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Improving the Linearity of the AD8361 “Tru-Pwr” RF Detector IC

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Abstract— The AD8361 is a wideband linear RMS radio-frequency (RF) detector IC widely used in the RF industry. This paper presents a method to extend the dynamic range of the detector to nearly 40 decibels, over a range from less than -30dBm to +8dBm with absolute accuracy typically +0.5 /-1dB. In addition, most samples can be made to track to a very high degree over an even wider range.

The increase in accuracy and tracking allows improved power calibration, real-time power regulation, and calculation of VSWR (voltage standing wave ratio) for the multi-megawatt RF transmitters used to heat plasmas on NSTX at PPPL. The method presented here is simpler and lower cost than the dual-detector-amplifier technique presented by its manufacturer. Test results and distributions are presented for approximately 20 samples of a dual-detector module built by PPPL.

I. INTRODUCTION

The AD8361 “Tru-Pwr” RF detector IC is widely used in a variety of radio-frequency detector applications because of its superior linearity over a conventional diode detector. At lower signal levels, however, most samples deviate from linearity in a somewhat random fashion (ref 1). Analog Devices publishes a method of improving low-level performance using two ADD8361s, an RF amplifier and a fuzzy-logic controller (ref 2). Even the manufacturer admits that it is difficult to align. This paper presents a simpler method of improving the low-level response of the AD8361 for signal levels between -20dBm and -35dBm.

The AD8361 consists of a pair of analog squaring amplifiers in a feedback circuit configured to perform the root-mean-squared calculation in real-time. The “mean” term is provided by an external filter capacitor connected to a device pin. Optimum low-level operation of the circuit depends on the tracking of the two squaring amplifiers. Manufacturing variances in the silicon appear as linearity and offset errors at low RF levels.

II. LINEARITY CHALLENGE

A survey of about 30 samples with production dates in 2001, 2002 and 2009 operating at 30MHz showed that most samples deviate from linearity on the “low” side (insufficient output) for signal levels below -20dBm. Figure 1 shows the unadjusted linearity error for a batch of 6 AD8361 samples. This is similar to results from the manufacturer (ref 1). The error has a wide spread from +0 to -13dB at -30dBm and +0.5 to -5dBm at -21dBm. This leads to poor tracking in VSWR-calculations over a range of power levels of our transmitters.

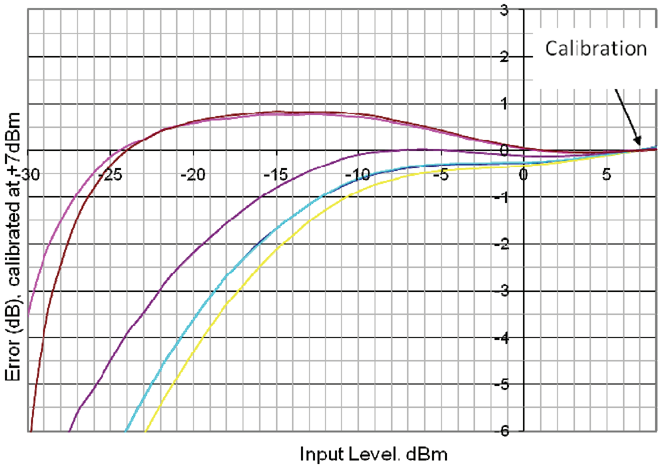

Figure 1. Unadjusted linearity, batch of 6 AD8361s from 2002 production

Many of the same parts also exhibited high output offsets approaching 80mV, and there seemed to be a correlation between output offset and linearity. This led to the conjecture that perhaps the nonlinearity was being caused by an unbalance in the internal squaring amplifiers; and that correcting the unbalance could improve both the output offset and the linearity simultaneously. Hints in an applications note (ref 3) led credence to this theory.

It was discovered that the linearity errors presumed to be in the squaring amplifiers can be corrected for most samples by inserting a small DC bias current into the “filter” pin. The filter pin rests at about 4.5V for a 5V supply, and a +/- 1 to 2 microamp current can correct the device’s linearity to +0.5/-1dB or better from -33dBm to +8dBm. A potentiometer connected across a well-regulated 10-volt supply and 1-megohm resistor between the potentiometer wiper and the filter pin provided the bias current for the results shown in Figure 2. The linearity biasing circuit is shown in Figure 3.

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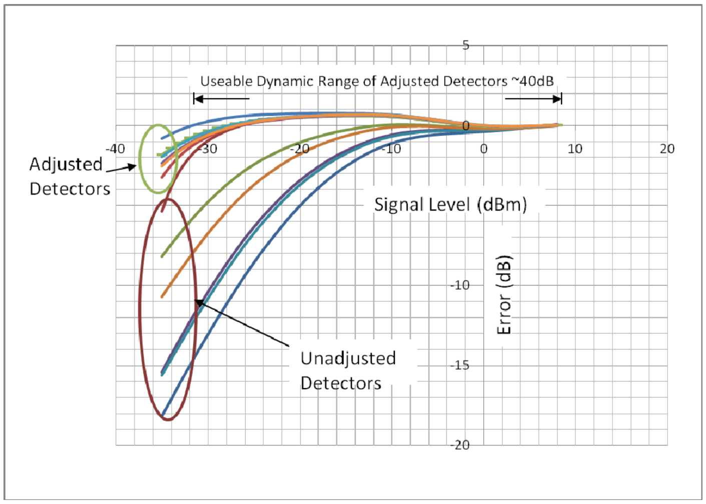

Figure 2. Adjusted and unadjusted error for 6 AD8361 samples, 2009 production

Note that although the device still departs from linearity at extremely low signal levels, most samples showed dramatic linearity improvements below -20dBm. They also tracked one another to within a fraction of a dB over wide range. There were only a few outliers in 30 samples. At the same time, the typical output offset was reduced to 20 millivolts or better.

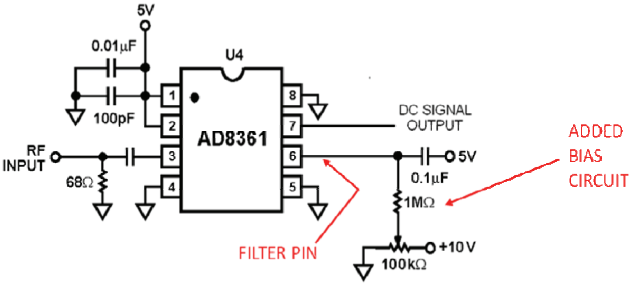

Figure 3. Linearity adjustment circuit

A simple LabView program was written to evaluate and graph linearity using a programmable signal generator and a GPIB digital voltmeter. Using this program, a technician made adjustments of the linearity bias potentiometer while observing the linearity of the AD8361 over a sweep of RF input from -35dBm to +8dBm in steps of 1dB. The best setting was empirically found to be 5 to 10 millivolts above the zero output intercept point for most samples. The procedure was the following:

1. With zero RF input and a voltmeter connected to the output, adjust the potentiometer wiper voltage for an AD8361 output voltage of about 50 to 100mV.

2. Lower the potentiometer wiper voltage while observing the output voltage for a "knee" (decrease in slope) as the AD8361 output nears zero millivolts.

3. Set the potentiometer for an output voltage approximately 3 to 5mV above the knee.

4. Run the linearity test with RF to check the results. If the low-level linearity errs on the low side at low signal levels (insufficient output voltage), try raising the potentiometer slightly; if the linearity errs on the high side, try reducing the potentiometer.

With this simple correction, the AD8361 can be used from +8dBm to better than -33dBm with error typically less than +/-1.5dB, with tight unit-to-unit tracking. A post-amplifier can be added to remove remnant offset. The success rate of filter-pin biasing is about 85 to 90 percent as shown in Figure 4. The alignment process could be readily automated with an on-board digital potentiometer.

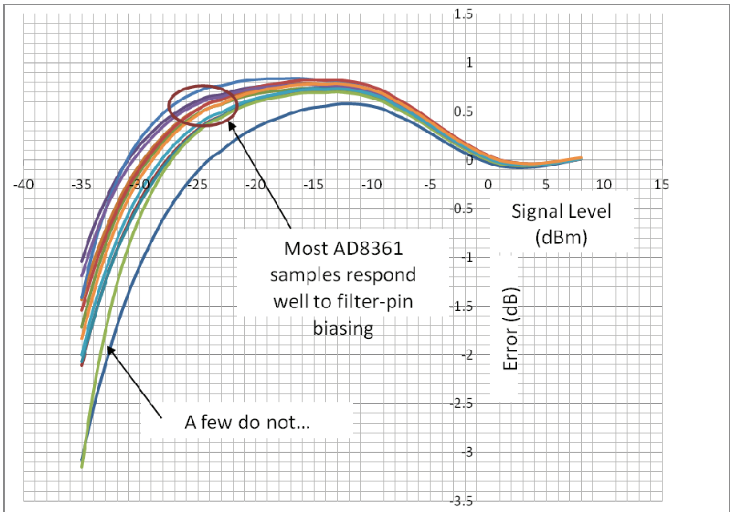

Figure 4. Success rate for 12 AD8361 samples

III. IMPLEMENTATION

A dual-detector circuit has been designed incorporating the linearity correction and approximately 20 samples have been reproduced for use at PPPL and elsewhere. The PPPL circuit includes a postamplifier-cable driver and several additional features.

Postamplifier- The PPPL Dual-Detector has a cable driver and output offset adjustment circuit built in. This removes remnant output offset from the AD8361. Selectable polarity is also available for legacy diode-detector replacement applications.

Missing-cable detection- Things happen and cables get broken or left disconnected. The AD8361 responds to DC just as well as RF. This characteristic can be exploited to add missing-cable detection. A diode across the input coupling capacitor and a DC bias injected into the "cold" side of the input termination resistor will cause the output to "rail" should the input cable become disconnected. The diode will remain back-biased for all credible RF signals applied to the AD8361 and does not affect normal operation. This feature relies on a DC termination at the RF source driving the detector.

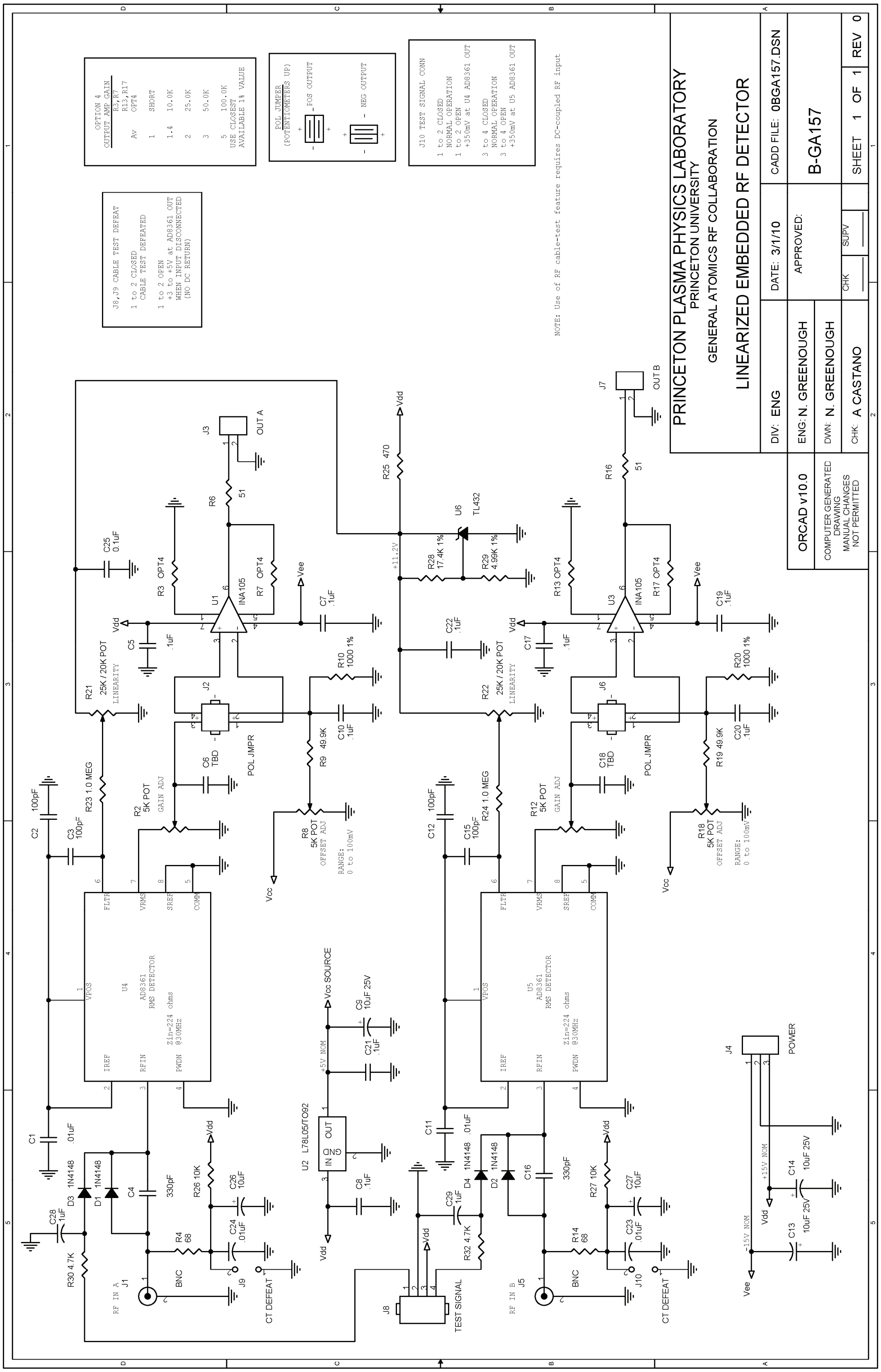

Figure 5. Schematic of the AD8361 Dual RF Detector

Simple self-test- Small DC currents injected into the AD8361 input pin will cause the detector to produce the corresponding RMS output. This can be exploited to add self-test features to the detector. An isolating diode and series resistor couple a small DC test current to the AD8361 input pin. The isolating diode will remain back-biased for normal operation by the self-bias of the AD8361 input pin. External circuitry can switch on the DC test current at an appropriate time and monitor the detector output for correct operation.

All of these features are incorporated into the dual-detector circuit of Figure 5. A photo of an unassembled unit is shown in Figure 6.

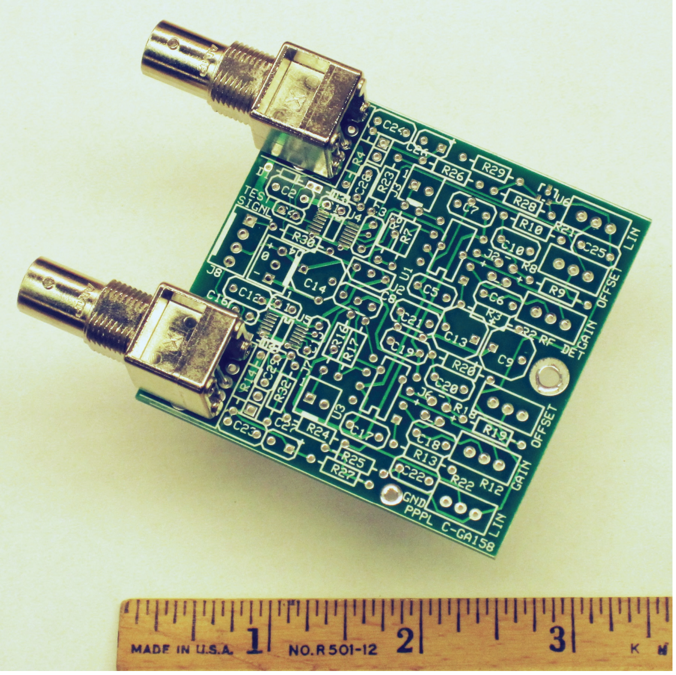

Figure 6. AD8361 Unassembled dual-detector PC board

IV. ACKNOWLEDGMENTS

The author wishes to thank Alba Castano of PPPL for bringing her former test experience at an RF components company to development of the alignment procedure.

V. CONCLUSIONS

The dynamic range of the AD8361 RMS RF detector can be dramatically improved by the addition of a single potentiometer and series resistor driving its filter pin. Most samples achieve a 40dB dynamic range with an accuracy of +1/-1.5dB. With this improvement it can be used in a wide variety of RF diagnostic and protection circuits for high power transmitters. A dual version has been implemented on a small PC board and a number of samples have been in use for several years with good results. The project files are available upon request.

VI. REFERENCES

[1] Datasheet for AD8361, Rev. C, (2004) Fig. 10; available from www.analog.com

[2] Datasheet for AD8361, Rev. C, (2004) Fig. 60; available from www.analog.com

[3] M. Pilotte "Operation of RF Detector Products at Low Frequency", Analog Devices App Note AN-691, 2005.

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