

# RF POWER DETECTOR/MONITOR UPGRADE FOR THE 500MHZ SYSTEMS AT THE ALS\*

K. Baptiste,  
LBNL, Berkeley, CA, 94720 USA

## Abstract

Several systems rely on the accurate and linear detection of 500 MHz signals, (the fundamental frequency of both the Booster Ring and Storage Ring) over a dynamic range in excess of 25dB. Prior to this upgrade, the detector/monitor was diode based and though this type of detector could handle the dynamic range requirement it could not do so in an accurate and linear manner. In order to meet the requirements, (dynamic range greater than or equal to 25dB, accurate and linear to  $\pm 0.25$ dB over the range, and additional circuitry to interface to the legacy control system and interlocks) a new RF Power Detector/Monitor has been developed using two AD8361, Analog Devices TruRMS Detectors and a fuzzy comparator, which extends the overall detector's range to twice that of the AD8361. Further information is available [www.analogdevices.com/]. Details of the design requirements and the detector/monitor's circuit as well as the performance of the detector will be presented.

## INTRODUCTION

In the Advanced Light Source (ALS) Booster Ring and Storage Ring RF Systems there are a total of 16-500 MHz signals of which the signal power level must be measured accurately. The signal levels in these systems can range from tens of watts to 330 kW and via couplers, dividers, attenuators, and cable loss these signals have been attenuated down to a range of  $-20$  to  $+10$  dBm. Once detected, some of the signals are used in a variety of sub-systems, which include control loops, personnel and equipment interlock control chains and they are sent to the computer control system. The old detectors utilized the square-law functionality of a diode detector and though they had a large enough dynamic range they were not accurate or completely linear from device to device. The primary objectives in this redesign are to improve the linearity and accuracy over a minimum dynamic range of 25dB, to interface to the legacy analog loops and control systems, to improve the local meter display capabilities, and to achieve interchangeability amongst the detectors with out the need for recalibration.

## DESIGN

The new design, which came from the AD8361 Data Sheet [1], employs a dual channel detector system to extend the dynamic detection range for a given accuracy. The system is built using two AD8361 (Analog Devices TruRMS Detectors). See block diagram in Figure 1.

\*Work supported by the Director, Office of Energy Research, Office of Basic Energy Science, Materials Science and Engineering Division, of the U.S. Department of Energy under Contract No. DE-AC03-76F00098

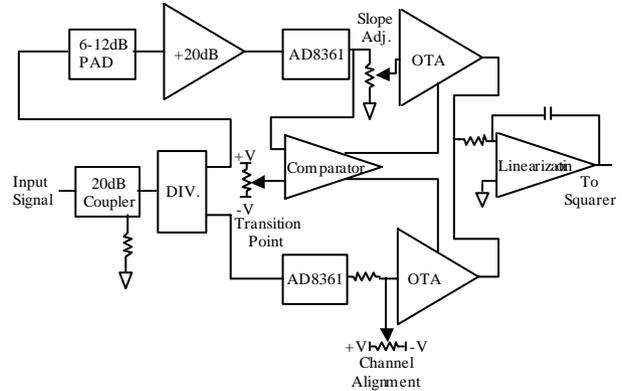


Figure 1: Detector Front End Block Diagram

## Dual Channel Detector System

The incoming signal is split into two channels, one for weak signals and the other for strong signals. The weak signal channel has a net gain, which boosts the weak signals up into the usable and accurate range of the AD8361. The circuit utilizes fixed value attenuators to adjust the net gain in the weak signal channel in order to optimize the channel for variations in the amplifiers gain and the detectors sensitivity. This method of optimization proved to be time consuming during the configure and test phase since several of the detector chips had wide variations in gain/sensitivity and accuracy. The strong signal channel has no additional gain.

## Cross-Fader & Fuzzy Comparator

The outputs of the two detectors are connected to the input of a cross-fader via a slope-equalization and offset adjustment circuit. Since the detection range of the two detectors overlap, the cross-fader must transition smoothly between the weak and strong signal channels over an approximate 3dB range. This transition is controlled by a fuzzy comparator, which controls the relative gains of the two detected signals thereby providing a weighted dynamic combination of the two detectors as a function of RF input level. As stated in the AD8361 Data Sheet Application section, the cross-fader is comprised of two Operational Transconductance Amplifiers, (OTA), and the comparator is comprised two transistors. The amplifier final stage applies feedback in order to linearize the transfer function of the transconductance amplifiers. A transition point adjustment is provided at one input of the comparator.

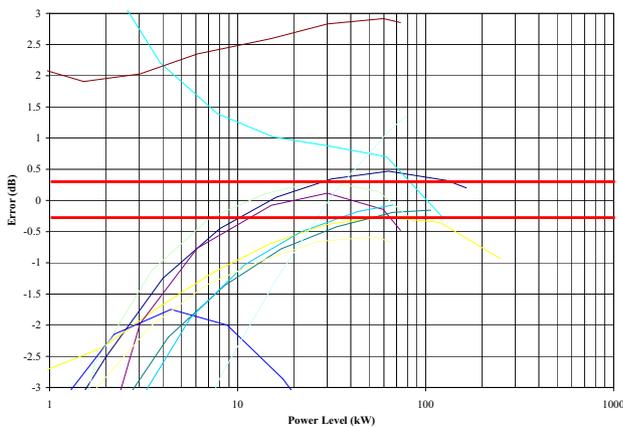
### User & Legacy Systems Interface

Additional requirements for the new detector/monitor are to fit into existing Eurocard chassis, provide front panel controls and indicators, and to interface with the existing control system.

The front panel of the module was redesigned to hold an auto ranging digital display, set point set and monitor controls, test/operate controls, and RF and detected signal monitors. The front panel interface is used for local system set-up and monitoring as well as by maintenance personnel for periodic interlock system tests. The legacy control system interface consists of an analog voltage linear in watts, relay contacts for power level interlocks (latching or non latching), open collector interlock for fast response, remote interlock reset, and various analog outputs for feedback loops.

### PERFORMANCE

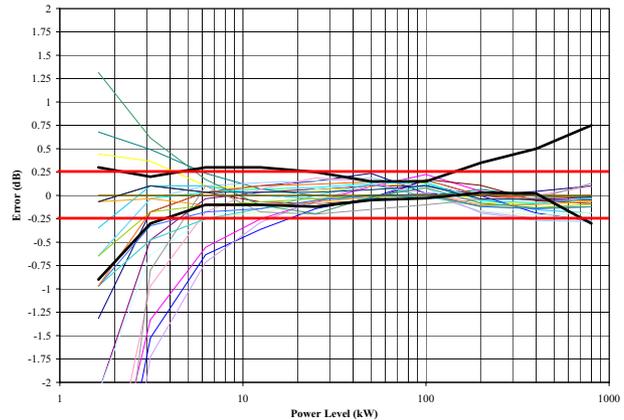
The main reasons to upgrade the power detectors was to increase their linearity and accuracy. The previous detectors were diode based, their linearity was poor therefore, and their accuracy was poor as well. Out of the 12 detectors in service in the ALS Storage Ring RF System only one unit exhibited  $\pm 0.5\text{dB}$  linearity over a 20dB range though its absolute accuracy was off by +2.5dB. See Figure 2, which shows the legacy detectors error on a logarithmic scale.



**Figure 2: Legacy Detector, Error from Linear Reference vs. Input Level**

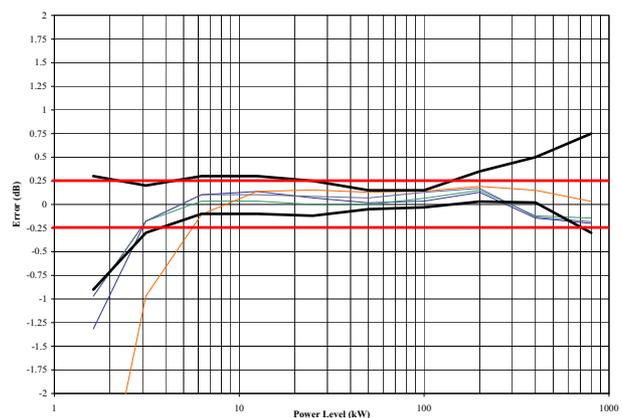
The redesigned detector, which utilizes the AD8631, is vastly superior in linearity as compared to the diode version. The AD8631 data sheet claims the device has up to 30dB dynamic range however it also states that for  $\pm 0.25\text{dB}$  error the range is reduced to 14dB. This limitation is the reason for using a dual channel detection method in order to extend the range while maintaining accuracy. The data sheet also shows a graph of the error from a linear reference versus input power for a large sample of devices at 900MHz. The black upper and lower error bars on Figure 3, which were extrapolated down to 500MHz from the 900MHz data, determine the expected accuracy range. The red bars determine our targeted accuracy range. Of the 26 units measured, (for both

500MHz and 1.5GHz operation) 16 units were within and 10 fell outside of the  $\pm 0.25\text{dB}$  accuracy requirement over a dynamic range  $>25\text{dB}$ . The measurement uncertainty was estimated to be 0.1dB due to temp drift and connections. However, one can see in Figure 3 and 4 that the low-end accuracy is much worse than the high-end accuracy. According to the data sheet for the AD8631, the low-end problems are due to signal offsets in the internal squaring circuits.



**Figure 3: Redesigned Detector (500MHz), Error from Linear Reference vs. Input Level**

In order to set-up the two channels slope, offset, and transition point I developed a LabView application, which controlled an ESG Series Signal Source that produced a 100 step linear power ramp and read data from a TDS 744A oscilloscope. See Figure 5 for a partial screen shot of the application. This application allows me to select only the ramp portion of the measured data array, which is then compared to a linear reference to generate the error plot. Due to the low resolution of the digital scope and the inaccuracy of the linear input power ramp from the signal source, the application was used only to initially tune the channels visually by observing the computed error for each power ramp. After the detector was initially set, I measured the accuracy at ten different power levels while making fine adjustments to slope and offset of the two channels.



**Figure 4: Redesigned Detector (1.5GHz), Error from Linear Reference vs. Input Level**

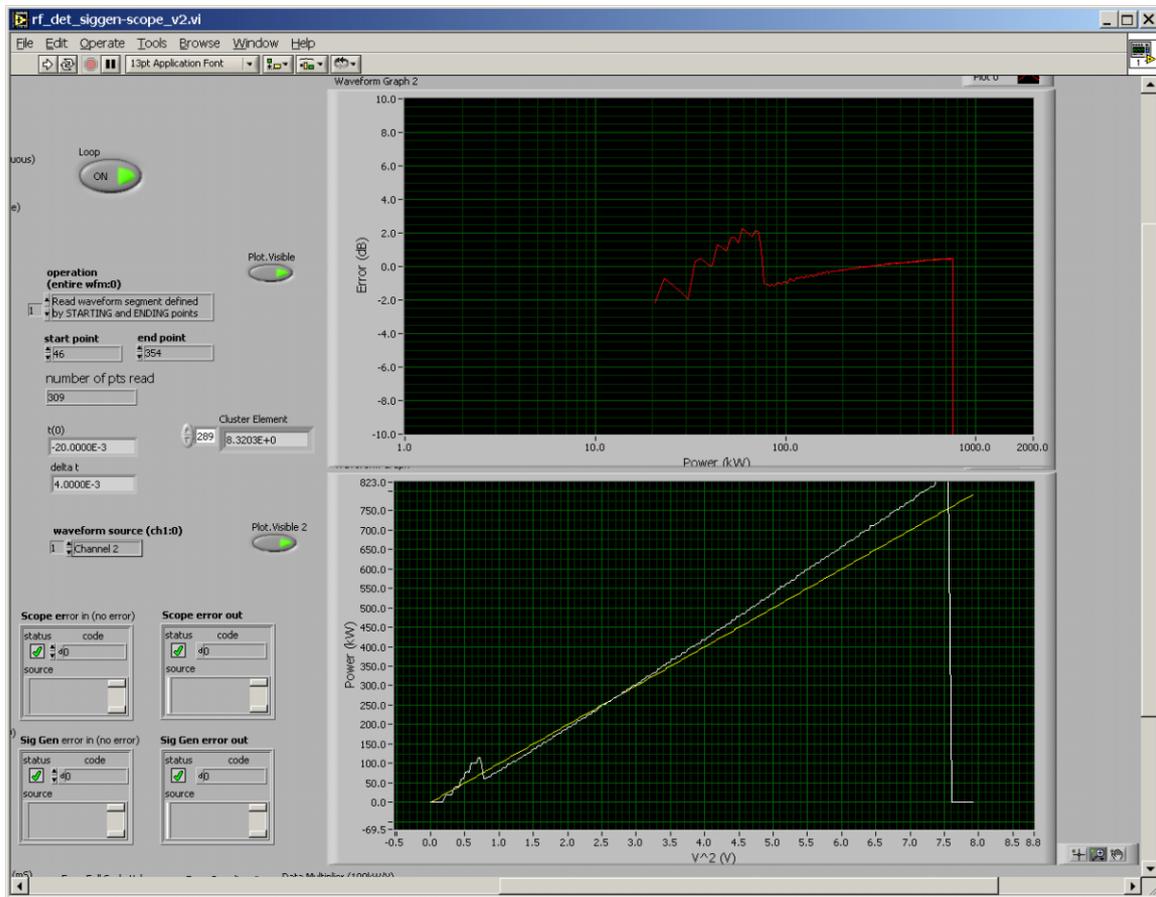


Figure 5: Partial Screen-Shot of LabView Application used to Initially Tune Each Channel.

### Operation at 1.5GHz

It was decided to utilize the redesigned detectors at 1.5GHz on ALS's 3rd Harmonic Cavities. The detector was modified by changing the matching networks at the input to the AD8631's and by replacing the directional coupler and power divider with higher frequency devices. Results can be found in Figure 4.

### FURTHER IMPROVEMENTS

- As mentioned earlier, it was very time consuming to set the correct net gain value in the weak signal channel by changing fixed attenuators. An improvement would be to use an electronically controlled variable attenuator.
- In order to minimize differences between detector chips one could digitize the outputs of the two AD8631s and once characterized, optimization and cross fading could be applied via programmable logic and software. This would produce more consistency between detectors.
- Installing a digitized temperature sensor would allow for software correction of gain and offset drift as a function of temperature.

- Installing an on board reference, which can be switched in via logic would allow for on board calibration.
- Installing a programmable gain amplifier used to set the analog output's scaling.

### CONCLUSION

The redesigned detectors, 12 500MHz and 3 1.5GHz models of which have been installed in the Storage Ring RF and Third Harmonic Cavity Systems have been in service since December 2002 and April 2003 respectively. Four 500MHz detectors are scheduled for installation during an upcoming installation and maintenance period. The performance of the installed units has been as expected based on the bench tests discussed in this paper. The detectors exhibit +0.25dB accuracy, due to their good linearity, and their dynamic range meets our operational requirements. The operational staff now has at their disposal linear and accurate RF power data that they can rely on.

### REFERENCES

- [1][http://www.analog.com/UploadedFiles/Datasheets/541602412AD8361\\_b.pdf](http://www.analog.com/UploadedFiles/Datasheets/541602412AD8361_b.pdf).