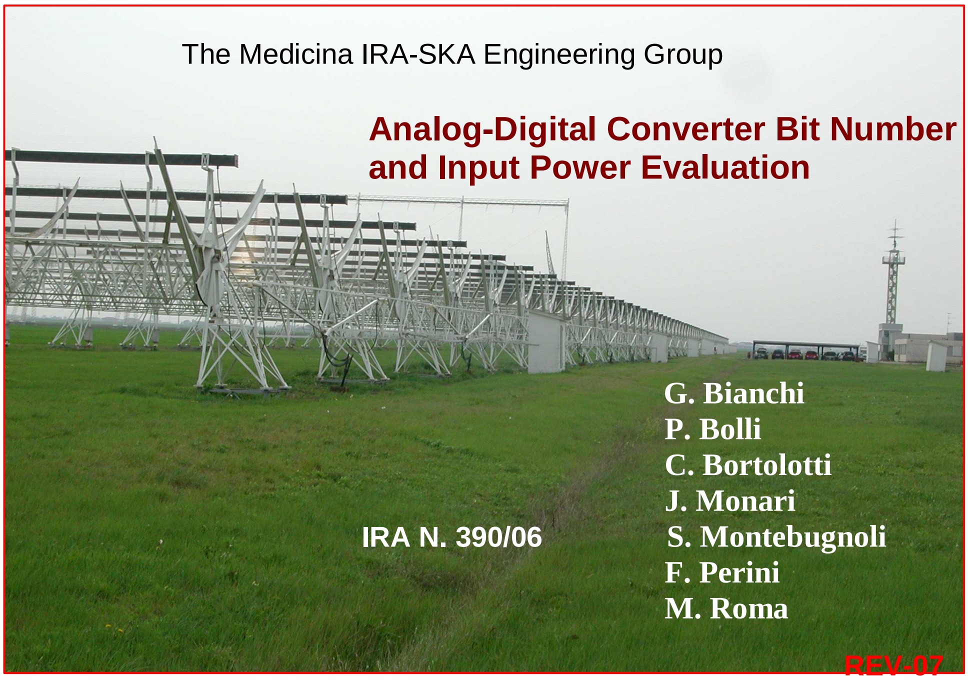
The Medicina IRA-SKA Engineering Group

Analog-Digital Converter Bit Number and Input Power Evaluation



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G. Bianchi
P. Bolli
C. Bortolotti
J. Monari
S. Montebugnoli
F. Perini
M. Roma

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Abstract

In this document is reported a methodology to find the number of bit needed in an A/D converter and its required input signal power for radio astronomical applications.
Also, here we show an example of this methodology applied to the BEST project [1].

ADC: bit number and input power evaluation

To evaluate the number of bit necessary in an ADC system, the dynamic range of the input signal has to be analyzed. Theoretically a radio telescope should receive only the very weak sky noise and 2 or 3 bit could be sufficient to describe it. But, due to presence of stronger man made RF signals (only if they fall in a protected frequency band we can call them RFI-Radio Frequency Interference), the raise of the received power has to be taken into consideration to avoid the saturation of the converter.
A measurement campaign has to be performed to evaluate the maximum dynamic range of the ADC input signal. To obtain a worst case estimation of the radio frequency band in Medicina, a spectrum analyzer in max-hold configuration has been connected to 2 Yagi antennas, one for the vertical polarization and one for the horizontal one (see Figure 1) while they were rotating continuously to scan all the azimuth directions at an height of $22mt$. These two antennas are part of the RFI receiver system of the Medicina radio telescopes.

Figure 1 *The 22mt Medicina RFI monitoring tower.*

A $20MHz$ bandwidth around $408MHz$ has been scanned, obtaining the result shown in Figure 2.

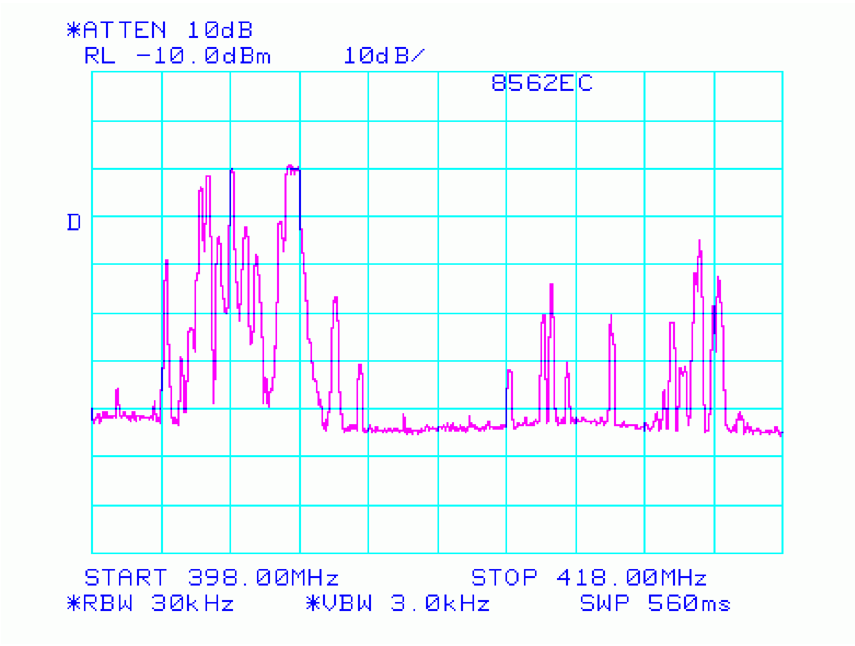

Figure 2 *Radio spectrum obtained from the RFI monitoring tower.*

To consider the overall power contribution of the full bandwidth, all the values detected, in each $30 KHz$ bandwidth, have been linearly added. The final result (subtracted the antenna gain, cable loss, amplifier contributions) was:

$$P_{0dBi} = -69.4 \ \ dBm$$

where the subscript $0dBi$ indicates that the power level is referred to an isotropic antenna with an unitary gain in all directions (for more details see [2]).

This could be considered a good estimation of the maximum, worst-case[1], RF power that can be received by each BEST-1 and BEST-2 receiver (the sky contribution should be considered too, but it is negligible in comparison to man made RF signals).

To evaluate the ADC dynamic range, the minimum input power has to be calculated: this is the cold sky temperature (i.e. the temperature of an area of the sky far from the galactic plane where there are not radio sources) plus the equivalent system noise referred to the antenna terminals. The theoretical antenna noise temperature for BEST-1, when the antenna is pointed to the zenith direction, is [3]:

$$\mathrm{T_A} = 35K \ @ \ 408 \ MHz$$

Considering [3] and [4], T_{SYS} is:

$$T_{\mathrm{SYS}} = 86.2K$$

Therefore, the equivalent system input noise power for a $16MHz$ bandwidth (as in the BEST project) is:

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[1] The N/S focal lines are at an height of about 5*mt* above ground, so they have a shorter radio horizon than the RFI monitoring system. In the BEST-3 system, some receivers will be placed on the E/W focal line, at about 30*mt* above ground, higher than the antennas of the RFI monitoring tower. So the situation could be worse (i.e. P_{0dBi} could be higher than -69.4*dBm*).

$$P_{sys} = 10\log_{10}\left(\frac{kT_{sys}B}{1\cdot 10^{-3}}\right) = -107.2\ dBm$$

The maximum dynamic range results:

$$P_d = P_{0dBi} - P_{sys} = -69.4 - (-107.2) = 37.8\ \ dB$$

In order to evaluate the number of bit needed to describe this power dynamic, since an ADC converts voltage into bit and not power into bit, we need a relationship between the power and the voltage at the input of the AD converter.

If we consider the simplest possible situation, where there is only a monochromatic tone at the input of the ADC, we can easily find the relationship (considering a 50Ω matched system):

$$P = 30 + 10\log_{10}\left[\frac{V_P^2}{2R}\right] = 30 + 20\log_{10}\left[\frac{V_P}{100}\right]$$

where V_P is the voltage peak value, expressed in Volt, and the power P is expressed in dBm. From this equation we obtain also that if the voltage is doubled $\left(2V_P\right)$, there is a $6dB$ of power increase $\left(20\log_{10}(2) = 6\right)$. So, each bit corresponds to an increment of, respectively, $3dB$ in voltage and $6dB$ in power, of the input signal. If we divide the dynamic range P_d by 6, we can obtain the required ADC number of bit to sustain such dynamic. But, the previous relationships are rigorous only in that simple situation: if we look at the Figure 2, we can see that a real RF scenario can be very different from a single CW tone. In that situation doesn't exist a simple closed form to express the relationship between the input power and the input voltage (and so the number of bit). And even if it is still true that at each more significant bit corresponds to a doubling of the instantaneous input voltage, not necessarily each bit corresponds to a 6dB of input power increase. As a rule of thumb we can say: more the RF scenario is dominated by a single strong signal, more accurate the previous relationships are.

That said, for a first attempt we consider the relationships valid also for the BEST system RF scenario, so:

$$N_d = \frac{P_d}{6} = 6.3\,bit$$

The integer value greater than N_d is 7. Considering 3 bit to describe the radio astronomic signal, the final number of bit is:

$$N_{bit} = \lceil N_d \rceil + 3 = 7 + 3 = 10\,bit$$

In our case the ADC chosen is the AD6645, which presents 14 bit and a peak to peak input voltage of $2.2V$. From the datasheet, the effective number of bit (ENOB) is 12, so the device sensibility (minimum detectable input signal voltage variation) results:

$$V_{PP\_LSB} = \frac{V_{PP\_IN}}{2^{12}} = \frac{2.2}{2^{12}} = 537\mu V$$

Considering 3 bit for the radio astronomic signal (8 quantization levels), the peak to peak voltage excursion is:

$$V_{PP\_N} = 2^3 \cdot V_{PP\_LSB} = 8 \cdot 537 \cdot 10^{-6} = 4.3\,mV$$

The effective voltage, computed in a radio astronomic band, is:

$$V_{RMS} = \frac{V_{PP\_N}/2}{\sqrt{20}} = \frac{4.3 \cdot 10^{-3}/2}{\sqrt{20}} = 0.48\,mV$$

Considering the ADC driven by a 50Ω input impedance buffer, the input power level needed is:

$$P_{IN} = 30 + 10 \cdot \log\left(\frac{V_{RMS}^2}{\left|Z_{input}\right|}\right) = 30 + 10 \cdot \log\left(\frac{\left(0.48 \cdot 10^{-3}\right)^2}{50}\right) = -53\ dBm$$

References

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