# Characterization of ADC083000 and EV8AQ160 based ADC boards for VEGAS

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## Abstract

ADC boards with ADC083000 and EV8AQ160 were evaluated for use in Versatile GBT Astronomical Spectrometer (VEGAS). VEGAS is designed to digitize signals with bandwidth $\sim$ 1.5 GHz and hence the ADCs are characterized with sampling frequency close to 3 GHz. The frequency response, spur-free dynamic range and spurious pickups of both ADC boards are similar. The spurious pickups were found to be mostly harmonics of 46.875 MHz, which may be related to the 156.25 MHz clock used by the 10 Gb Ethernet link in ROACH I board. The measured phase noise at an offset frequency of 400 KHz is about 5 dB better for ADC083000 based board. The cross coupling and Allan variance measurements are not complete.

## 1 ADC test setup and Data Analysis

A block diagram of the test setup used for ADC characterization is shown in Fig. 1. It consists of two identical ADC boards (referred to as ADC board 1 and ADC board 2) connected to ROACH I. $N$ voltage samples are recorded in the internal memory of ROACH I and read out through 10 Gb Ethernet port by a data acquisition PC. The recording is done in burst of $N$ samples, referred to as burst mode acquisition. $N = 32$ K and 64 K for ADC083000 and EV8AQ160 based boards, which were due to limitations from firmware design. In addition to the burst mode acquisition, data were collected with VEGAS mode 1 FPGA code to determine the effect of ground noise when the actual system is in operation. This latter data are used for measuring the cross coupling with mode 1 FPGA code and Allan variance.

The ADCs used for characterization have multiple cores – ADC083000 has 2 cores and EV8AQ160 has 4 cores. These cores are independent ADCs working in parallel to achieve the high sampling speed through interleaving technique. The offset and gains of the cores are not identical. In the data acquisition system, there are no provision to correct for the gain and offset of each of the cores. Therefore these corrections are made during the analysis of the data. In most cases the offset and gain, whenever appropriate, are estimated from the data taken for characterization itself. The estimated offsets are subtracted from the samples from each core and then corrected for relative gain.

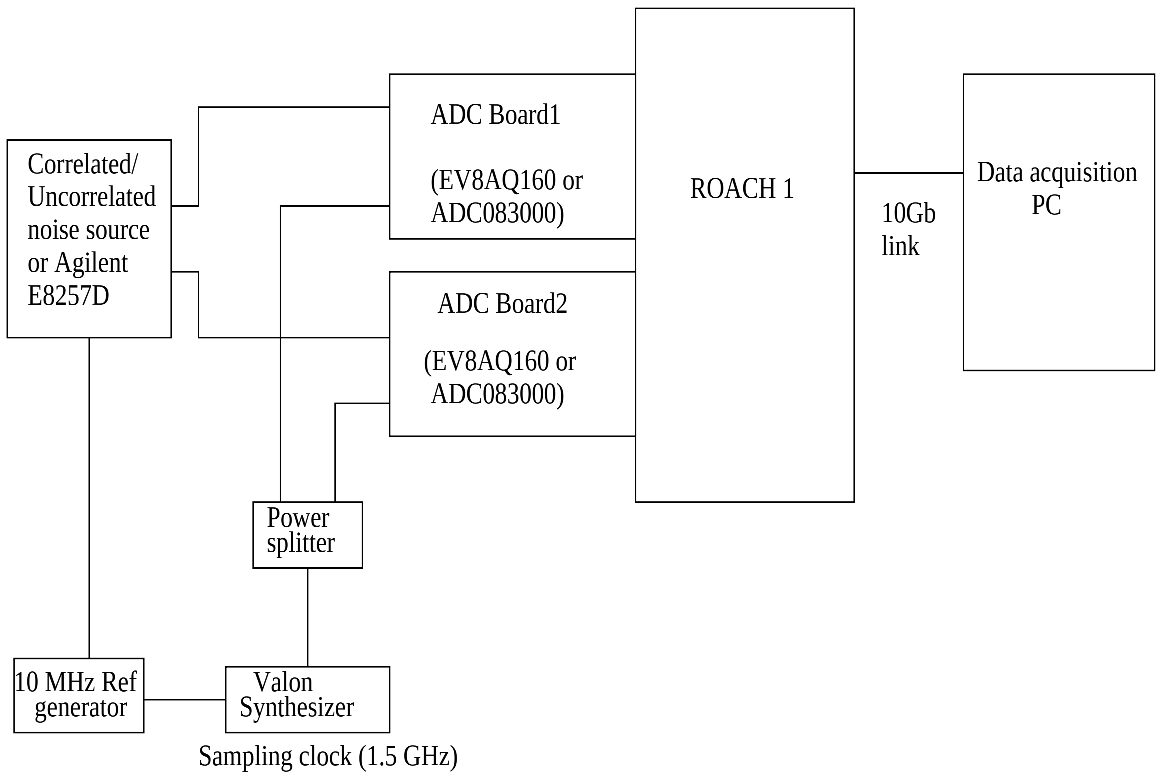



Figure 1: A schematic of the test setup used for ADC characterization

## 2 Frequency response of the ADCs

The frequency response of the two ADCs are shown in Fig. 2. They are measured using a set of sine waves at different frequencies as the input to the ADC and then taking the power spectrum of the samples.

## 3 Spurious pickups

The data to identify spurious pickups are obtained by terminating the inputs of the ADCs with 50 $\Omega$. Fig 3 shows histogram obtained from this data before offset and gain correction. For ADC08000 the terminated data shows a +/- 1 bit fluctuation but for EV8AQ160 the fluctuations are more like 2 bits. The power spectrum of this data is used to identify spurious pickups. Signals with power $\gtrsim$30 times the RMS fluctuations in the spectrum are taken as spurious signal. Spectrum of the spurious signals are shown in 4 and their frequencies are given in Table 1. We have excluded signals below 90 MHz when identifying spurious pickup. Also signals near 750 MHz and 1500 MHz are affected by the residual of offset correction and hence are excluded when identifying spurious pickups. As seen in Table 1 most of the spurious pickups are harmonics of 46.875 MHz and thus may be related to the 156.25 MHz clock used in ROACH I for 10Gb Ethernet.

## 4 Phase noise

The spectrum of a tone at offset frequencies close to (close-in spectrum) the frequency of the tone gives information about the phase noise. We measured the close-in spectra for two frequencies

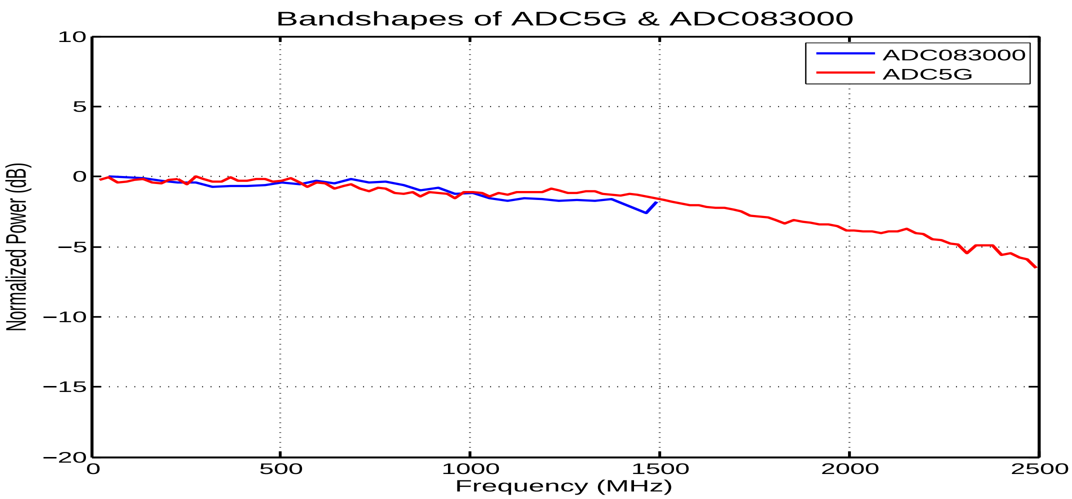



Figure 2: Frequency responses of ADC083000 (blue) and EV8AQ160 (red)

(274.6582 and 1464.8438 MHz) with the ADC board and compared them with those measured with spectrum analyzer. Fig. 5 shows the close-in spectra. The close-in spectra measured for the 1464.8438 MHz is similar for ADC083000 board and spectrum analyzer. The spectral power measured with EV8AQ160 at an offset of 400 KHz from 1464.8438 MHz shows about 5 dB increase compared to those measurements made with ADC083000 board.

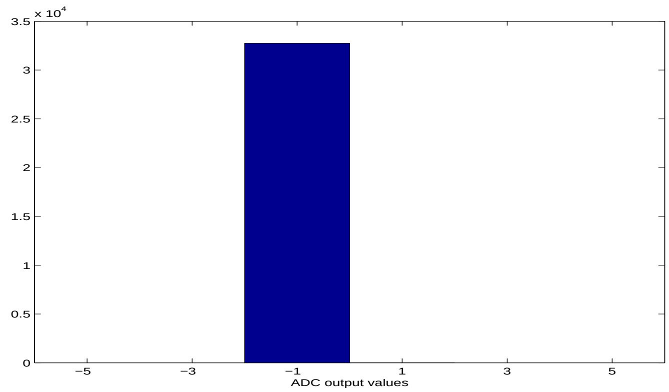
# 5 SFDR

The Spur-free dynamic range of the two ADCs are measured by injecting tone frequencies at different frequencies. The signal used for the test has second harmonic at -46 dB relative to the fundamental (see Fig. 6). The spectrum of the signal measured with the EV8AQ160 and ADC083000 ADC boards are shown in Fig. 7 and 8 respectively.

# 6 Cross coupling

## 6.1 EV8AQ160

Cross coupling is measured by connecting un-correlated noise sources to ADC boards 1 and 2 connected to roach 1 (see Fig. 1). The cross correlation coefficient of the digitized samples obtained from the two ADC boards gives a measure of the cross coupling. The cross coupling in dB is 20



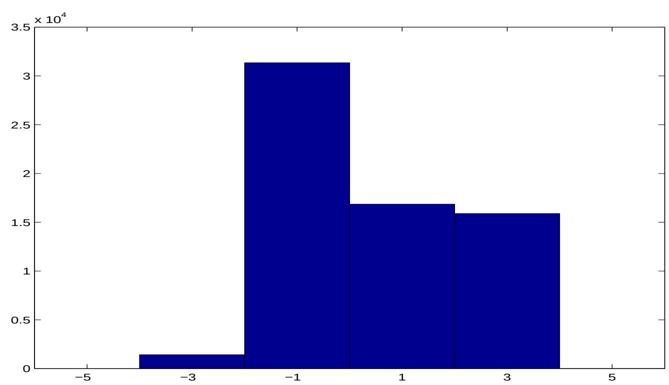
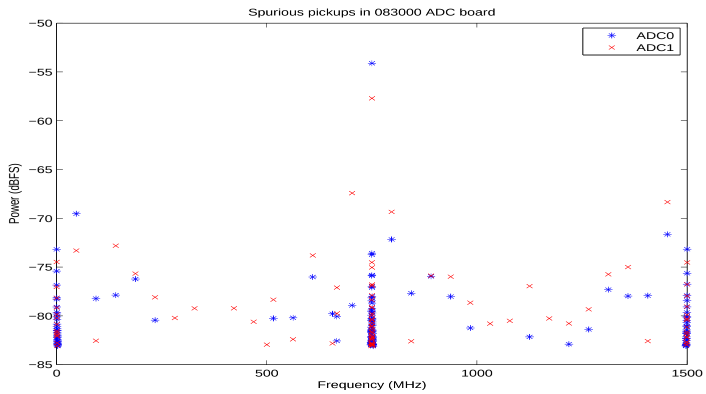




Figure 3: Histogram of data obtained with the ADCs with their inputs terminated with 50 Ohms. Top: for ADC083000; Bottom: for EV8AQ160.



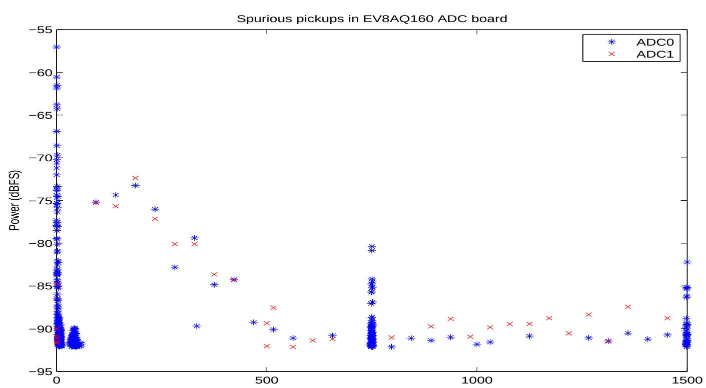




Figure 4: Spectrum of spurious signals with power about 30 times the spectral noise. The signals near 750 and 1500 MHz are residual of the offset correction. The spurious pickup in ADC board 1 and 2 are shown in blue and red respectively. Data from ADC083000 and EV8AQ160 are shown on the top and bottom plots respectively.

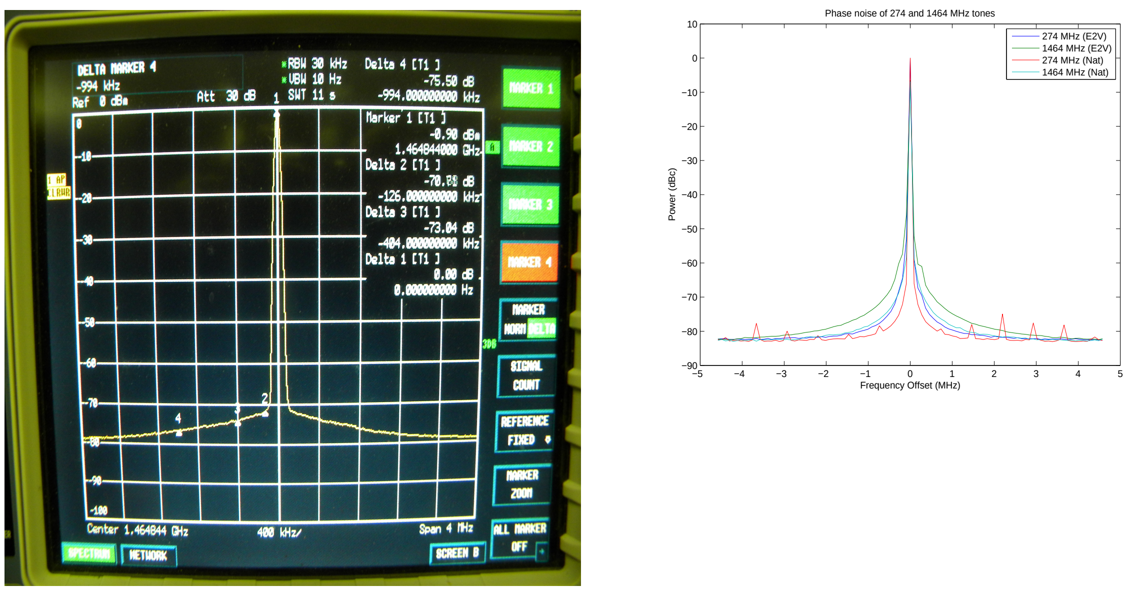



Figure 5: Close-in spectrum of 1464.8438 MHz tone measured with a spectrum analyzer (left) and the ADC boards (right). The curves marked '274 MHz (E2V)' and '1464 MHz (E2V)' on the right plot are the spectra of 274.6582 and 1464.8438 MHz tone measured with EV8AQ160 ADC board. The curves marked '274 MHz (Nat)' and '1464 MHz (Nat)' on the right plot are the spectra of 274.6582 and 1464.8438 MHz tone measured with AC083000 ADC board. At offset frequency of 300 KHz, the spectral power measured with EV8AQ160 ADC board is about 5 dB higher than that measured with ADC083000 ADC board.

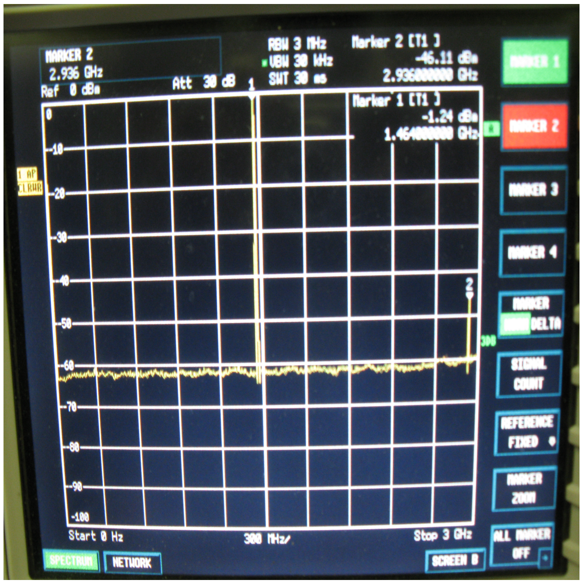



Figure 6: An example spectrum of the input signal with frequency 1464.8438 MHz. The second harmonic is at -46 dB relative to the fundamental.

$\times$ $\log_{10}$ of the cross correlation coefficient. Several burst of data are averaged to get the cross correlation coefficient. The relative phase between the data samples from one burst to the next should be stable for these measurements. This stability is checked by measuring the cross correlation using same noise connected to both ADC boards. The spectrum of the noise source measured with the spectrum analyzer and from the ADC samples are shown in Fig. 9. Fig. 10 shows the amplitude and phase of the correlation coefficients obtained when same noise is injected to the two ADC boards. Data from 1000 bursts are averaged to get the correlation coefficient. The phases measured for different spectral channels from each burst of data are also shown in Fig. 10. The phase varies by about 10°or so over 1000 bursts; the origin of this variation is uncertain. Since the phase variation is about 1/6th of a radian it may not affect the cross coupling measurements.

The cross correlation measured when uncorrelated noise sources are connected to the two ADC boards is shown in Fig. 12. The self-spectra measured with spectrum analyzer and ADC boards are shown in Fig. 11. The excess power [1] near 1.8 GHz is aliased back in the spectrum obtained with the ADC data.

[1]This excess power near 1.8 GHz is not seen in Fig. 9 because of the limited frequency response of the power splitter used for connecting the same noise source to the two ADC boards.

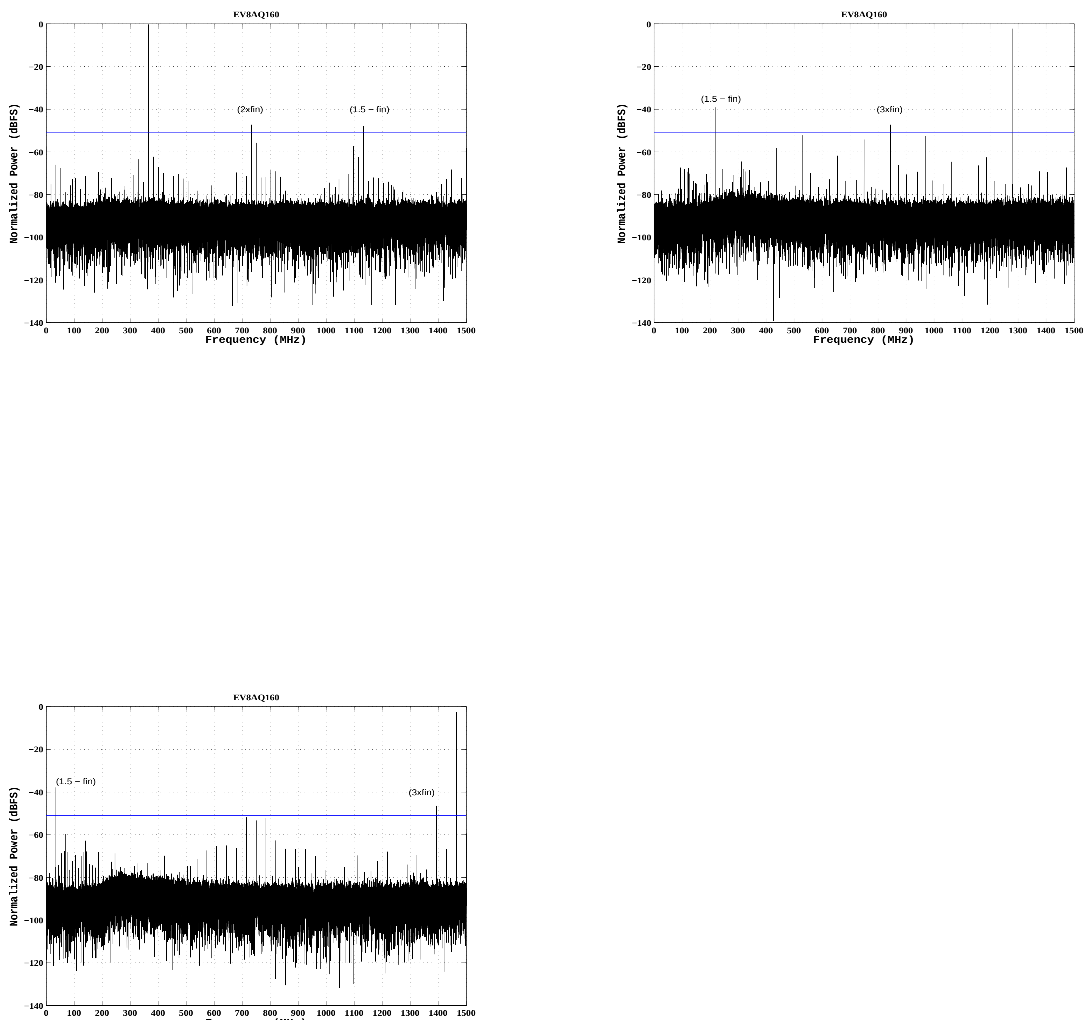



Figure 7: Spectra of the tones obtained with EV8AQ160 with frequencies $\sim$ 366, 1281 and 1464 MHz are shown respectively on top-left, top-right and bottom-left figures. The blue line indicates the manufacture specified SFDR level. The signals above this line are identified as harmonics of the tone or beat frequency of the tone with the 1.5 GHz input clock to the ADC board. The spectral noise is larger in these plots compared to Fig. 8 is because the plots are obtained with just one burst of the data.

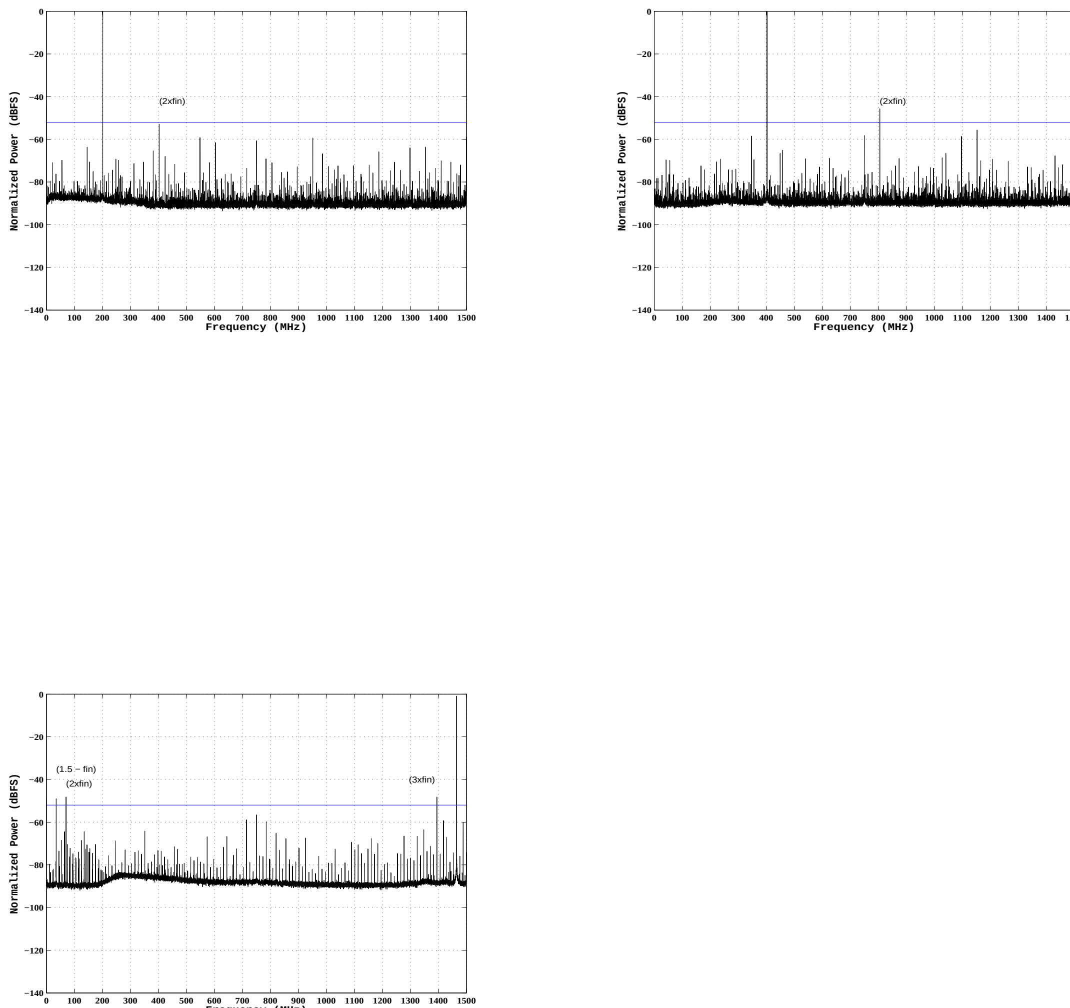



Figure 8: Spectra of the tone obtained with ADC083000 with frequencies 201, 402 and 1464 MHz are shown respectively on the top-left, top-middle and bottom-left figures. The blue line indicates the manufacture specified SFDR level. The signals above this lines are identified as harmonics of the input tone or beat frequency of the tone with the 1.5 GHz input clock to the ADC board. No gain and offset corrections, discussed in Section 1, are applied to the data shown in these spectra. About 50 bursts of data were averaged to obtain these plots.

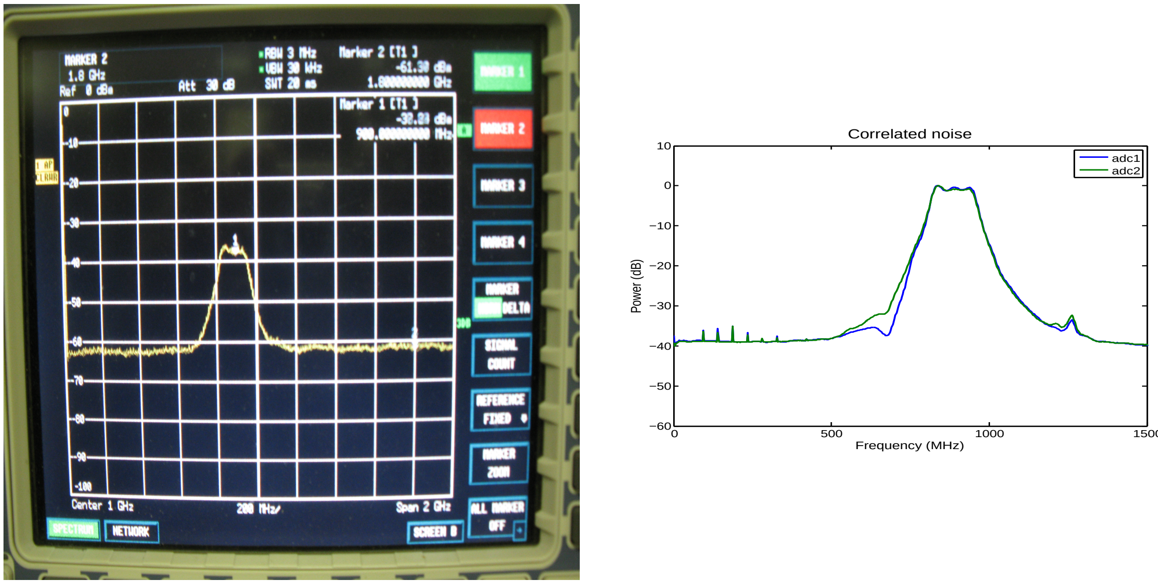



Figure 9: Spectra of the noise connected to the two ADC boards using spectrum analyzer (left) and using the ADC data (right).

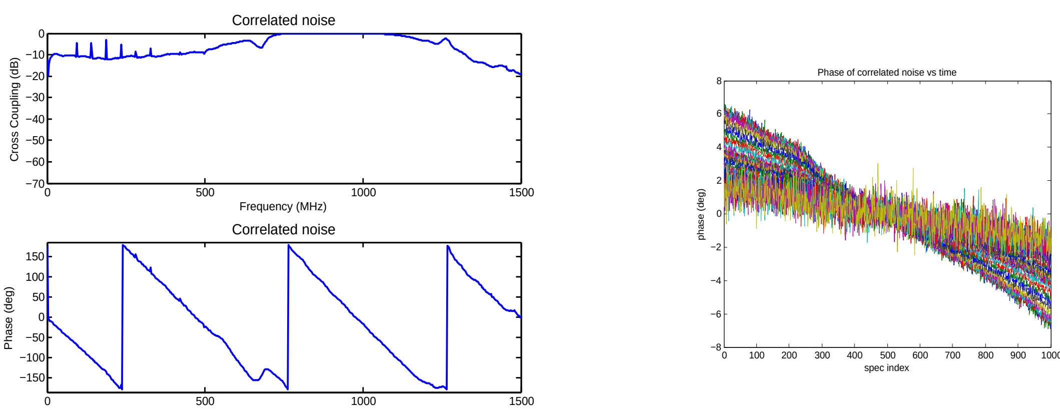



Figure 10: Average cross correlation amplitude (left,top) and phase (left,bottom) obtained from 1000 burst of data are shown on the left. The phases measured for different spectral channels from each burst as a function of burst number is shown on the right.

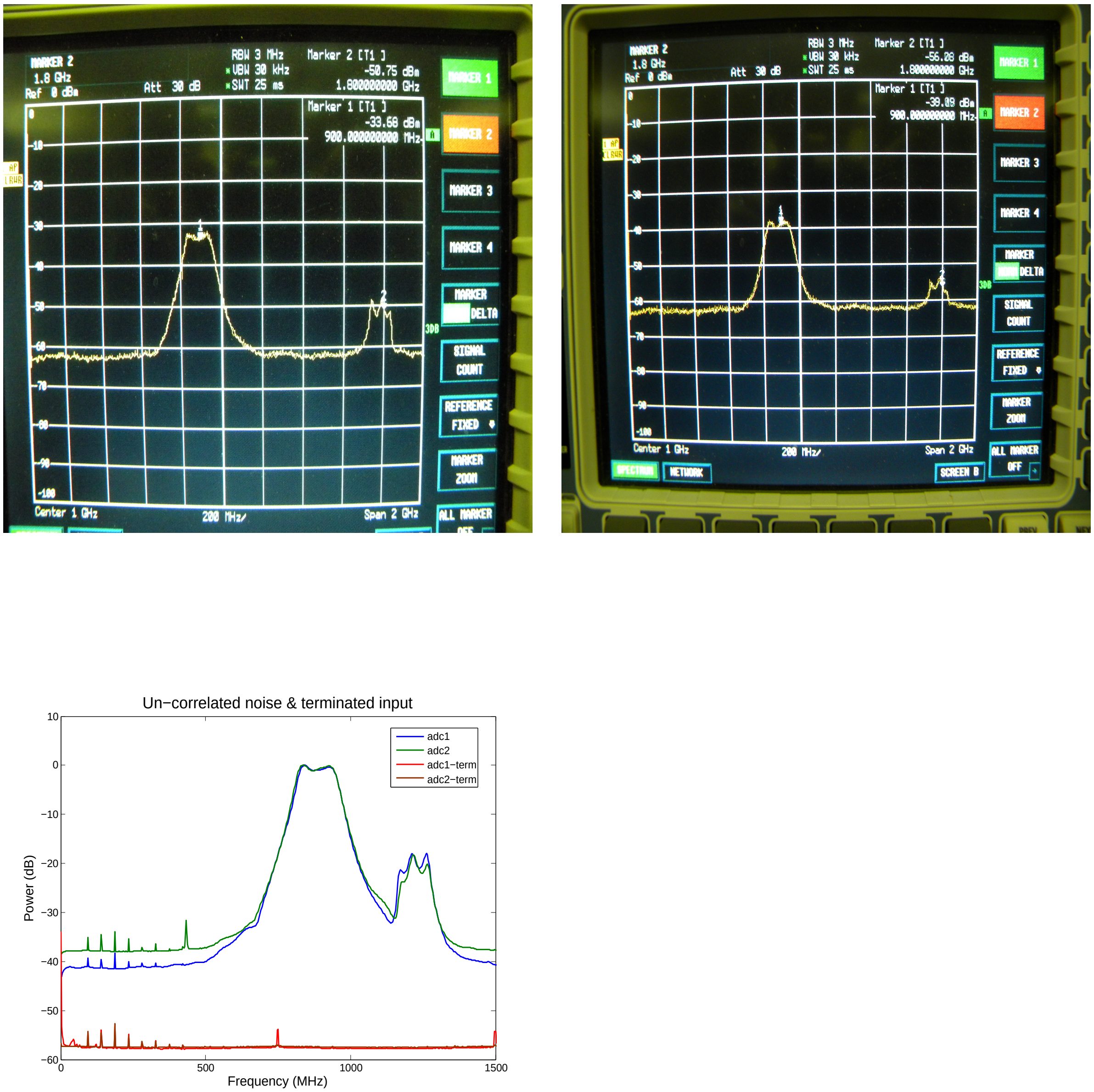



Figure 11: Spectra of the uncorrelated noises connected to the two ADC boards obtained using spectrum analyzer (top) and using the ADC data (bottom). The spectra obtained from the ADC data when the inputs are terminated are also shown in the bottom data. These spectra are labeled as adc1-term and adc2-term.

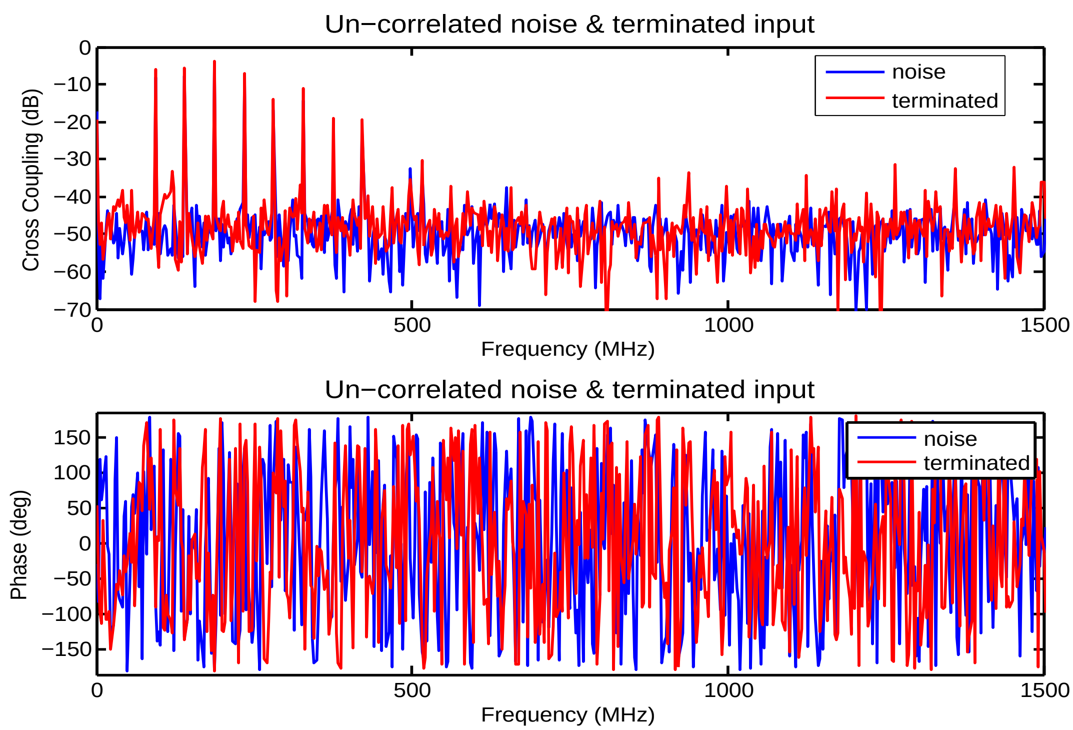



Figure 12: Amplitude (top) and phase (bottom) of the cross correlation obtained with un-correlated noise (blue) and with data obtained by terminating the ADC inputs (red). Data from 1000 bursts are averaged to obtain these plots.

Table 1: List of Spurious pickups in the ADC

| Frequency (MHz) | | Harmonic of | Frequency (MHz) | | Harmonic of |
|---|---|---|---|---|---|
| ADC083000 | EV8AQ160 | 46.875 MHz | ADC083000 | EV8AQ160 | 46.875 MHz |
| ADC board 1 | | | ADC board 2 | | |
| 93.75 | 93.75 | 2 | 93.75 | 93.75 | 2 |
| 140.625 | 140.625 | 3 | 140.625 | 140.625 | 3 |
| 187.5 | 187.5 | 4 | 187.5 | 187.5 | 4 |
| 234.375 | 234.375 | 5 | 234.375 | 234.375 | 5 |
| | 281.25 | 6 | 281.25 | 281.25 | 6 |
| | 328.125 | 7 | 328.125 | 328.125 | 7 |
| | 333.297 | | | | |
| | 375.0 | 8 | | 375.0 | 8 |
| | 421.875 | 9 | 421.875 | 421.875 | 9 |
| | 468.75 | 10 | 468.75 | | 10 |
| | | | 499.969 | 499.969 | |
| | | | | 500.015 | |
| 515.625 | 515.625 | 11 | 515.625 | 515.625 | 11 |
| 562.5 | 562.5 | 12 | 562.5 | 562.5 | 12 |
| 609.375 | | 13 | 609.375 | 609.375 | 13 |
| 656.25 | 656.25 | 14 | 656.25 | 656.25 | 14 |
| 666.595 | | | 666.595 | | |
| 666.687 | | | 666.687 | | |
| 703.125 | | 15 | 703.125 | | 15 |
| 796.875 | 796.875 | 17 | 796.875 | 796.875 | 17 |
| 843.75 | 843.75 | 18 | 843.75 | | 18 |
| 890.625 | 890.625 | 19 | 890.625 | 890.625 | 19 |
| 937.5 | 937.5 | 20 | 937.5 | 937.5 | 20 |
| 984.375 | | 21 | 984.375 | 984.375 | 21 |
| | 999.984 | | | | |
| | 1031.25 | 22 | 1031.25 | 1031.25 | 22 |
| | | | 1078.125 | 1078.125 | 23 |
| 1125.0 | 1125.0 | 24 | 1125.0 | 1125.0 | 24 |
| | | | 1171.875 | 1171.875 | 25 |
| 1218.75 | | | 1218.75 | 1218.75 | 26 |
| 1265.625 | 1265.625 | 27 | 1265.625 | 1265.625 | 27 |
| 1312.5 | 1312.5 | 28 | 1312.5 | 1312.5 | 28 |
| 1359.375 | 1359.375 | 29 | 1359.375 | 1359.375 | 29 |
| 1406.25 | 1406.25 | 30 | 1406.25 | | 30 |
| 1453.125 | 1453.125 | 31 | 1453.125 | 1453.125 | 31 |