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ADC for Virgo Photodiodes Readout Final Tests Results

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1 Introduction

This note presents the final results of the tests that we made on a first batch of 12 main Virgo ADC boards. These boards, model Etep 264A, have 4 channels each, a total cost of 30000 FF for board (7500 FF for channel) and will be used to acquire the dark fringe signal. The technical features and preliminary results of some tests can be found in the Technical Report from LAPP: VIR-TRE-LAP-4200-101.
We can remember here the requirements we put on these ADC:

- Sampling frequency: $F_s = 20\ KHz$;
- Readout frequency: $F_r = 10\ KHz$,
- Simultaneous acquisition of 8 boards in a crate, with 32 bit block transfer capability;
- Input signal dynamic: $A = \pm 10\ V$;
- 16 Bits output;
- White spectral noise $< 0.9\ \frac{\mu V_{rms}}{\sqrt{Hz}}$ ($\sim$ 16 effective bits).

2 Readout Tests

In the previous tests we concluded that some work had to be done in order to solve the following problems:

- Not acceptable readout errors were present;
- Some channels were affected by electronic noise (offset peak too large);
- The number of effective bits was below the requirements for many channels, even without input signal;
- The Spectral Noise was not white, with lines at $\sim 1420, 2840\ Hz$ and at $F_b, F_{b/2}$ (only on the slave boards).
- An excessive harmonic distortion was present, when a 20 V_{pp} signal was input.

Hardware alterations have been carried out from Etep's planners during summer 1997. Then, we run systematic tests, in order to validate the performances of the boards in real operating conditions.

We have verified the readout procedure of 8 boards in a VME crate, controlled by a cpu CES RIO8062, by making histograms of hours of data sampled at 20 kHz and with analogical inputs closed on 50 Ω. During one week of continuous running we didn't notice any readout errors or offset peak degradation; its maximum width is $4-5$ ADC bins for all the boards. At the end of this note (figure 7 and 8) are plotted two boards (indicated with their production number) histograms of 16 hours data.

We have measured the spectral noise and the corresponding number of "effective bits", first without input signal. The analysis was on 131072 points (6.5 seconds of data sampled at 20 kHz), the FFT on 16384 points (bin width 1.22 Hz), and 8 rectangular windows were used. The number of "effective bits" is the number of bits of an ideal (with only quantization noise)

ADC that shows the measured level of noise. This number can be deduced from:

$$N_{eff} = log_2 \left(\frac{2A}{\sqrt{12}\sqrt{F_s/2}\sqrt{S_{xx}}} \right) \quad (1)$$

At the end of this note (figure 9 and 10) Amplitude Spectral Densities (ASD) of two boards are plotted.
The noise is white, but some lines are still present; the most evident are at 5 kHz (half the readout frequency) on some channels, and at 1359 Hz and its double 2718 Hz.
In figure 11 and 12 the low part of the same spectra are plotted, and the number of effective bits is calculated between 1 Hz and 1000 Hz.

We summarize in figure 1 the noise measures with input closed on 50 Ω, for the 12 boards. The number of effective bits has been calculated from the signal RMS (root mean square of the full power spectrum).
The mean value of the background noise is 1.1 $\frac{\mu V_{rms}}{\sqrt{Hz}}$, or 15.75 $Bits_{eff}$.

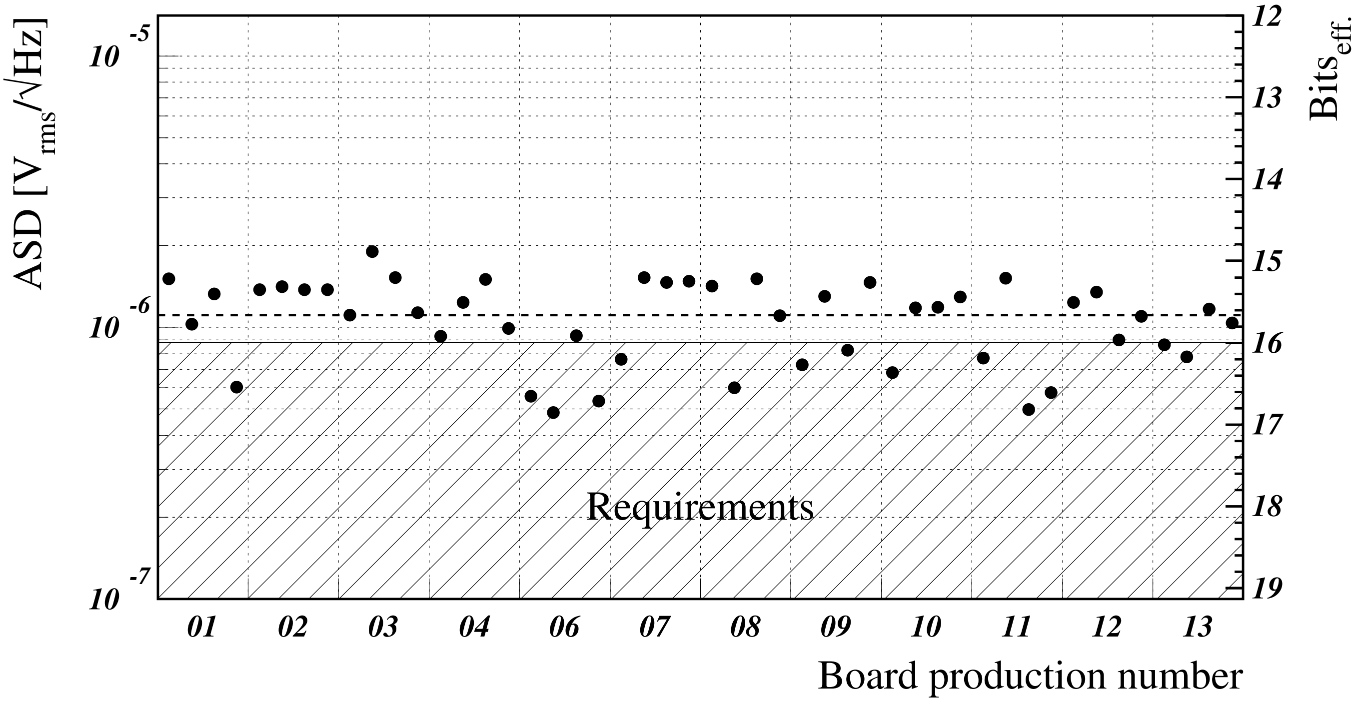

Figure 1: Measured Amplitude Spectral Density (ASD) and Effective Bits, as calculated from eq. (1), for the 12 boards (48 channels). It is also indicated the requirement $ASD \leq 0.88\ \mu V_{rms}/\sqrt{Hz}$ (corresponding to a number of $Bits_{eff} \geq 16$), and with a dashed line the ASD mean value 1.1 $\mu V_{rms}/\sqrt{Hz}$ or 15.75 $Bits_{eff}$.

3 Signal to noise ratio

A real estimation of the ADC effective bits comes from the noise level when a monochromatic signal is converted to digital values. The converters linearity could also be tested, if the signal has amplitude close to the ADC range.

In order to produce a signal as close as possible to a monochromatic sinusoid we used a signal generator, filtered by a resonant filter with:

- Resonance 482 Hz;
- Working gain $\simeq$ 40 Db;
- Working resonance noise 5 $\mu V/\sqrt{Hz}$;
- Bandwidth (at -3 Db) 7 Hz;
- Attenuation at ± 200 Hz from the resonance: 28 Db.

We formed a 482 Hz filtered signal, of amplitude ± 9.66 V (6.83 V_{eff}), put into the four channels of one board, and we calculated the noise spectrum, plotted in figure 2.
The analysis conditions have been:

- Time of measure 13 s (262144 data @ 20 kHz);
- FFT on 32768 points (bin width 0.6 Hz);
- Hanning window;
- Average of 15 spectra (with 1/2 recovering);

The number of effective bits has been calculated from the PSD root mean square, in a region of 200 Hz without peaks near 5200 Hz. Its mean value on all the boards is 15.6 bits, and the corresponding mean noise is 1.16 $\mu V_{rms}/\sqrt{Hz}$.

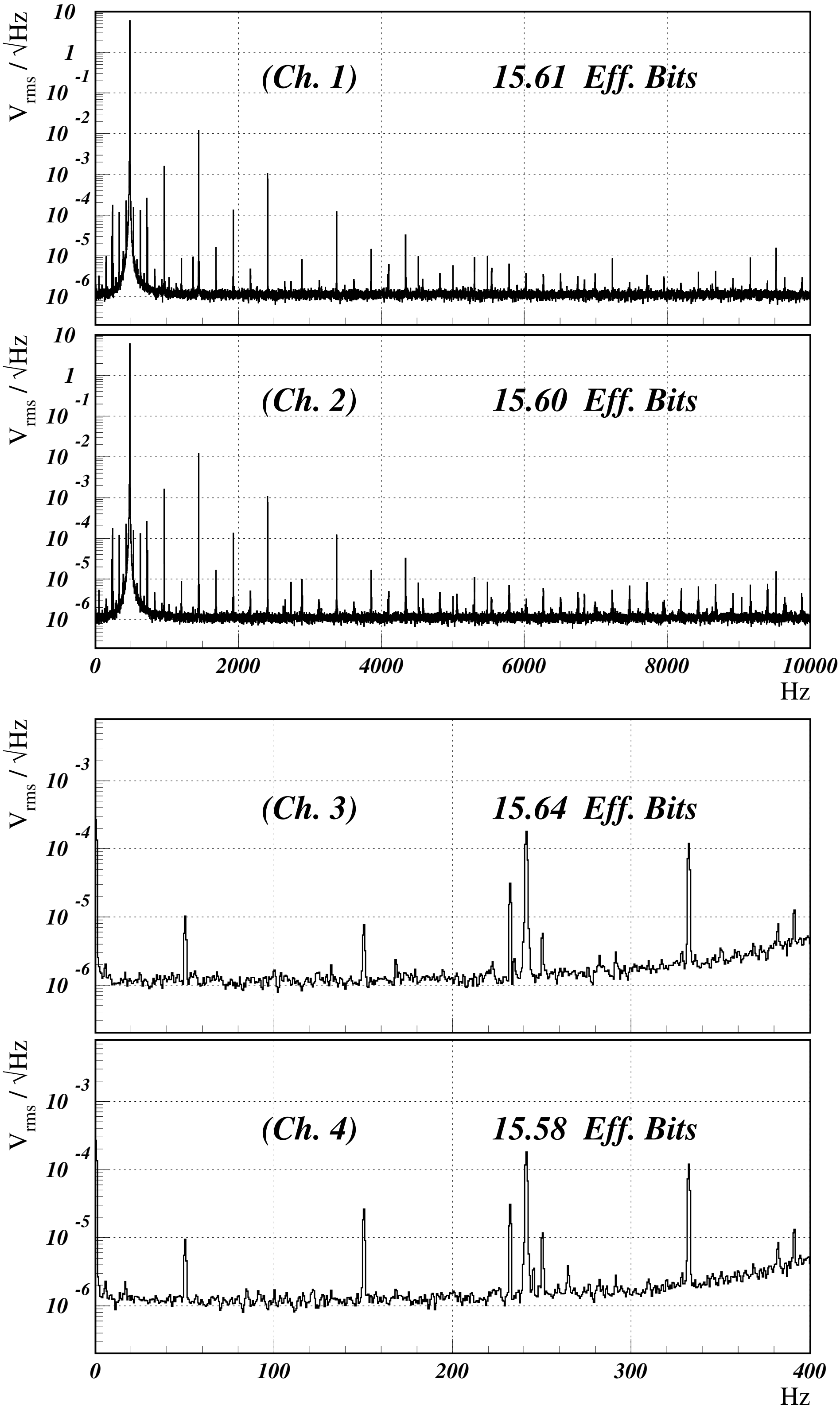

Figure 2: Amplitude Spectral Density of one board (production number 11) with 6.9 V_{rms} input. The last two plots are low frequency zooms. The number of effective bits has been calculated from the PSD in a region of 200 Hz without lines near 5200 Hz.

In figure 2 it's well visible the 964 Hz first order harmonic at -100 Db from the signal, and the 1446 Hz second order harmonic at -56 Db. A converters deviation from linearity could appear as harmonics of anomalous amplitude (harmonic distortion), but the same effect could come directly from input signal; we would like to detect the first effect without the last one.
A second resonant filter, with 0 Db at 1446 Hz and -90 Db at the signal frequency, can give us informations about the real ADC distortion. We put the 20 V_{pp} signal, produced by the generator and the first stage filter, in the second resonant one and then into the ADC. The noise spectra, taken without the second filter or with it, are plotted in figure 3.

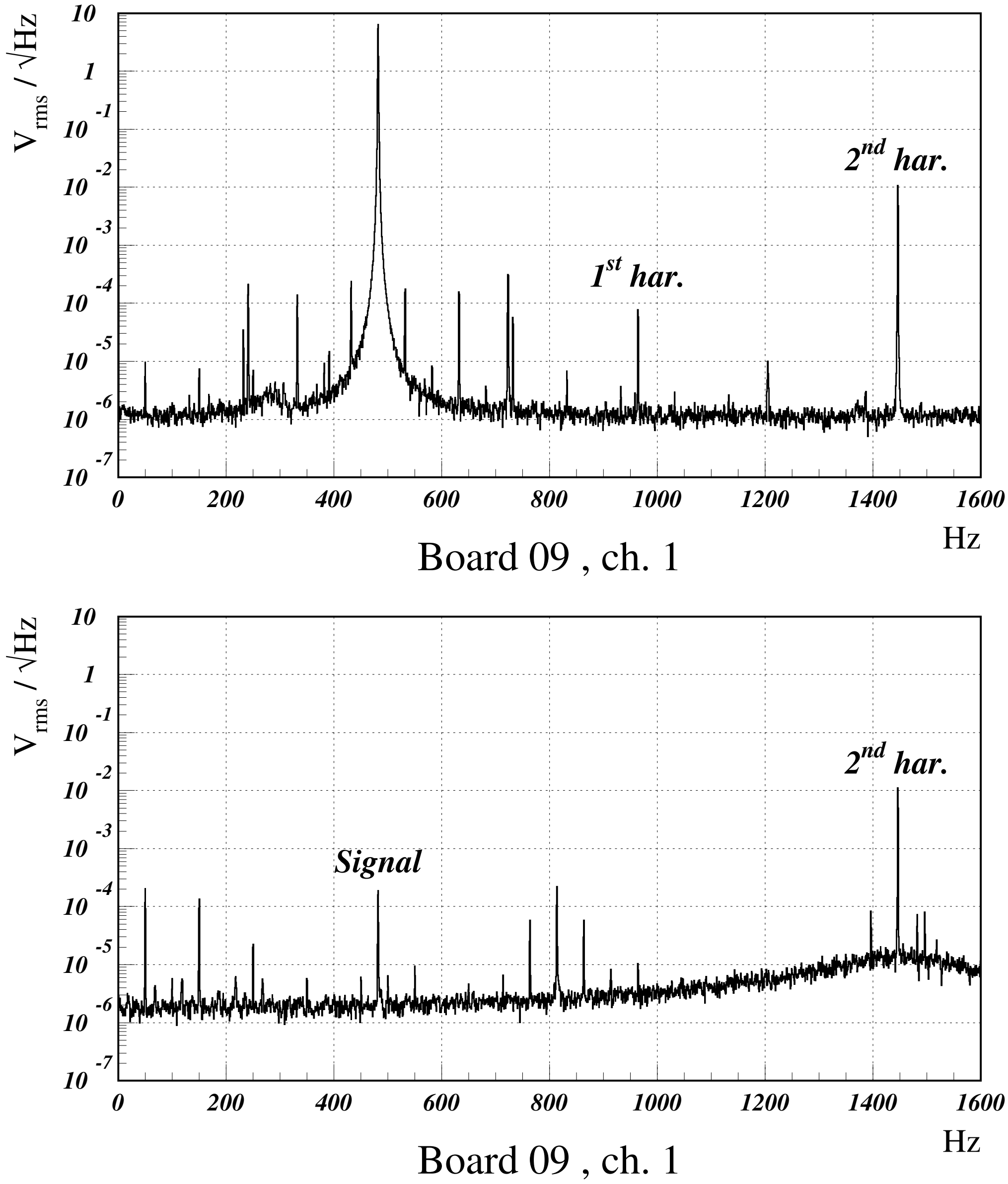

Figure 3: Low frequency zooms of the ASD for the 1^{st} channel of board 09. Up with a $\sim$ 20 V_{pp} (6.9 V_{rms}) signal produced by the generator and first stage resonant filter. Down, also with the second resonant filter, that reduce the signal by 90 Db.

The harmonic amplitude is unchanged, proving that it comes entirely from the generator and first stage filter, and is not due to ADC distortion.

We can now sum up the results for how concerned the signal conversion:

1. The noise level is near the value measured without input signal. Its mean value is $1.16 \times 10^{-6}\ \frac{V_{rms}}{\sqrt{Hz}}$ and the number of effective bits is 15.6;
2. The first harmonic distortion is less than $-100\ Db$ and the second one is even lesser;
3. The Signal to Noise Ratio (SNR), that we express as $\frac{\sigma_{in}}{\sqrt{S_{xx}} \times \sqrt{\Delta\nu}}$ to not depend on the peak resolution, is $SNR = 7.5 \times 10^{6}$;

4 Cross Correlation

As reported in the Technical Report VIR-TRE-LAP-4200-101, the cross talk between channels **of the same board** is $\leq -115\ Db$. In figure 4 and 5 are plotted the cross covariance estimators (normalized by the σ products so to give 1 for perfect correlation) and the cross power spectra of the first two channels of one board.

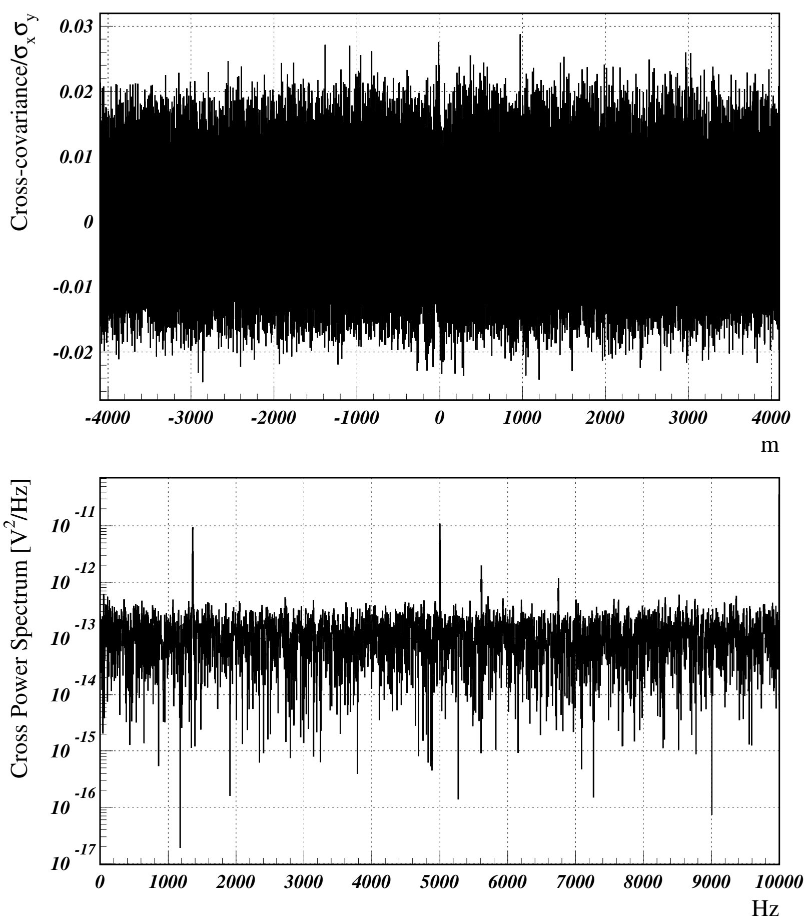

Figure 4: Up: Cross-covariance, normalized to 1 for perfect correlation, between two channels (with $50\,\Omega$) on the same board (01). 131072 points have been used and the cross-correlation has been calculated on 4096 points (32 means); for $0 < m < 4096$ is plotted $\rho_{xy}(m)$ and for $-4096 < m < 0$ $\rho_{yx}(m) = \rho_{xy}(-m)$. Down: Cross Power Spectrum of the same two channels, smoothed with an Hanning window of width 4096.

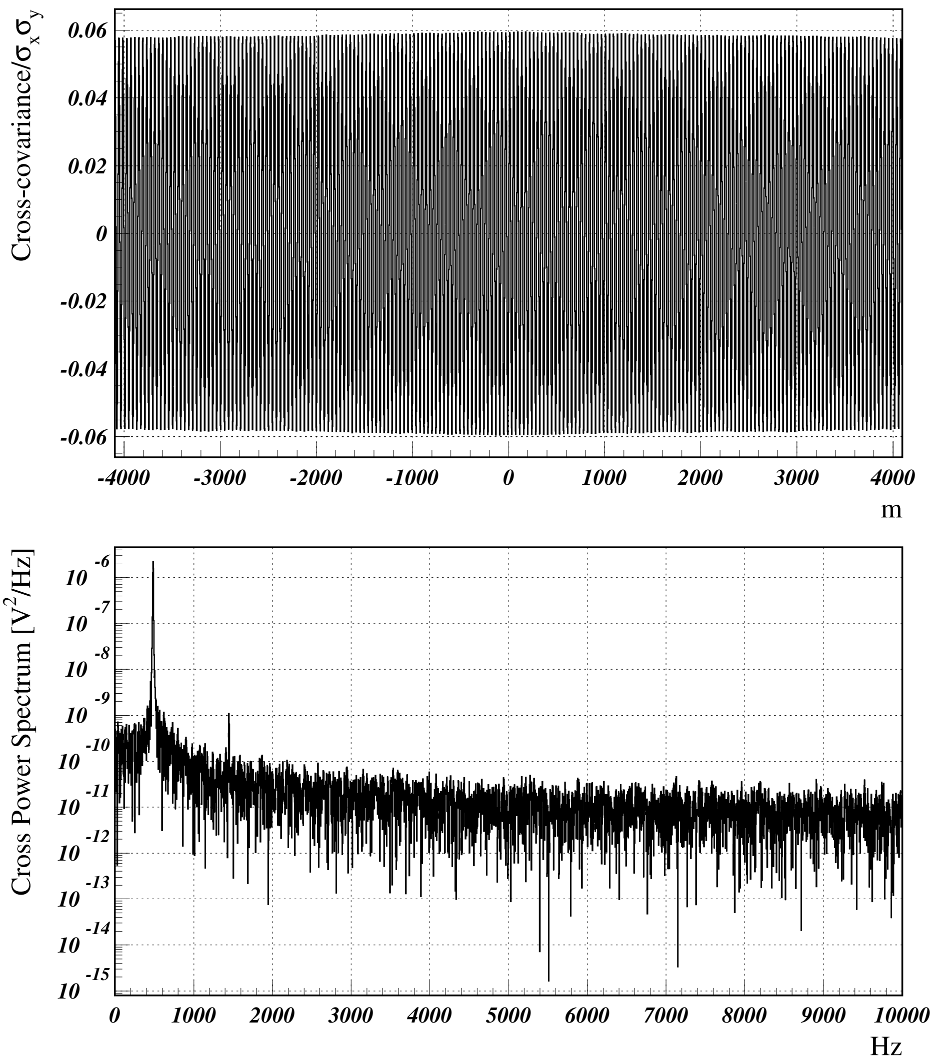

Figure 5: Up: Cross-covariance, normalized to 1 for perfect correlation, between two channels (with 20 V_{pp} and 50 Ω in) on the same board (09). 131072 points have been used and the cross-correlation has been calculated on 4096 points (32 means)Down: Cross Power Spectrum of the same two channels, smoothed with an Hanning window of width 4096.

The cross-covariance estimate module is smaller than 0.028 when no signal is input, and is smaller than 0.06 even with 20 V_{pp} in one channel (it would be 1 for perfect correlation). This supports our conclusions on the very low channels correlation, as reported in the previous Technical Report, and suggests a strategy to low the ADC noise, by averaging some channels output. If they are independent and with equal level of noise, each adding operation will low this level by a factor $\sqrt{2}$, and the gain will be of 0.5 effective bits each time.
In the next picture (figure 6, on next page) we have plotted the ASD of four channels mean (up, of board 01), of two boards (8 channels) mean (boards 01 and 02), and so on till four boards (16 channels) added. The *noise ratio* here indicated is the ratio between the ASD level of the plot before and the present one; the theoretical values are, in the order: $\sqrt{2}$, $\sqrt{3/2}$, $\sqrt{4/3}$.
When 16 channels are averaged, the gain in the noise level would be of a factor 4 (or 2 bits), and would be of a factor 2 (or 1 bit) respect to 4 channels averaged (first plot). As we can see, the noise ratios are near to the theoretical values, even if the channels noise level is not the same.

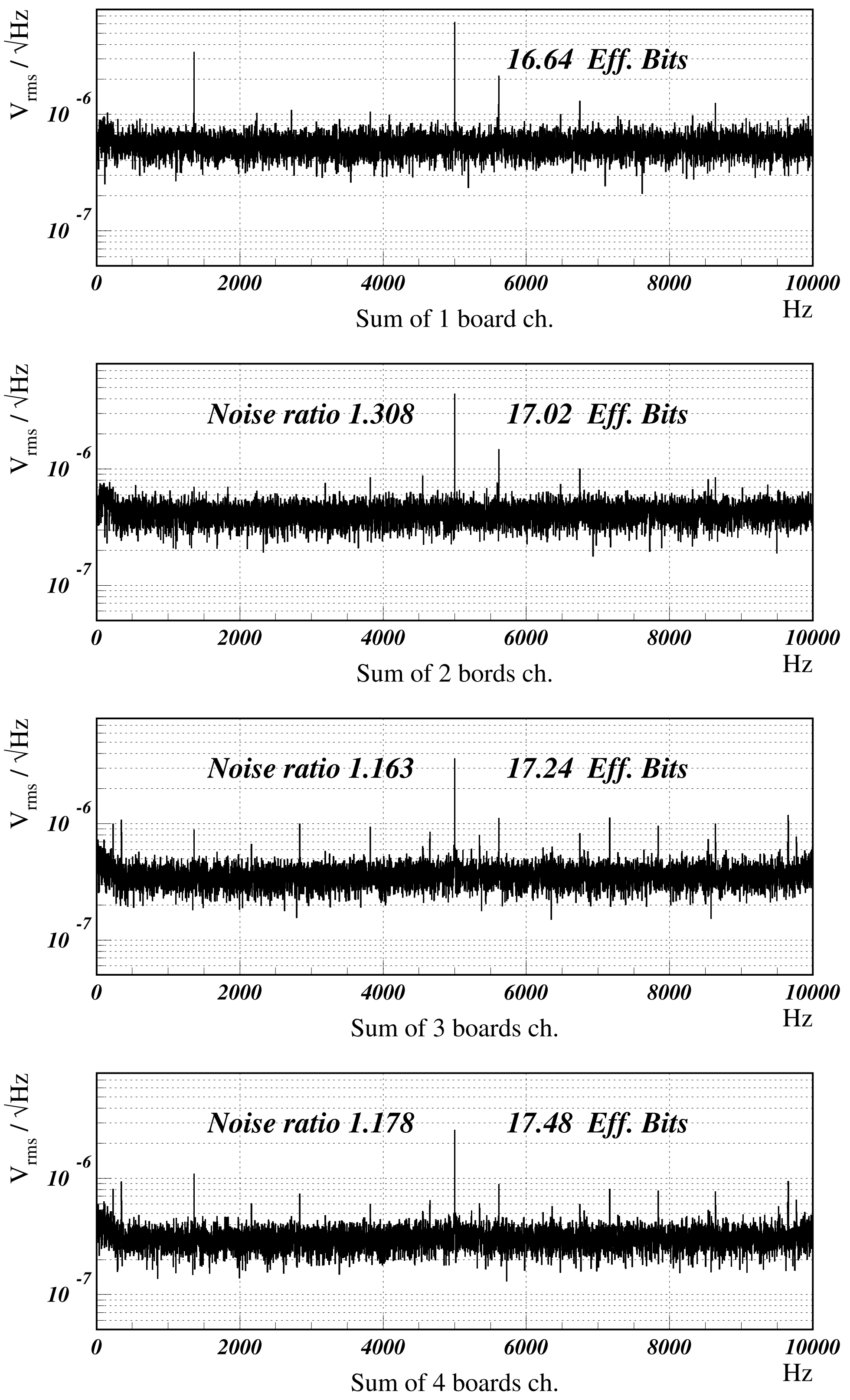

Figure 6: From up to down: ASD of 4 channels averaged (board 01), 8 channels (2 boards, 01 and 02), 12 channels and 16 channels averaged. The number of *effective bits* and the *noise ratios* has been calculated between 5100 Hz and 9900 Hz.

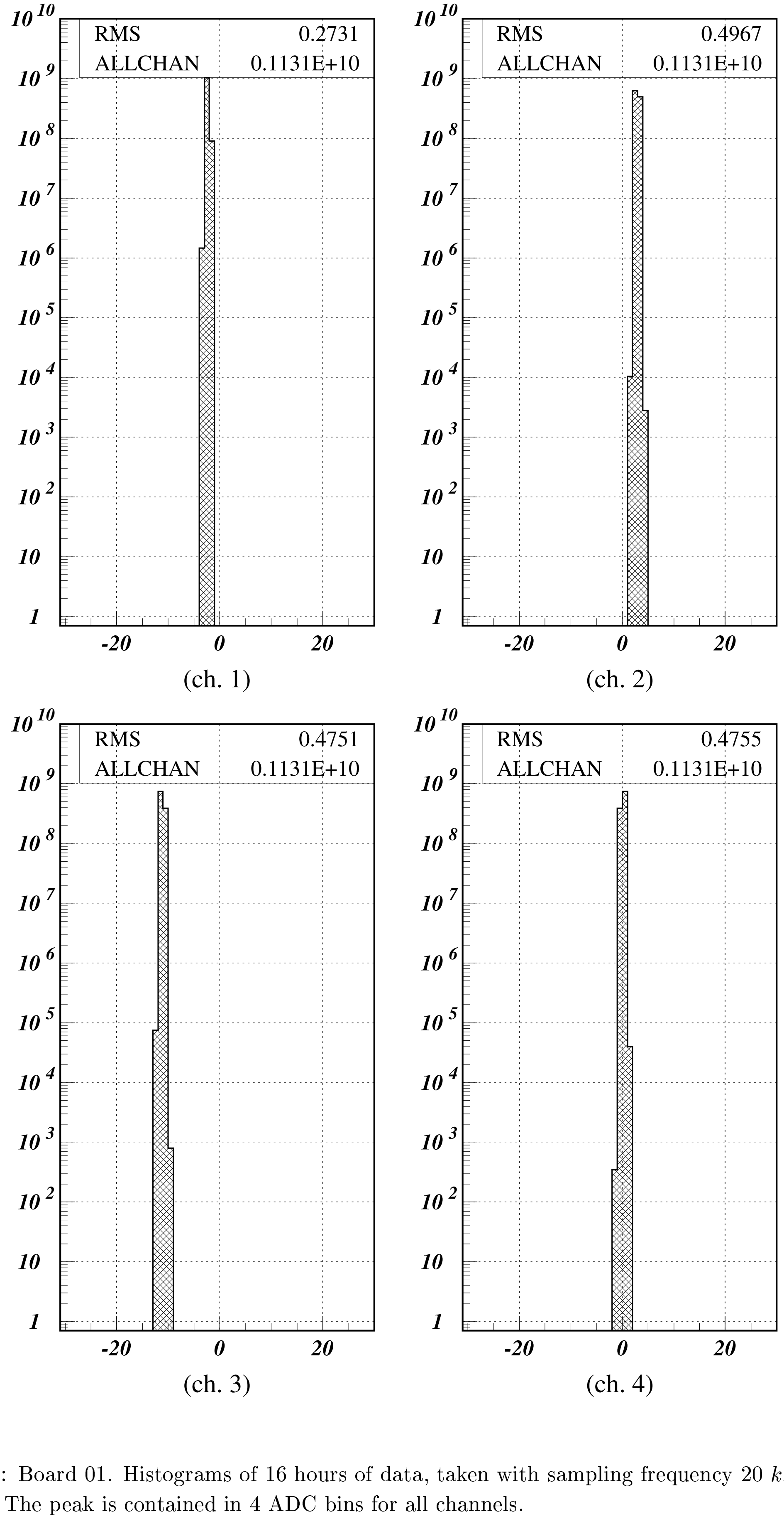

Figure 7: Board 01. Histograms of 16 hours of data, taken with sampling frequency 20 kHz and input on 50 Ω. The peak is contained in 4 ADC bins for all channels.

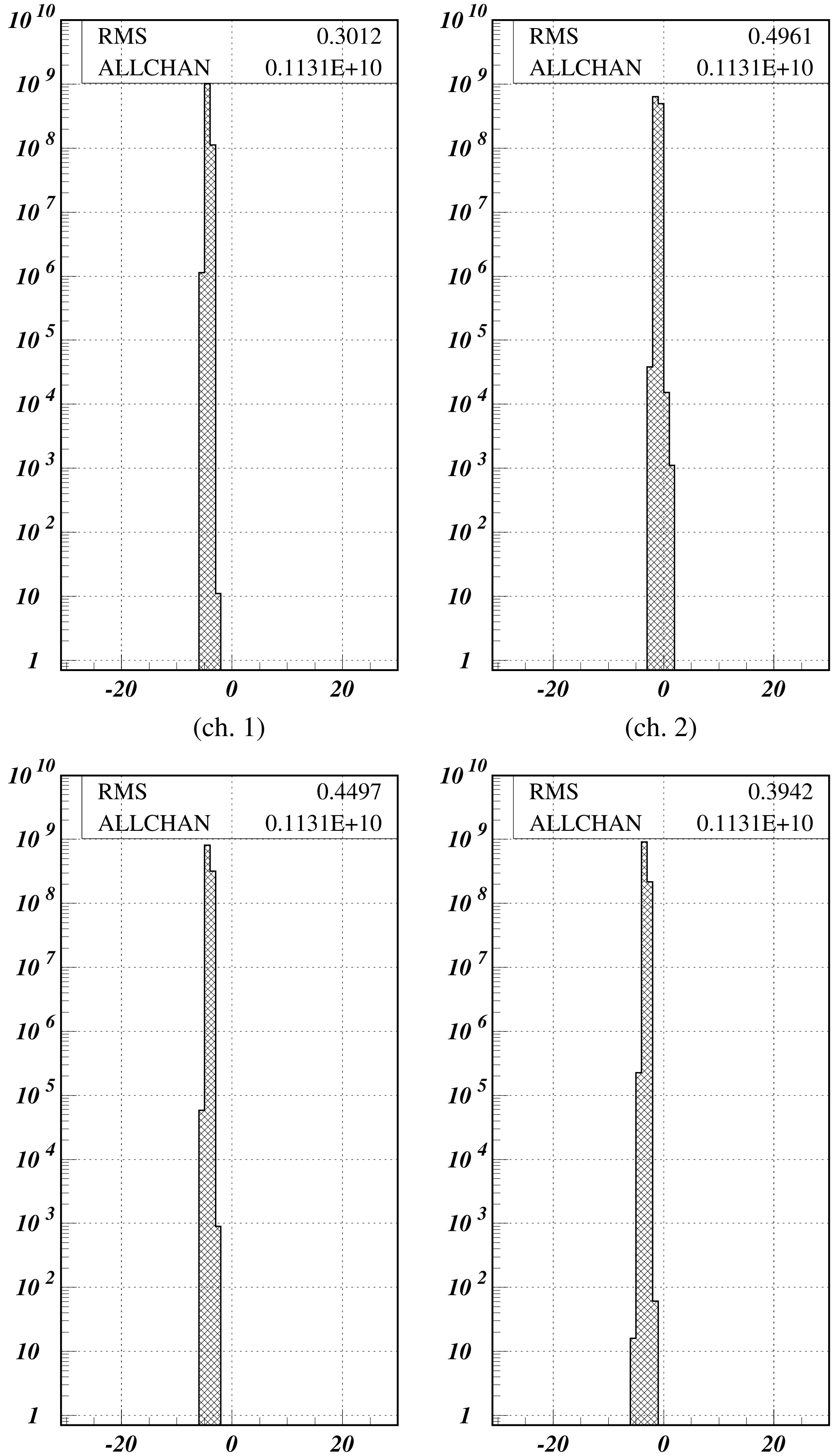

Figure 8: Board 07. Histograms of 16 hours of data, taken with sampling frequency 20 kHz and input on 50 Ω. The maximum offset width is 5 bins.

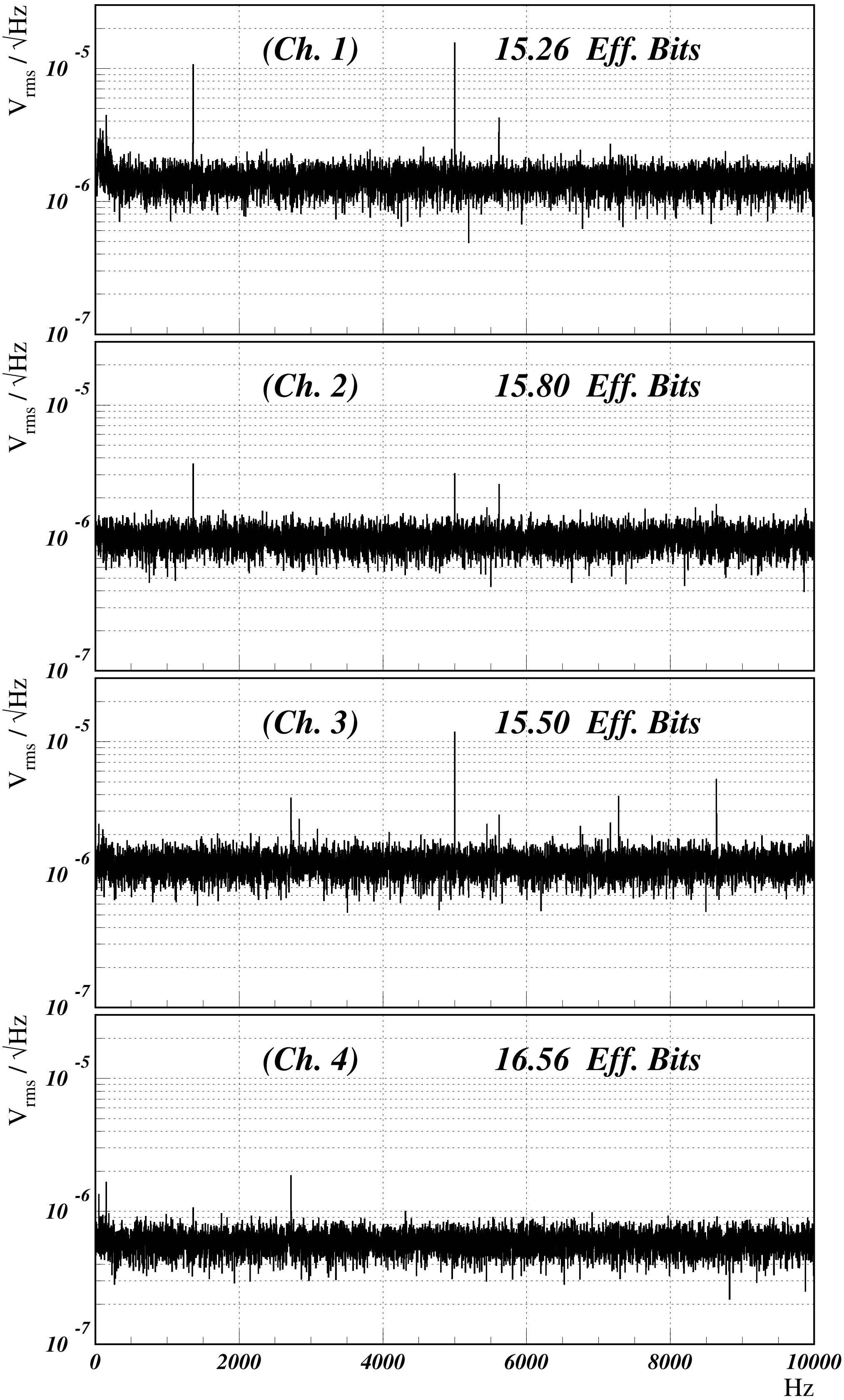

Figure 9: Amplitude Spectral Density of board 01, input on 50 Ω. Here the number of effective bits has been calculated from the PSD between 5100 Hz and 9900 Hz.

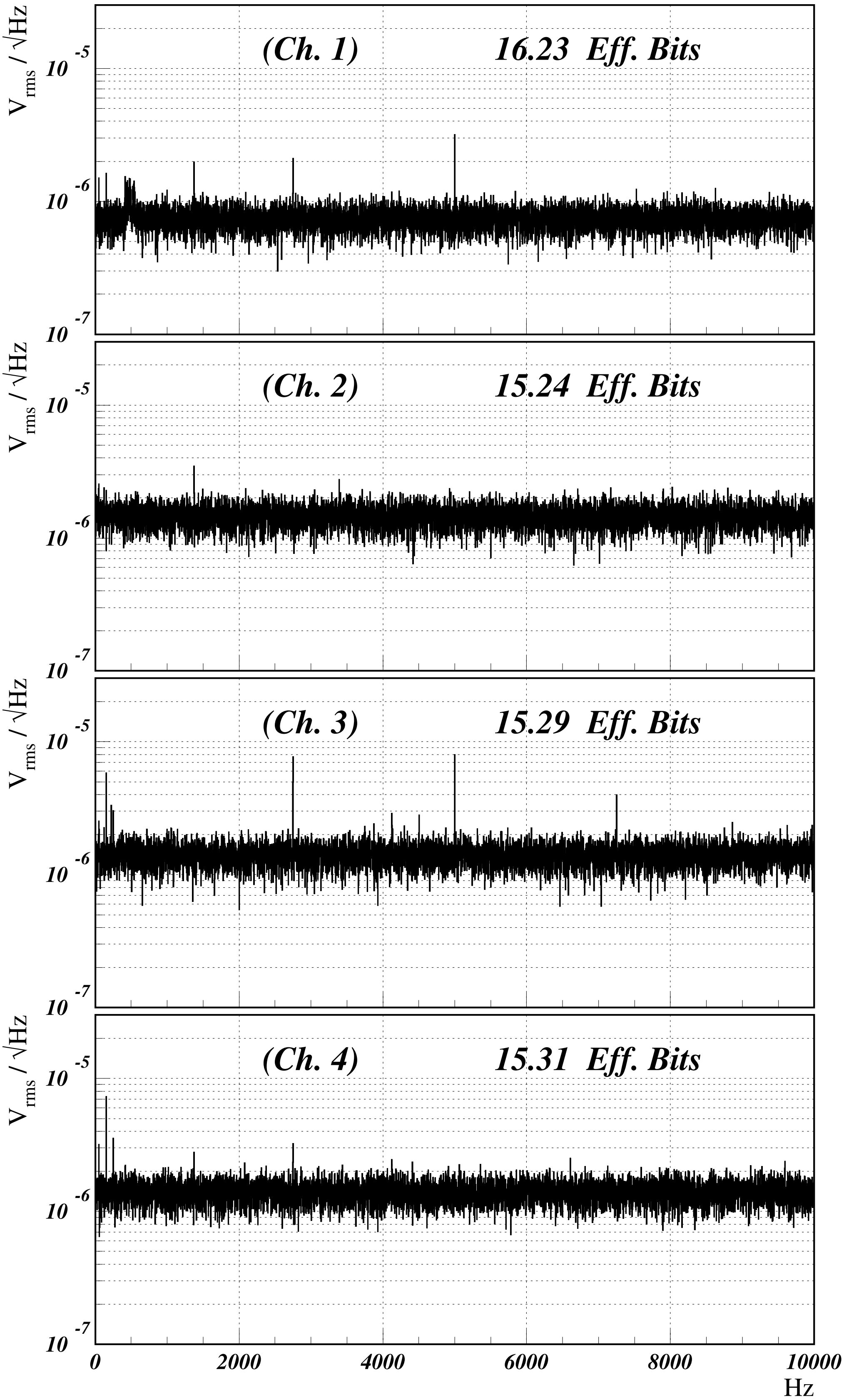

Figure 10: ASD of board 07, input on 50 Ω. Here, the number of effective bits has been calculated from the PSD between 5100 Hz and 9900 Hz.

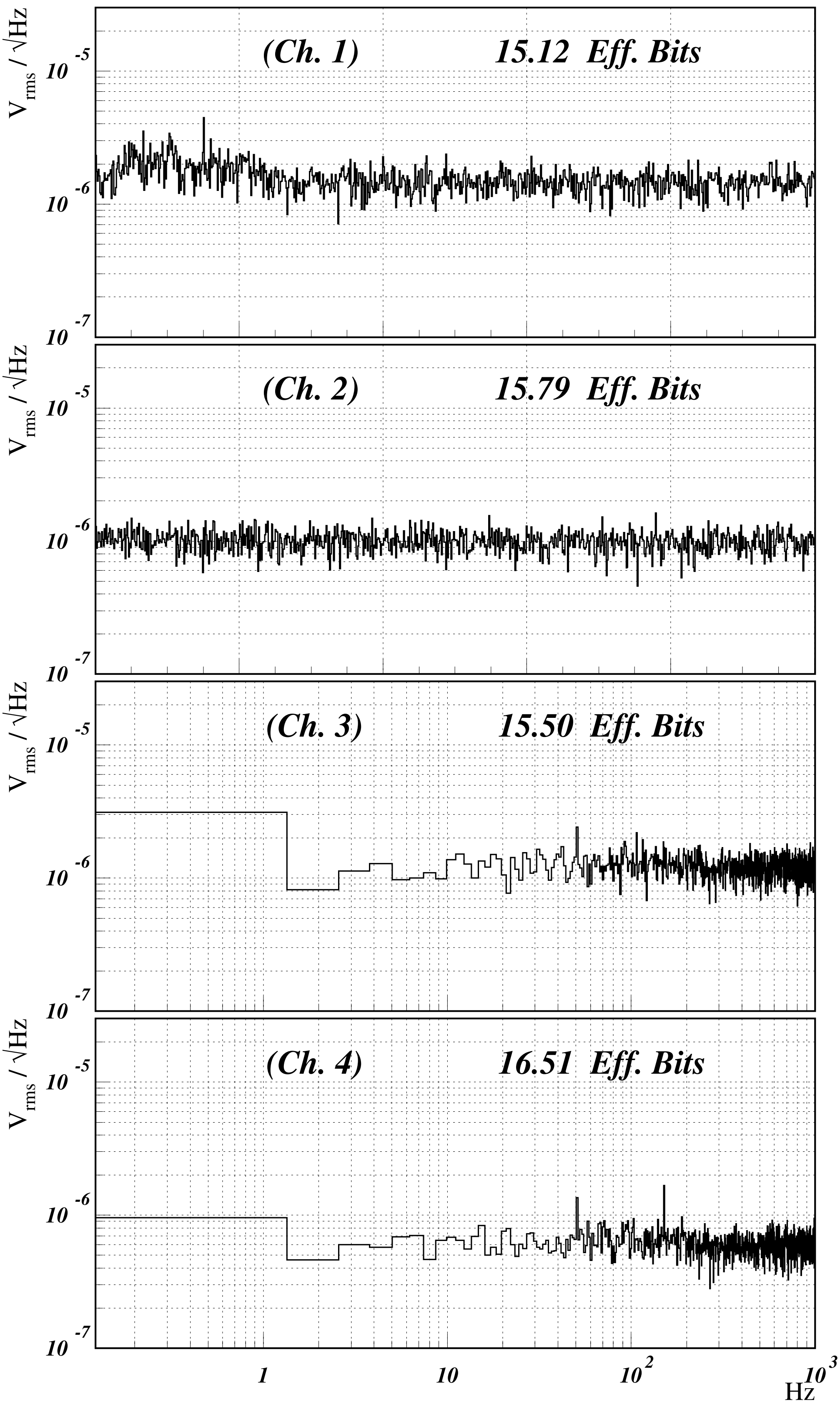

Figure 11: ASD of board 01 between 1 Hz and 1000 Hz, input on 50 Ω. The number of effective bits has been calculated from the PSD in the plotted spectral zone.

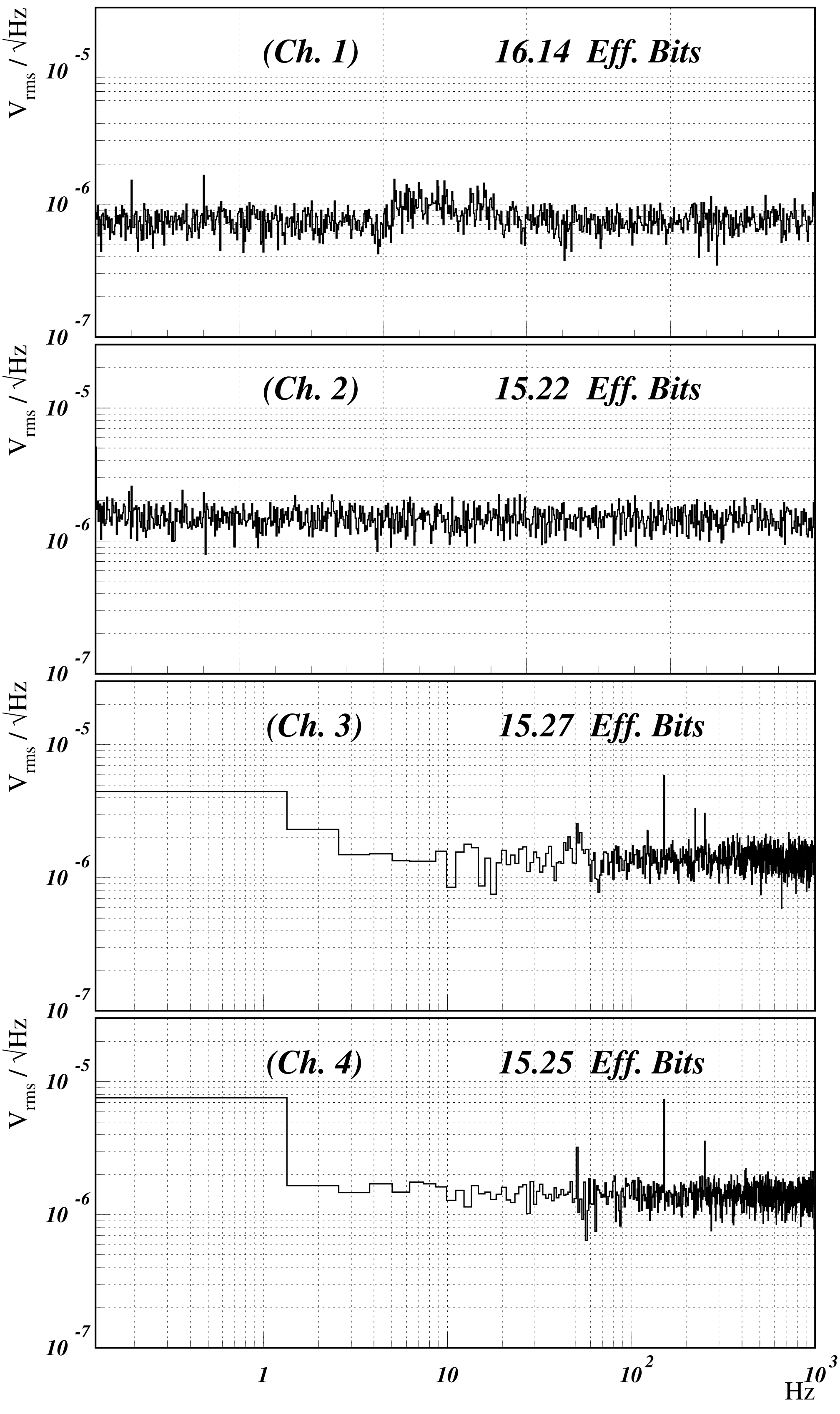

Figure 12: ASD of board 07between 1 Hz and 1000 Hz, input on 50 Ω. The number of effective bits has been calculated from the PSD in the plotted spectral zone.