Evaluation of the AD9230 and AD9211 Analog-to-Digital Converters

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Contents

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1 Summary

Preliminary selection of three candidate analog-to-digital converters (ADCs) for LWA was reported in LWA Memo 98 [1]. Two of these ADCs – the AD9230-250 [2] and the AD9211-200 [3] – have been evaluated with results reported here. The AD9230-250 is a 12-bit ADC whereas the AD9211-200 is a less-expensive 10-bit ADC with similar performance despite the reduced number of bits, according to the datasheets. It is convenient to report the results of these two ADCs together because evaluation hardware is available from the vendor, Analog Devices, which greatly simplifies the process of making an "apples-to-apples" comparison.

It should be noted that we have evaluated the 200 million-sample-per-second (MSPS) version of the AD9211 (the AD9211-200) as opposed to the 300 MSPS version (the AD9211-300) identified in [1]. This is because comparable evaluation hardware is not available for the AD9211-300, and also because the planned sample rate for LWA has, since the time [1] was released, been set at 196 MSPS [4].

A summary of numerical results including quantization signal-to-noise ratio (SNR), one-tone spurious free dynamic range (1T-SFDR) and 2-tone SFDR (2T-SFDR) appears in Table 1. Both ADCs perform roughly as indicated by their datasheets, although no test reported here is identical to a test reported in the datasheets (so, a direct comparison of that nature is not possible, nor would it be very useful). In terms of SNR, the AD9230 outperforms the AD9211, although not by the 12 dB margin that might be anticipated from the fact that the former is a 12-bit ADC whereas the latter is a 10-bit ADC. In fact, the difference in SNR is slight (only 1.6 dB) for a 69 MHz tone. The AD9230 performs significantly worse than the AD9211 in 1T- and 2T-SFDR tests at 5 MHz and 25 MHz, and is only slightly better than the AD9211 at 69 MHz. An alternative qualitative assessment of spurious performance can be made from an examination of Figures 3 and 4, which, in our opinion, suggests the AD9211 is preferable in our application. In summary, we conclude that neither ADC is clearly better than the other in our application, although based on a qualitative assessment of spurious performance we have a slight preference for the AD9211.

We also performed some additional testing using a prototype LWA analog receiver (ARX) to produce realistic receiver noise, a lab-generated ATSC signal, and actual sky input using ETA active antennas with the prototype LWA ARX. The results were generally consistent with expectations. Unfortunately, the latter two tests (lab-generated ATSC and ETA/sky) were compromised for the AD9230-250 due to a problem with the evaluation board. The AD9211-200 test results are valid for all tests conducted.

This report is organized as follows. In Section 2 we describe the specific hardware evaluated. In Section 3 we report on the procedure and results of laboratory measurements of the parameters reported in Table 1, as well as the laboratory ATSC signal testing. In Section 4 we report on additional tests conducted in an attempt to ascertain the relative performance of these ADCs in field conditions.

Metric	Frequency	AD9230-250	AD9211-200
Input Full Scale	5 MHz	+3.3 dBm (925 mV_{pp})	+3.6 dBm (957 mV_{pp})
	25 MHz	+3.5 dBm (946 mV_{pp})	+3.5 dBm (946 mV_{pp})
	69 MHz	+3.8 dBm (980 mV_{pp})	+3.6 dBm (957 mV_{pp})
SNR	5 MHz	64.0 dB	59.4 dB
	25 MHz	61.5 dB	58.2 dB
	69 MHz	55.7 dB	54.1 dB
1T-SFDR	5 MHz	82.7 dB	84.5 dB
	25 MHz	82.2 dB	86.4 dB
	69 MHz	65.0 dB	63.8 dB
2T-SFDR	25 MHz	71.9 dB	76.5 dB
	69 MHz	63.9 dB	62.0 dB

Table 1: Summary of Test Results.

2 Hardware Evaluated

The AD9230-250 and AD9211-200 are available as evaluation boards from the vendor. Images of the evaluation boards are shown in Figures 1 and 2. Documentation of the design is poor – other than the boards themselves, the only available information is a hardcopy schematic provided with the AD9230 board. The design of the AD9211 board appears to be similar or possibly identical. For both boards, both the analog signal input and clock input are AC-coupled through a single-ended coaxial 50Ω input jack and converted to differential form using a Mini-Circuits ADT1-1WT transformer in a balun configuration.

The vendor offers a third board, the HSC-ADC-EVALC (shown in Figure 2), which connects between the ADC evaluation board and a personal computer (PC) [5]. The HSC-ADC-EVALC is used to buffer high-speed output from the evaluation board, which is subsequently transferred to the PC via USB. MS-Windows based software for operation of this board is free and well-documented [6].

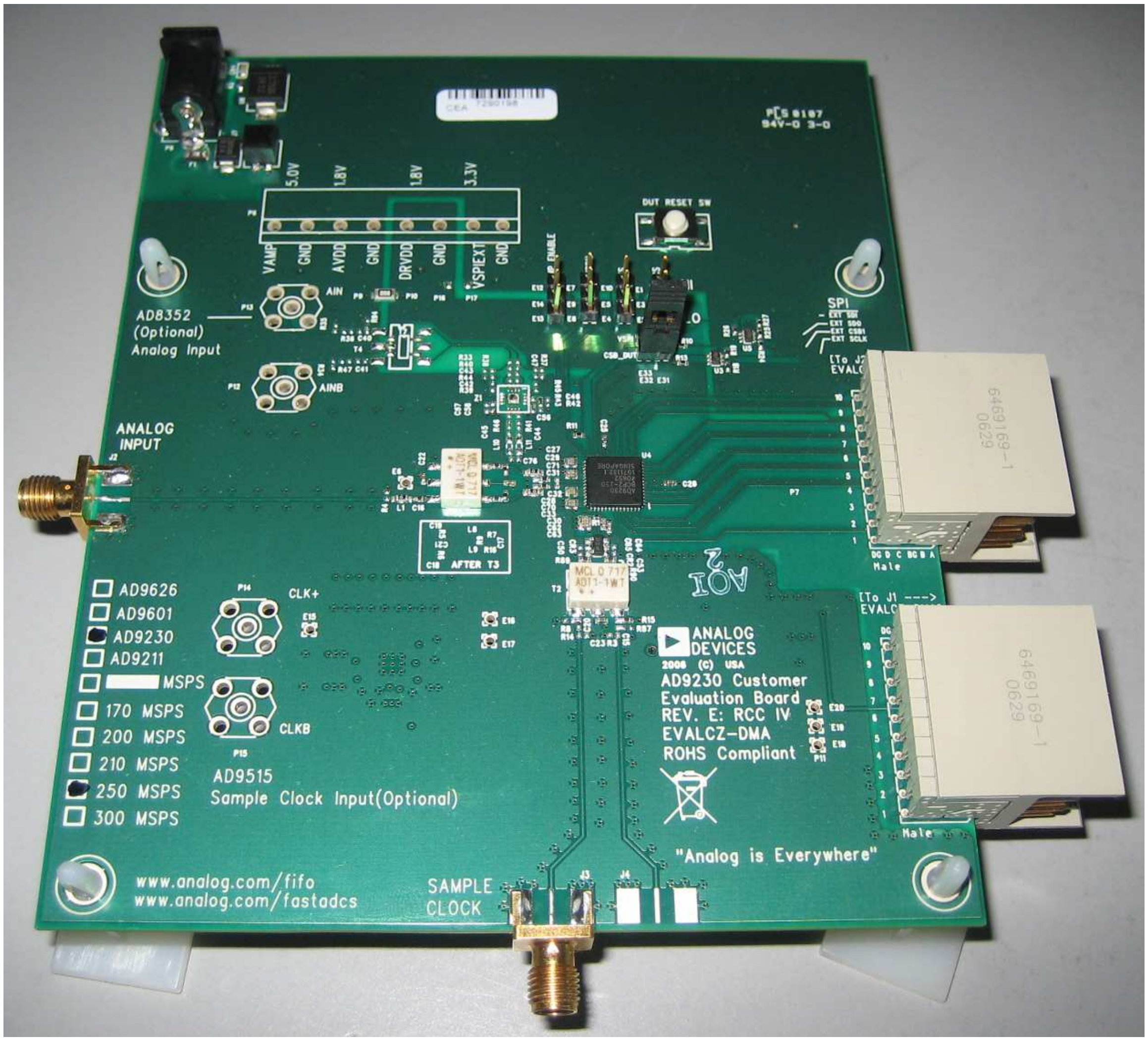


Figure 1: ADC9230-250 Evaluation Board (Analog Devices Part No. AD9230-250EBZ).

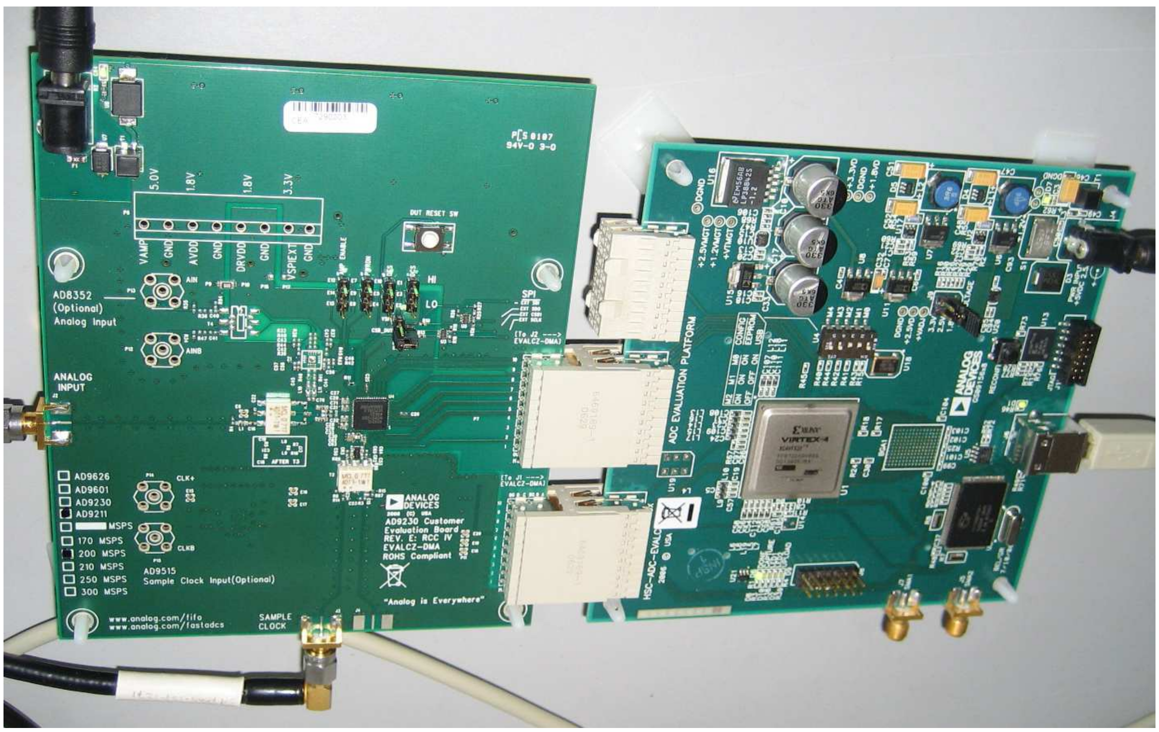


Figure 2: ADC9211-200 Evaluation Board (Analog Devices Part No. AD9211-200EBZ), on the left, with buffer board (Analog Devices Part No. HSC-ADC-EVALC) on the right.

3 Laboratory Testing

All testing was performed using an Agilent HP8648C signal generator to provide a 196 MSPS clock signal at +7 dBm. The signal source for lab testing was either one or two Novatech Model 408A 100 MHz quadrature frequency synthesizers[1], which permit tuning resolution of better than 1 mHz. Signals from the Novatech sources were bandpass-filtered prior to input to the ADC evaluation board. Specific frequencies and filter configurations are summarized in Table 2. Frequencies were selected to yield an integer number of periods in 64K samples when sampled at 196 MSPS.

Stated Frequency	Actual Frequency	Bandpass Filter	Bandwidth
5.8 MHz	5779011.203 Hz	K&L 5LB32-5.8/T0.4-0/0	400 kHz
25 MHz	24972534.175 Hz	TTE KC4-24.97M-2M-50/50-69A	2.5 MHz
26 MHz (2T tests)	25971435.542 Hz	(same)	(same)
69 MHz	68924194.323 Hz	CIRQTEL FBT/2-69/6-3/50-28A/28A	6 MHz
70 MHz (2T tests)	69923095.690 Hz	(same)	(same)

Table 2: Frequencies and filtering for input to ADC evaluation boards.

Figures 3 and 4 show the results for 1-tone and 2-tone testing, respectively. The results shown here and throughout this report use 64K FFTs with no windowing; except for the ATSC testing, which uses a Blackman-Harris window. The phase noise apparent within a few MHz of each of the primary sources is due to sources and does reflect a limitation in ADC performance. The estimate of quantization noise required for the SNR calculation was obtained by summing power over regions excluding the primary signal(s) (and the associated phase noise region(s)) and DC, but including any spurious and harmonic content, and then scaling the result to account for the excluded spectrum. 1T- and 2T-SFDR was computed with respect to the strongest discrete spurious signal (i.e., strongest bin not obviously the result of phase noise from external inputs), again excluding DC. For the 69 MHz tests, one of the signal sources was observed to produce a spurious 71.73 MHz signal which is included in the plots, but excluded in the calculation of SNR and 1T- and 2T-SFDR.

We also experimented with inputs using the LWA prototype analog receiver (ARX) described in LWA Memo 82 [7]. Specifically, we applied a 69 MHz tone to the ARX input, and connected the ARX output directly to the ADC evaluation board input. The level of the ARX input was adjusted to produce −1 dBFS at the ADC output. The results are shown in the top row of plots in Figure 5. These plots are the result of 100 FFTs which have been incoherently averaged. Also shown in this figure is the result when the tone is turned off at the source (middle row), and when both the source tone and ARX are turned off (bottom row). The spurious tone at 58 MHz is the 2nd harmonic of the source (138 MHz), generated in the ARX and appearing as an alias in the ADC output. The performance of both ADCs in this test appears to be essentially the same.

Some time between the completion of the testing described above and the ATSC testing described below, the AD9230-250 evaluation board developed a problem. We determined through additional testing that the problem involves erroneous values on one or more low-order bits; i.e., one or more low-order bits which are stuck or "jabbering". The effect is to produce additional quantization noise, which makes the effective number of bits appear less than actual. Additional statistical analysis of the raw ADC output accumulated during the testing described above confirmed that the problem did not exist in those measurements. Measurements which are effected by the AD9230-250 problem are indicated in the captions of subsequent figures as "AD9230 (broken)."

[1] \$795 each, http://www.novatech-instr.com/

We tested both ADCs with an ATSC (digital TV) waveform. We produced the waveform using a Stanford Research Systems Model DS345 function generator.[2] The DS345 has an arbitrary function generator mode which operates at 40 MSPS; we used this with an ATSC waveform generated by one of us (Lee) to produce an ATSC signal with center frequency 7 MHz. This we upconverted to 69 MHz by mixing with a 62 MHz local oscillator signal generated by one of our Novatech sources (see above), and the output was filtered to 6 MHz bandwidth using a cascade of two CIRQTEL filters, also described above. The results are shown in Figure 6. These plots are the result of 1000 FFTs which have been incoherently averaged. A Blackman-Harris window was employed in this case. The AD9211 does not appear to have any difficulty digitizing the ATSC signal without producing additional out-of-band spurious signals. The situation is the same for the AD9230, to the extent that this can be determined given the elevated quantization noise floor.

[2] \$1595, http://www.thinksrs.com/products/DS345.htm

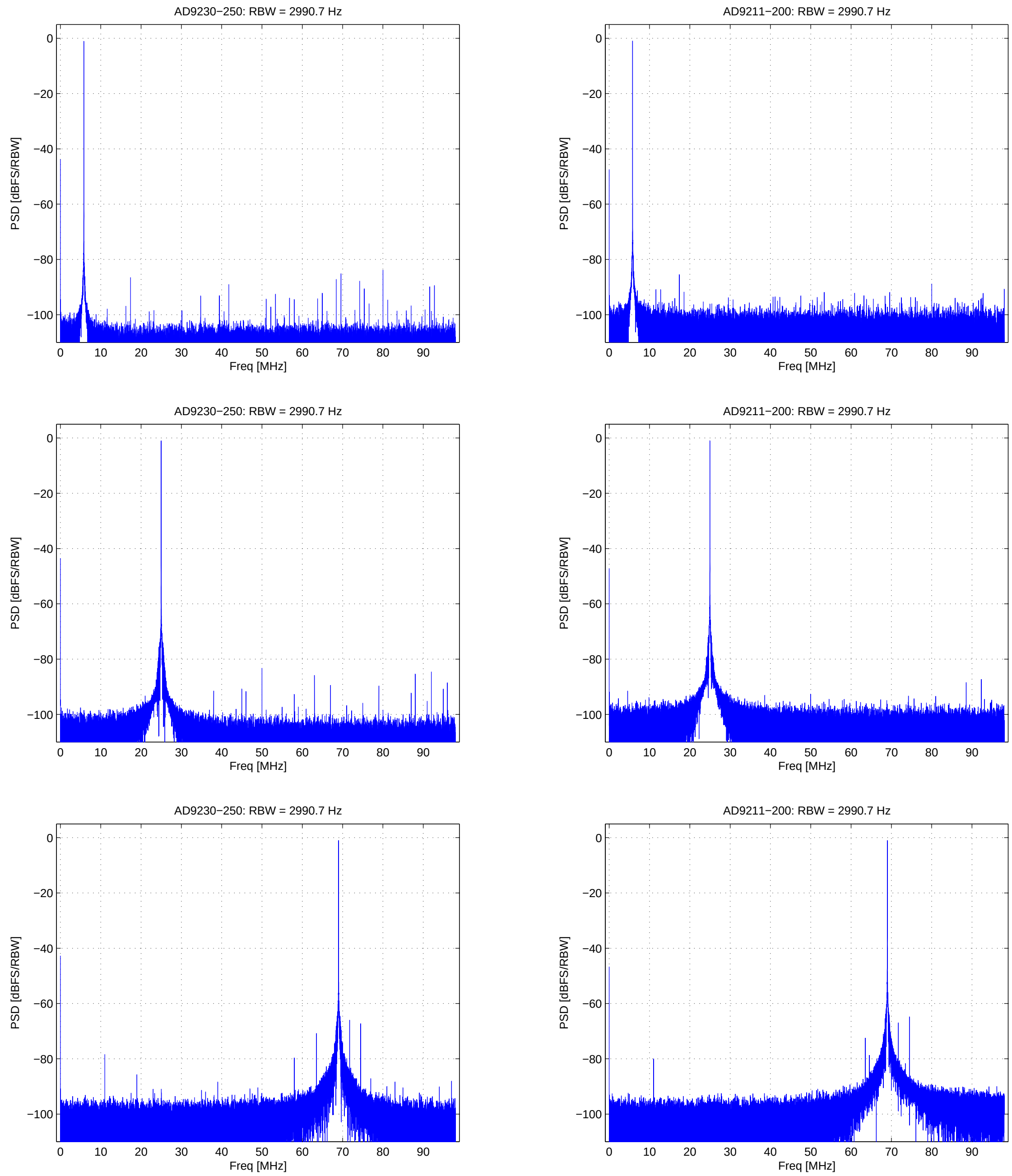


Figure 3: −1 dBFS tone applied at 5.8 MHz (top), 25 MHz (middle), and 69 MHz (bottom). AD9230 on the left, AD9211 on the right.

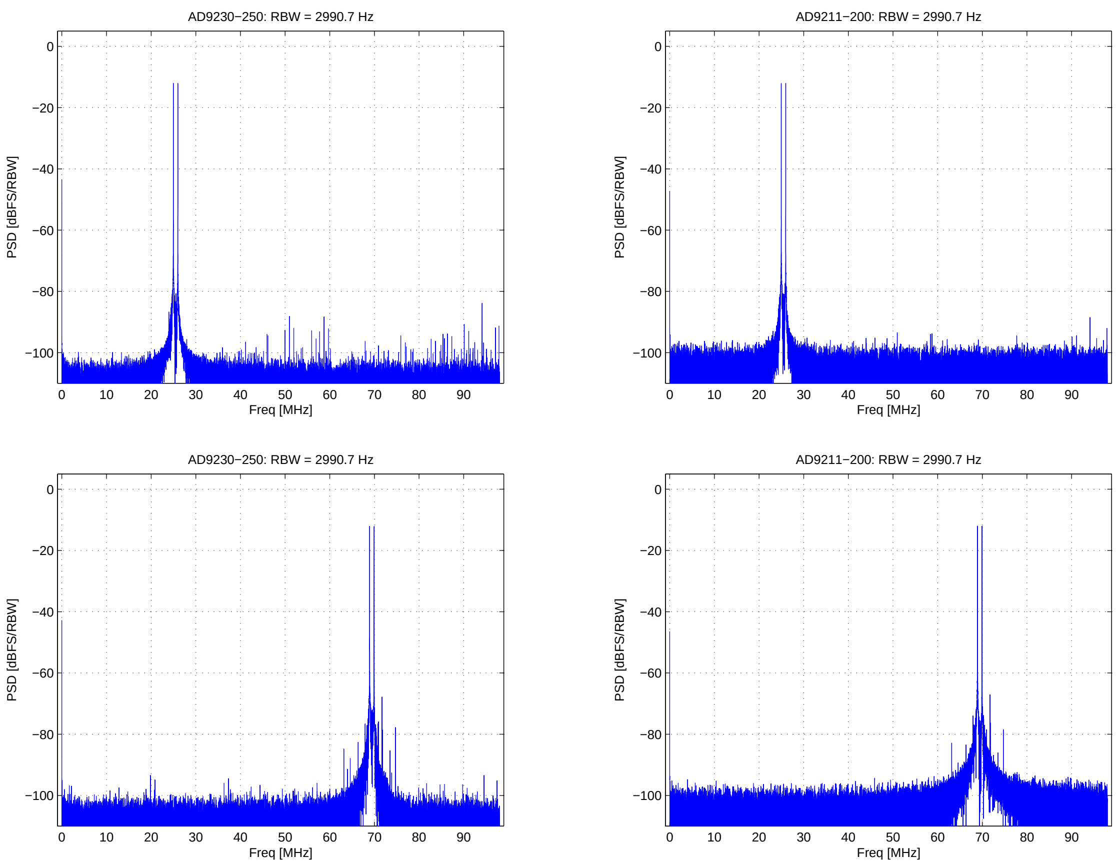


Figure 4: Two −12 dBFS tones separated by 1 MHz, applied at 25 MHz (top) and 69 MHz (bottom). AD9230 on the left, AD9211 on the right.

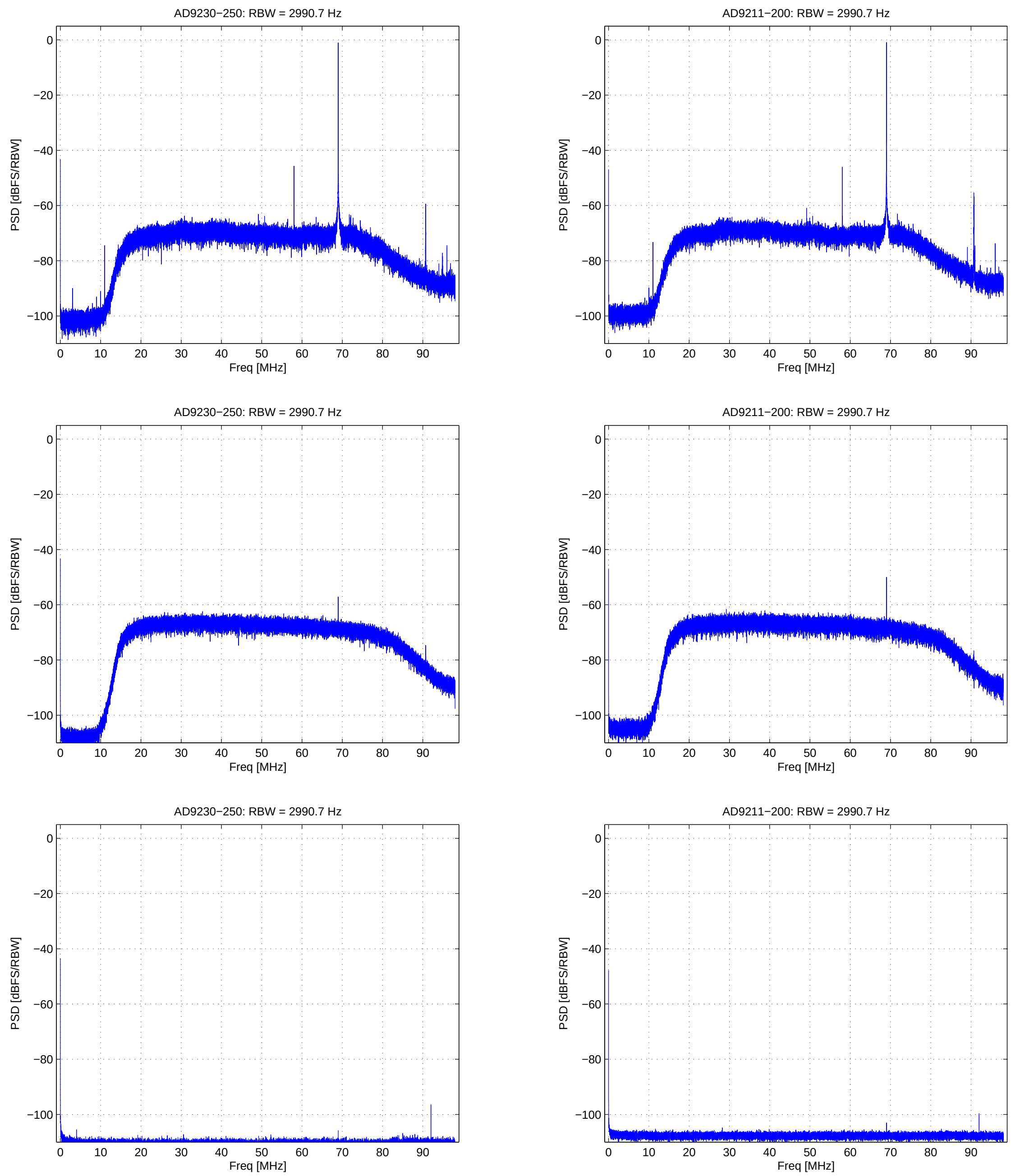
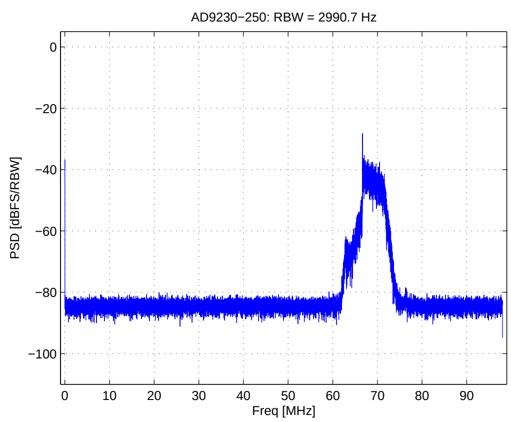


Figure 5: Using the prototype LWA ARX of Memo 82 to generate input for the ADC evaluation boards. 100 FFTs incoherently averaged. Top: One −1 dBFS tone at 69 MHz; Middle: Tone source turned off; Bottom: Tone source and ARX turned off. AD9230 on the left, AD9211 on the right.



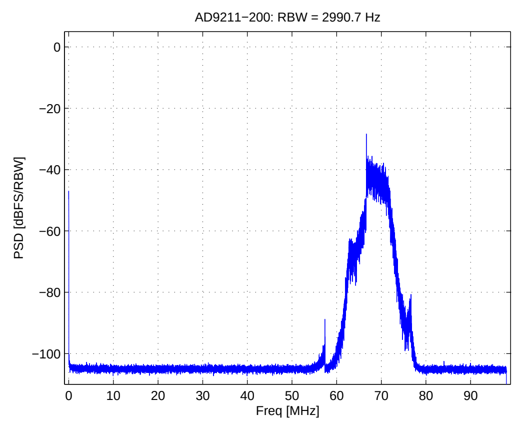


Figure 6: ATSC signal centered at 69 MHz, adjusted to produce 40% full scale output. AD9230 (broken) on the left, AD9211 on the right. Note the LO breakthrough (at 62 MHz), image breakthrough (image of ATSC pilot tone at 57.35 MHz), and other spurious surrounding the ATSC signal are present at the ADC input and thus are not ADC artifacts.

4 Field Testing

We attempted an informal test of the ADC evaluation boards in a field setting. The test was performed at the ETA primary site near Balsam Grove, NC (in a remote mountainous region about 1 hour drive southwest of Asheville, NC). The signal from a 29-47 MHz ETA active antenna [8] was redirected from an ETA ARX to the prototype LWA ARX. Although the ETA antennas have poor performance above 50 MHz, the active baluns intrinsic to the antennas pass signals effectively from about 5 MHz to about 95 MHz. This test proved difficult because a strong local TV broadcast signal on Channel 4 (around 70 MHz) makes it impossible to achieve Galactic noise-limited operation without driving the ARX into an unacceptable level of compression.[3] 10 dB of attenuation was required to achieve acceptable ARX performance, putting the Galactic noise floor just below the ARX noise floor in the 29-47 MHz band over which the ETA antennas are effective.

The results are shown in Figure 7. These plots were obtained by incoherently averaging 1000 64K FFTs, resulting in 334 ms effective integration time. The bottom row of plots in this figure show the results when the ARX input is terminated, confirming that the results are not Galactic-noise limited. It is nevertheless encouraging to see that both ADCs perform reasonably well despite the presence of the strong Channel 4 NTSC TV signal.

The apparent result that the AD9211 appears to be doing much better than the AD9230 in terms of apparent SNR below 20 MHz is due to the AD9230 low-order bit problem described in the previous section, and so is not actual. The 42 MHz "lump" appearing in the field spectra is a source of concern and may indicate a problem with the field test setup; this entirely possible considering the hasty manner in which this particular experiment was kludged together. Nevertheless, this illustrates the type of testing that will be most useful once *bona fide* LWA STD, ARX, and ADC ("DIG") subsystem prototypes are available.

[3]This does not occur with the ETA ARX due to aggressive filtering above 50 MHz.

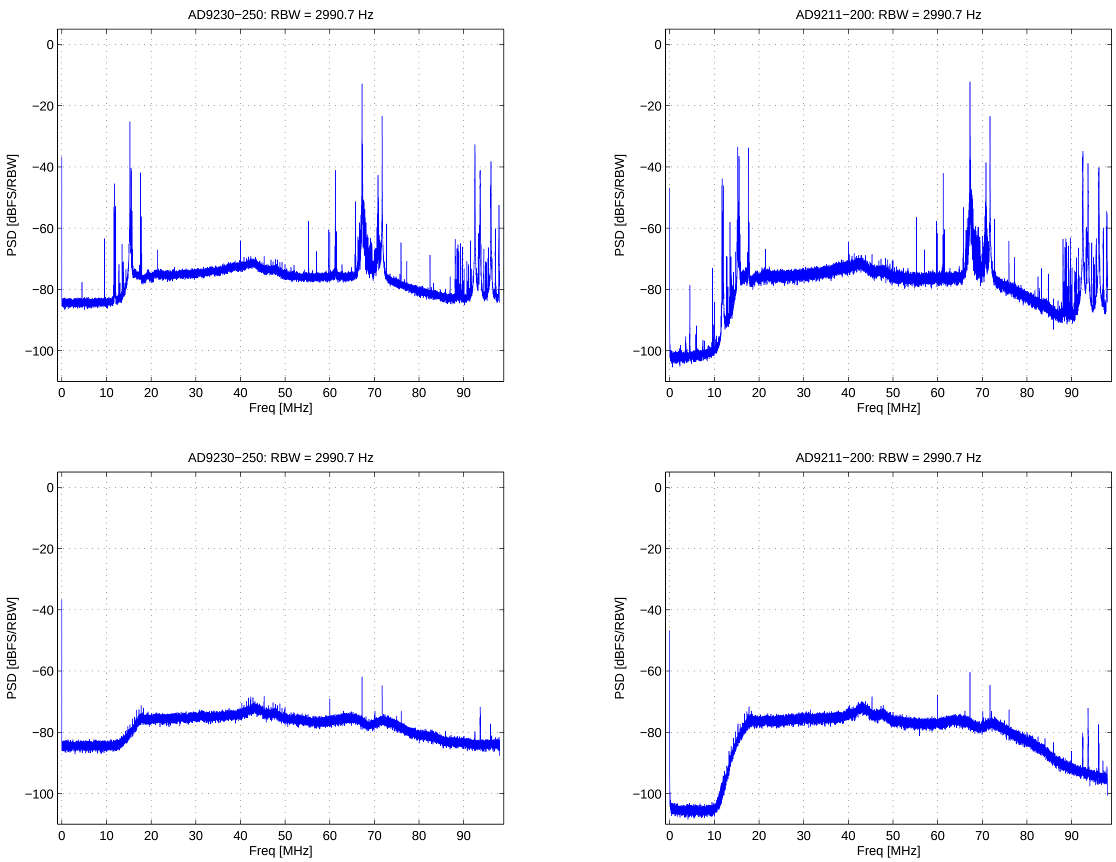


Figure 7: Using the prototype LWA ARX of Memo 82 with the ETA antenna and active balun at the ETA primary (Balsam Grove, NC) site. 334 ms integration. Top: Result; Bottom: Result with ARX input terminated. AD9230 (broken) on the left, AD9211 on the right.

References

[1] S. Ellingson, "ADC Selection," LWA Memo 98, August 31, 2007. http://www.phys.unm.edu/∼lwa/memos/.

[2] Analog Devices, Inc., "12-Bit, 170 MSPS/210 MSPS/250 MSPS, 1.8 V Analog-to-Digital Converter AD9230" (datasheet), Rev. 0, 2007.

[3] Analog Devices, Inc., "10-Bit, 200 MSPS/250 MSPS/300 MSPS, 1.8 V Analog-to-Digital Converter AD9211" (datasheet), Rev. 0, 2007.

[4] S. Ellingson, "ADC Sample Rate and Preliminary Design for a Full-RF ADC Post-Processor," LWA Memo 101, September 11, 2007.

[5] Analog Devices, Inc., "High Speed Converter Evaluation Platform HSC-ADC-EVALC," Rev. 0, 2007.

[6] Analog Devices, Inc., "VisualAnalog Converter Evaluation Tool Version 1.0 User Manual," Application Note AN-905, Rev. 0, 2007.

[7] Mahmud Harun and S.W. Ellingson, "A Prototype Analog Receiver for LWA," LWA Memo 82, March 28, 2007. http://www.phys.unm.edu/∼lwa/memos/.

[8] S. Ellingson, J. Simonetti, and C. Patterson, "Design and Evaluation of an Active Antenna for a 29-47 MHz Radio Telescope Array," *IEEE Trans. Ant. and Prop.*, Vol. 55, No. 3, March 2007, pp 826-831. Also available as LWA Memo 60.