All features can be accessed from the front panel controls to allow for stand-alone operation when a network connection is not available.

An EPICS screen has been developed to interface with the power meter and can be seen in Figure 3. It provides the capability to read or write any value to the device. Channel offset values can be modified from this screen to compensate for any cable losses, attenuators, or couplers that are in the signal path. Trip levels are settable from the screen along with the behavior of the interlock signal. Triggering can be configured to select the polarity of the trigger signal and the delay time between the trigger and the power reading. Finally, the temperature of the power meter and serial number is displayed.

The analog signals for measuring klystron voltage and current are not currently displayed on the screen but will be added in future releases. Klystron perveance calculations are also missing from the current screen.


SS Pwr Amp E Power Meter

	Power in dBm	Offset Value	Trip Level	Power in kW (calc)
Amp Module 1	6.5	56.7	67.0	0.0 KW
Amp Module 2	6.4	56.7	67.0	0.0 KW
Amp Module 3	7.1	57.0	67.0	0.0 KW
Amp Module 4	6.5	57.1	67.0	0.0 KW
Amp Module 5	6.7	57.0	67.0	0.0 KW
Amp Module 6	7.3	57.2	67.0	0.0 KW
Combined Rfel	26.3	76.3	64.0	0.0 KW
Combined Fwd	25.8	76.0	74.0	0.0 KW

Sample Mode Trig

Triggering Pos

Alarm Mode Off

Sample Delay 950 us

Temperature 80

Serial Number HF0004

Figure 3: Power Meter EPICS Screen

EPICS Control Implementation

To support the EPICS screens, an application of the EPICS remote control is running on a soft IOC, with StreamDevice support [3] and asynDriver solution.

StreamDevice, a generic EPICS device support for devices with a "byte stream" based communication interface, it comes with TCP/IP communication interface to asynDriver. It makes the data transfer simple between an EPICS record and a connected device. EPICS records with StreamDevice run protocols to read or write values. All protocols are defined in a protocol file in plain ASCII text, which includes the commands for power meter. Commands are sent to the power meter using asyn device support/driver to control power meter and get readback from power meter.

IMPROVEMENTS

The first generation pulsed power meter has been operational for over 1 year and supports the measurement of pulsed or CW RF signals from 500 kHz to 2.5 GHz. The system is currently utilized in the MEBT solid-state amplifier installation to monitor the individual amplifier segments. The second generation power meter was developed with additional analog channels to support klystron perveance measurements and is currently in field testing. Multiple software improvements have been implemented to make a more robust device that could withstand operating in a high voltage enclosure floating at -65 kV to support ion source 2 MHz RF systems.

While the current system works well and meets the current operational requirements, a new version is in development. The latest version will utilized an Altera Cyclone family field programmable gate array (FPGA) to implement the ADC read backs, complex interlock features, and trip delays for glitch immunity. With the addition of the FPGA, the power meter will be able to support most of the features of the current HPM to include providing remote waveform readouts.

SUMMARY

The first generation eight channel power meter has been deployed for over 1 year and has proven to be a reliable system. It provides needed remote RF power monitoring for systems that previously did not support it. The second generation system is complete and field testing is in progress. With the addition of analog signals, the power meter is capable of monitoring DC signals of interest. This has allowed for the calculation of perveance for the SNS klystrons. The system's firmware has proven to be readily upgradable as new features are requested. The Ethernet interface has made it easy to support remote power measurements in any location in the accelerator or test facilities. Plans to deploy the power meter throughout the superconducting Linac are in place as funding becomes available.

REFERENCES

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