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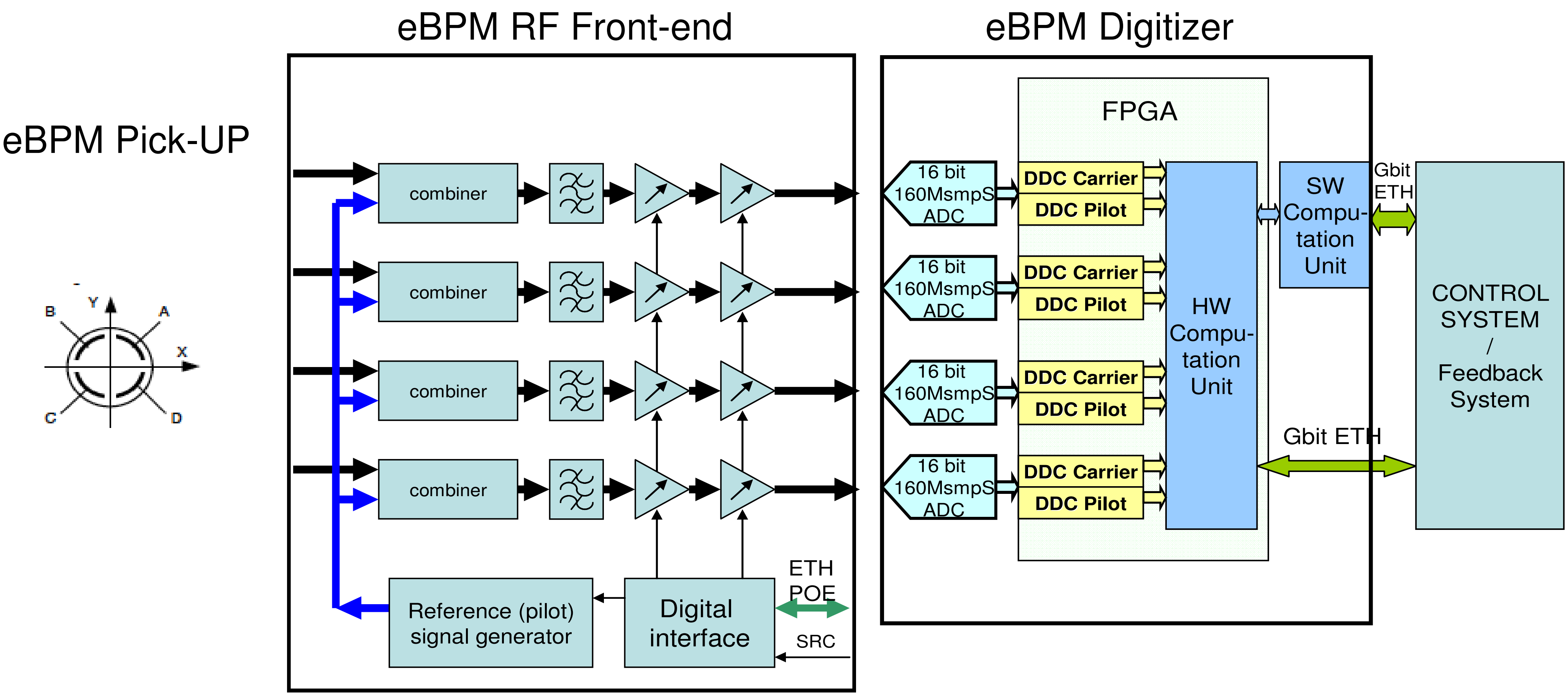
# ADC behaviours in Electron Beam Position Detectors (eBPM)

# Introduction to a eBPM Elettra project

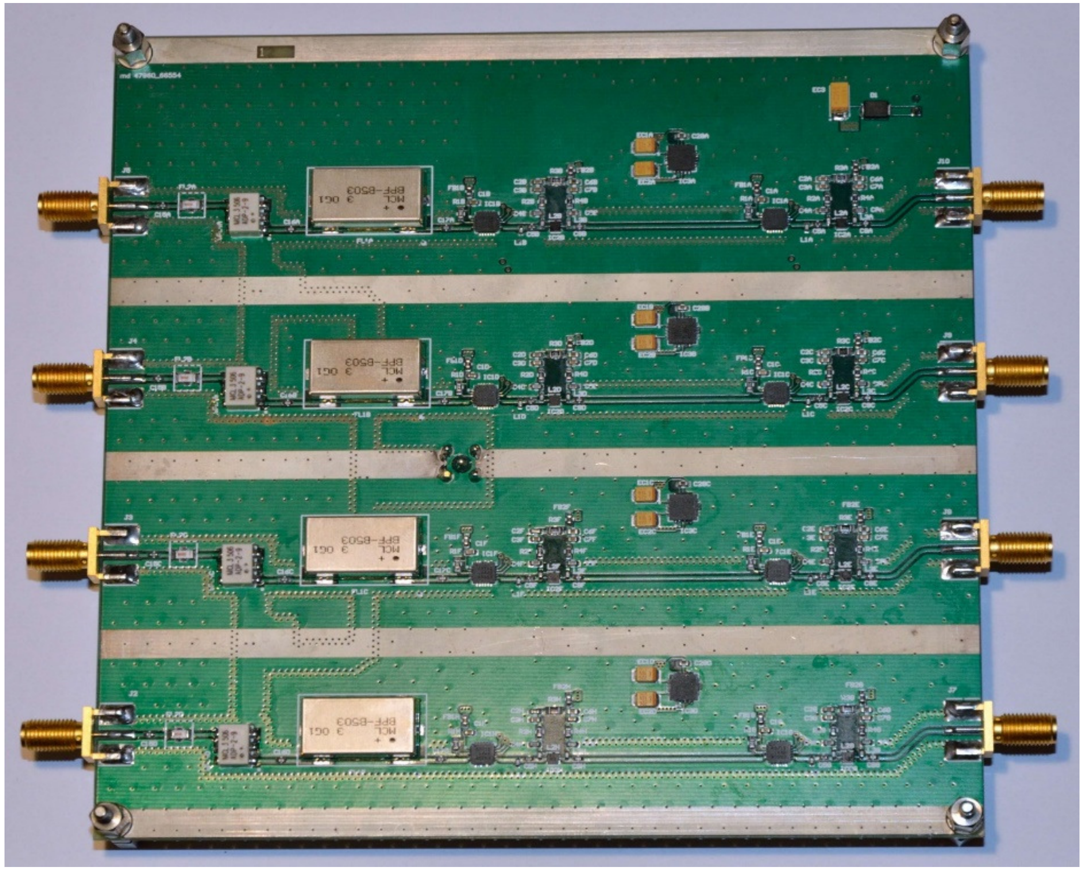
- ✓ Goal of the project is the development of the prototype of an innovative device for measuring beam position, for rings such as Elettra, Elettra2 and single-pass machines such as Fermi
- ✓ A measurement system consisting of a RF section, an FPGA-controlled ADC section able to detect the position of the beam with sub-sampling techniques and a section capable of performing high-level processing (position calculation, calibration, system communication control). Fully integrated in Accelerator Control Systems (Tango, Epics) and compatible with the "environmental" constraints required by these devices.
- ✓ Spatial resolution less than 1µ @100Hz
- ✓ Long term stability (24hrs) **and** beam current dependence (70% machine range) less than 4µ rms
- ✓ Communication through two Gigabit Ethernet connections: one dedicated to global feedback, driven by acquisition FPGA, with position data transmission > 20KHz
- ✓ **MODULAR SYSTEM**: Stand alone FrontEnd, digitizer and timing system.

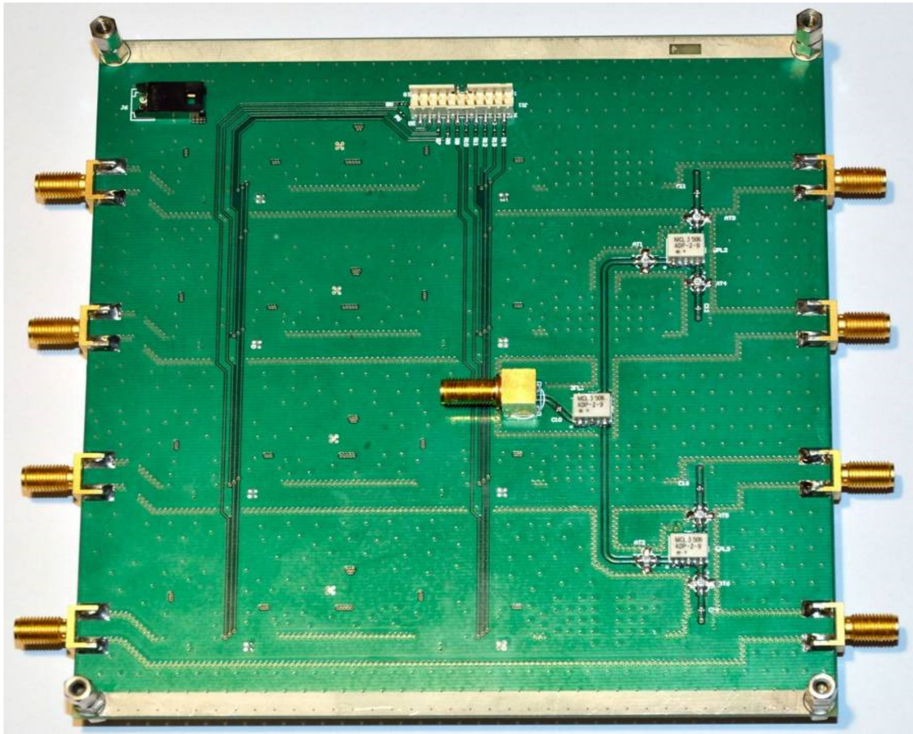
# eBPM: Block Diagram



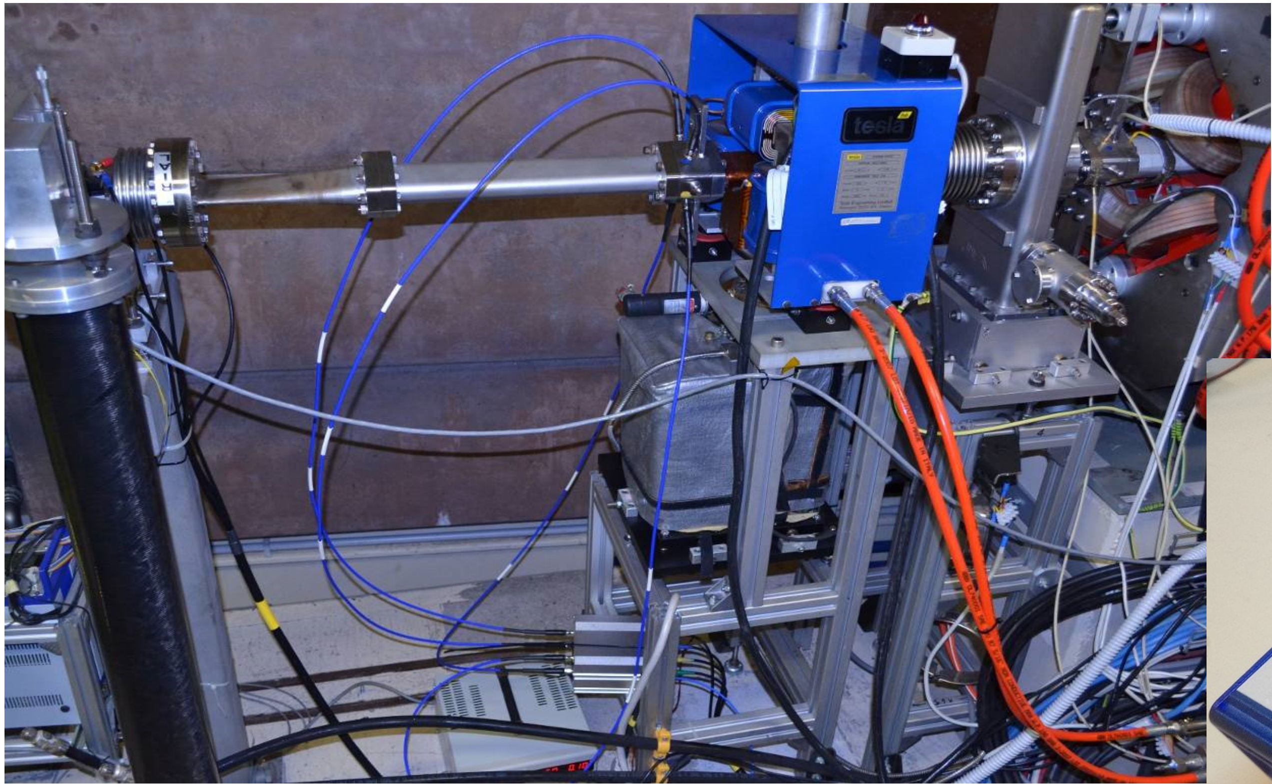
# eBPM: RF Front End

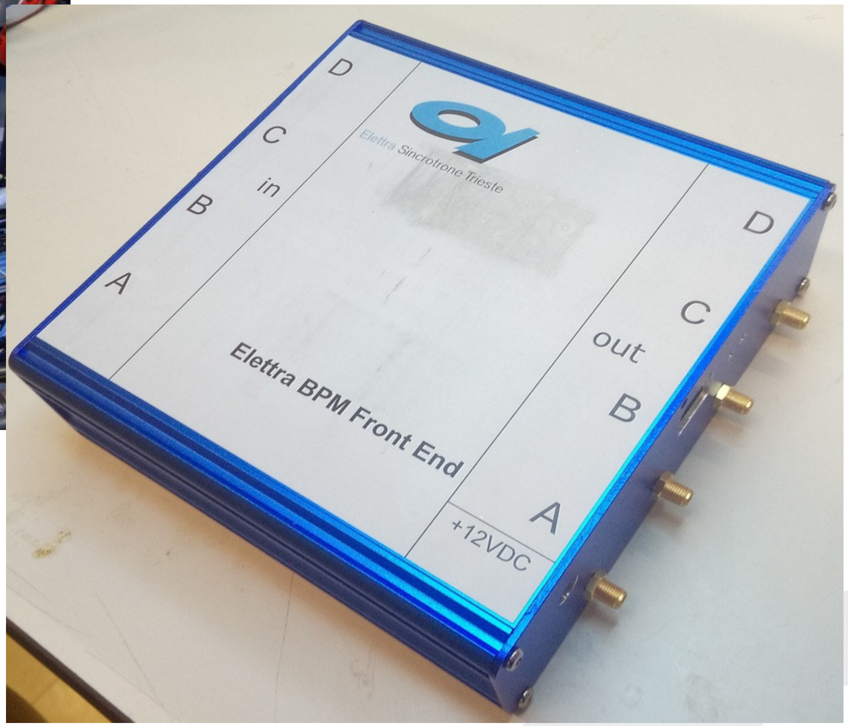
•RF Front End can be placed in machine tunnel to:
Compensate also the long run cables
Have better s/n ratio



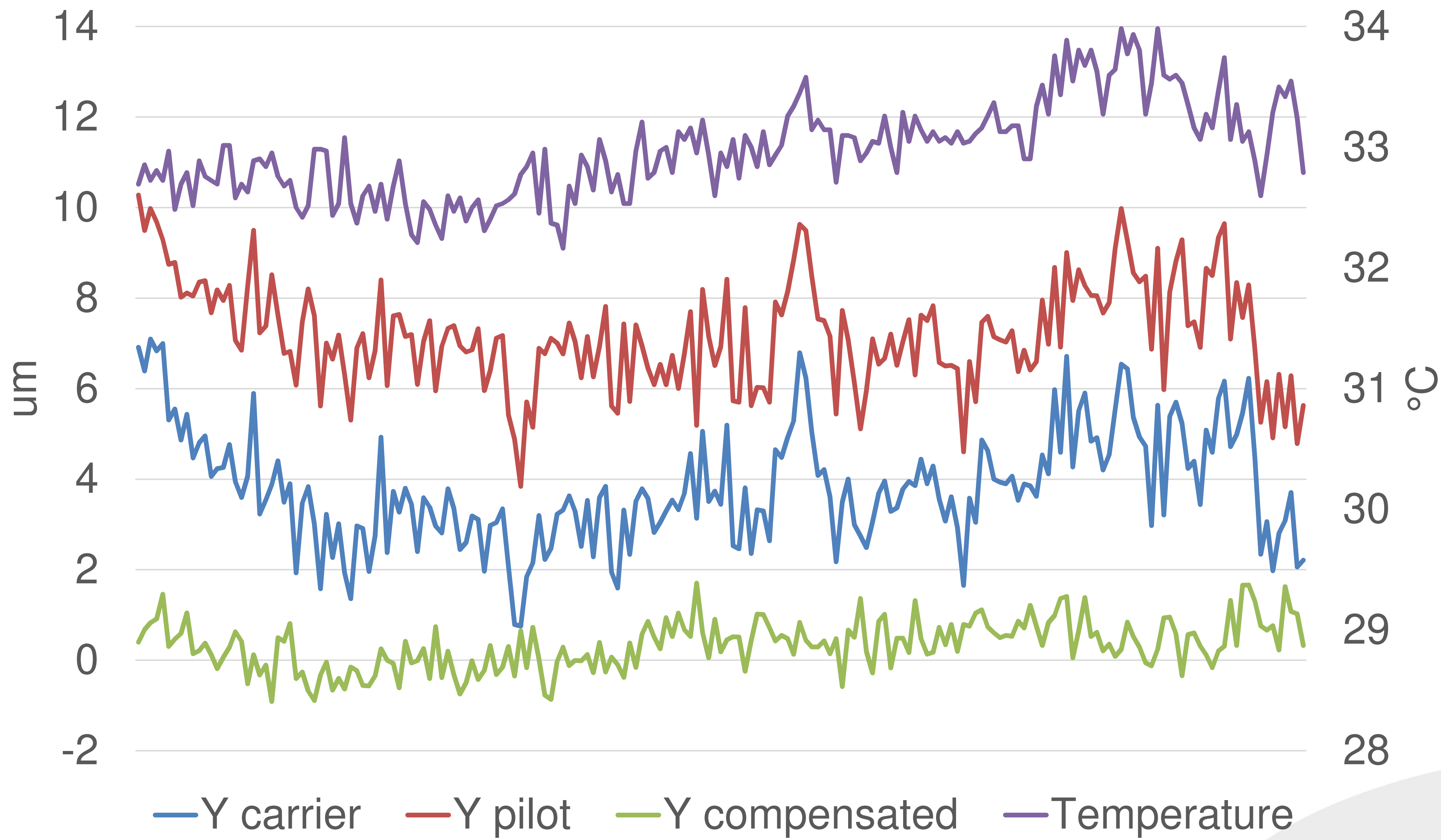


# RF Front End in tunnel test bench



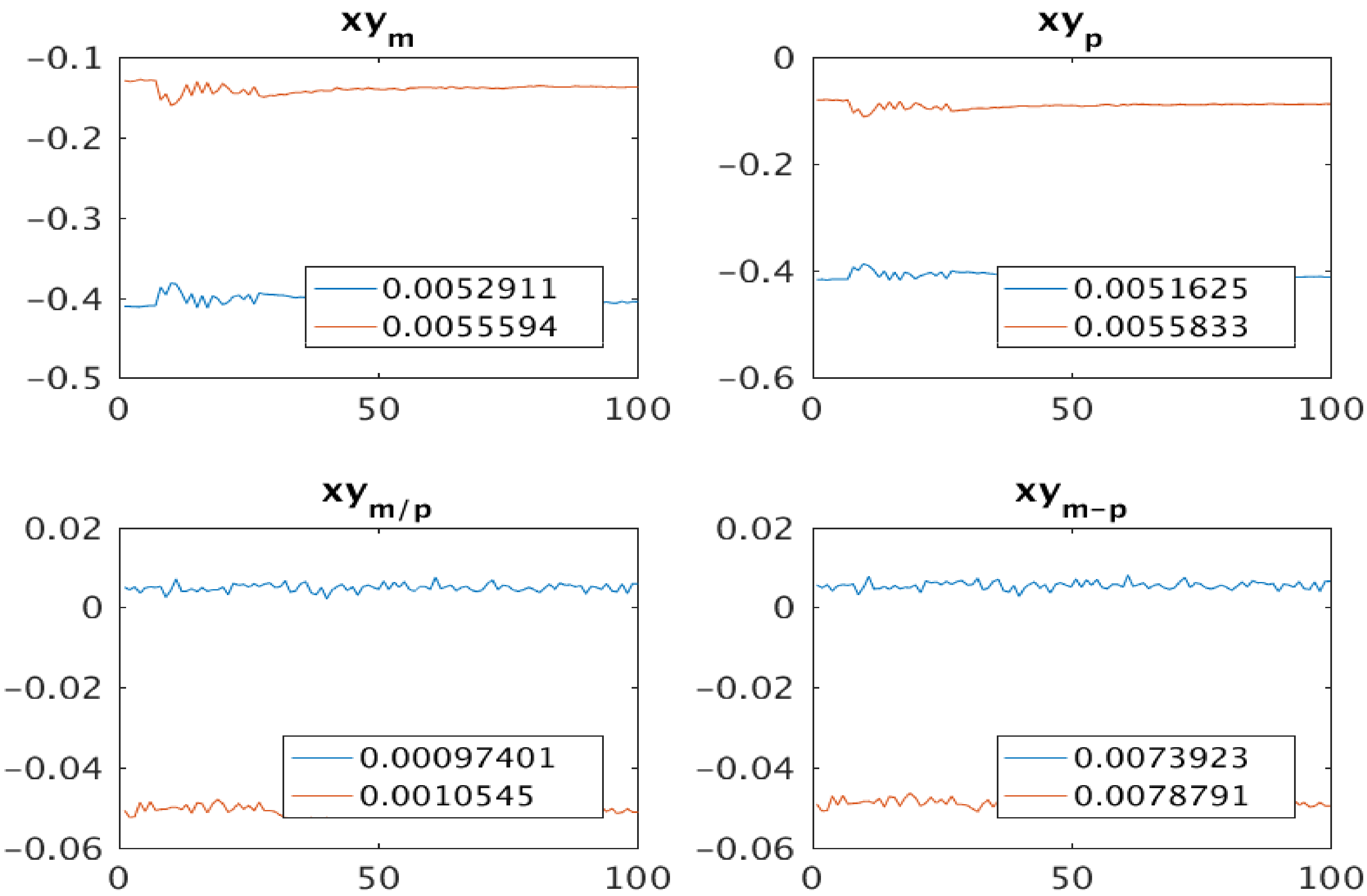


# Real beam 24hrs data acquisition @Elettra



# "Wobbled" cables during acquisition @ Diamond Light Source

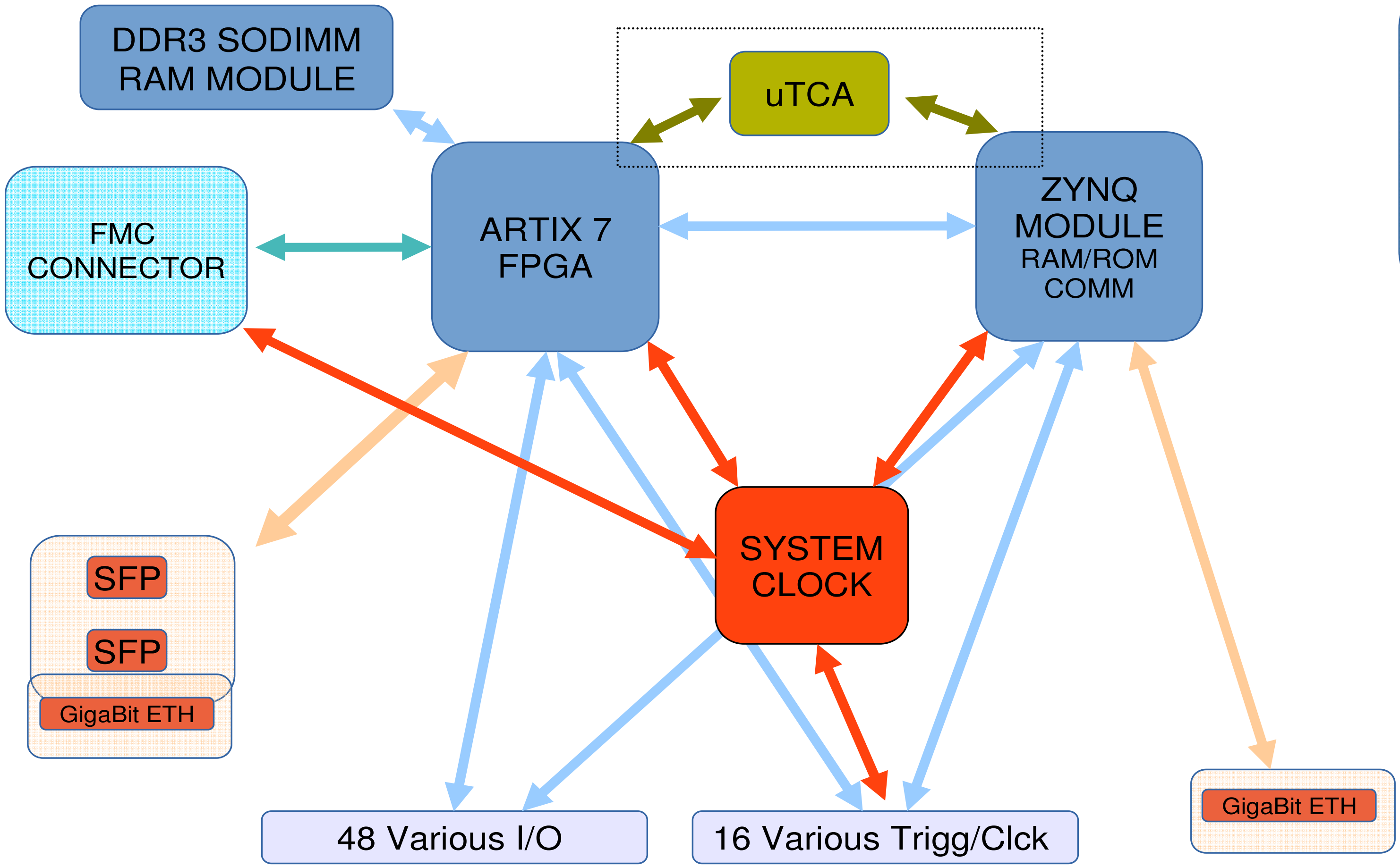
Courtesy of G. Rehm



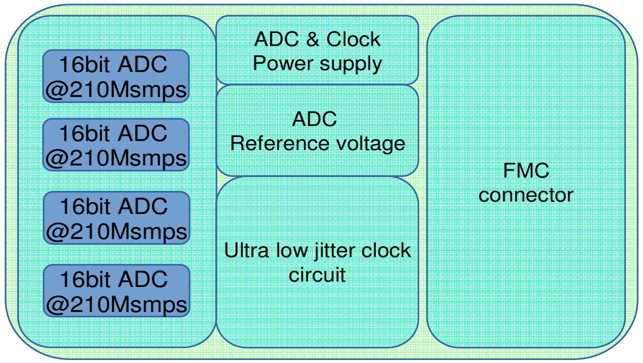
# ADC System

Currently @Elettra we are developing a new uTCA board (project name ADx)

ADx simplified Block diagram V3.1




**FMC Module : 4X ADC, 16-Bit, 210 MSPS**



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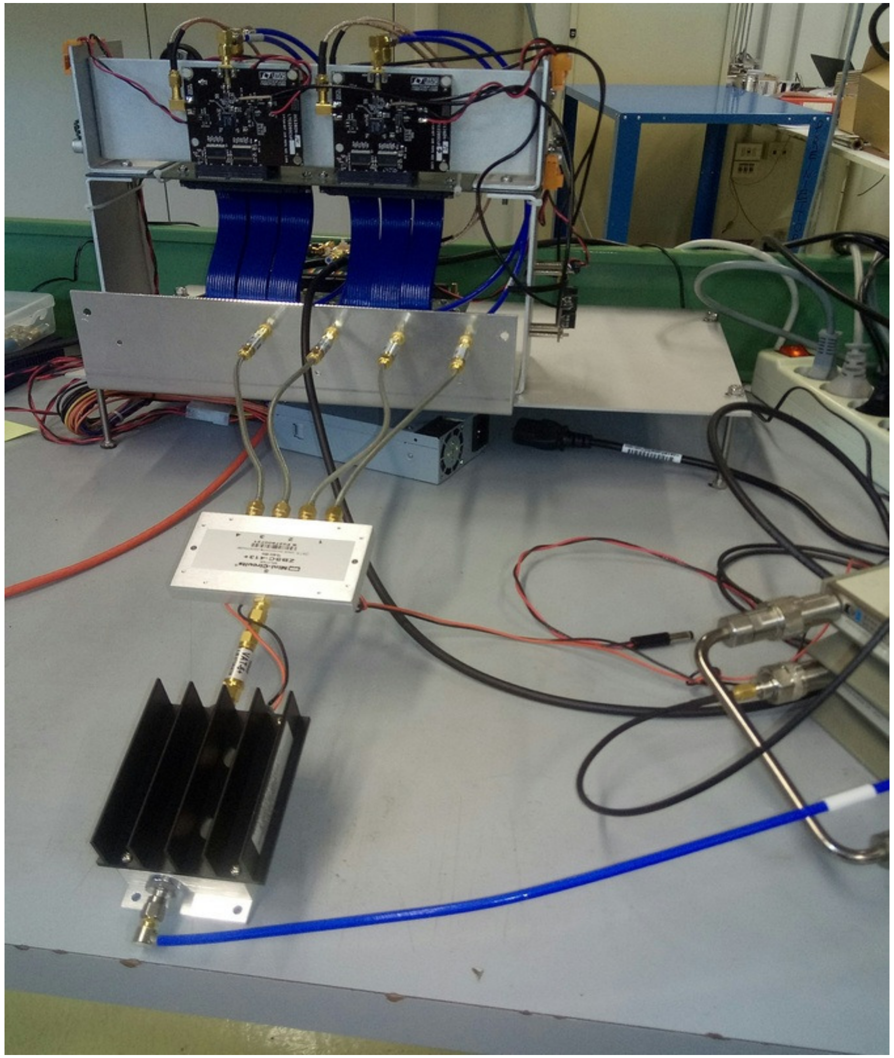
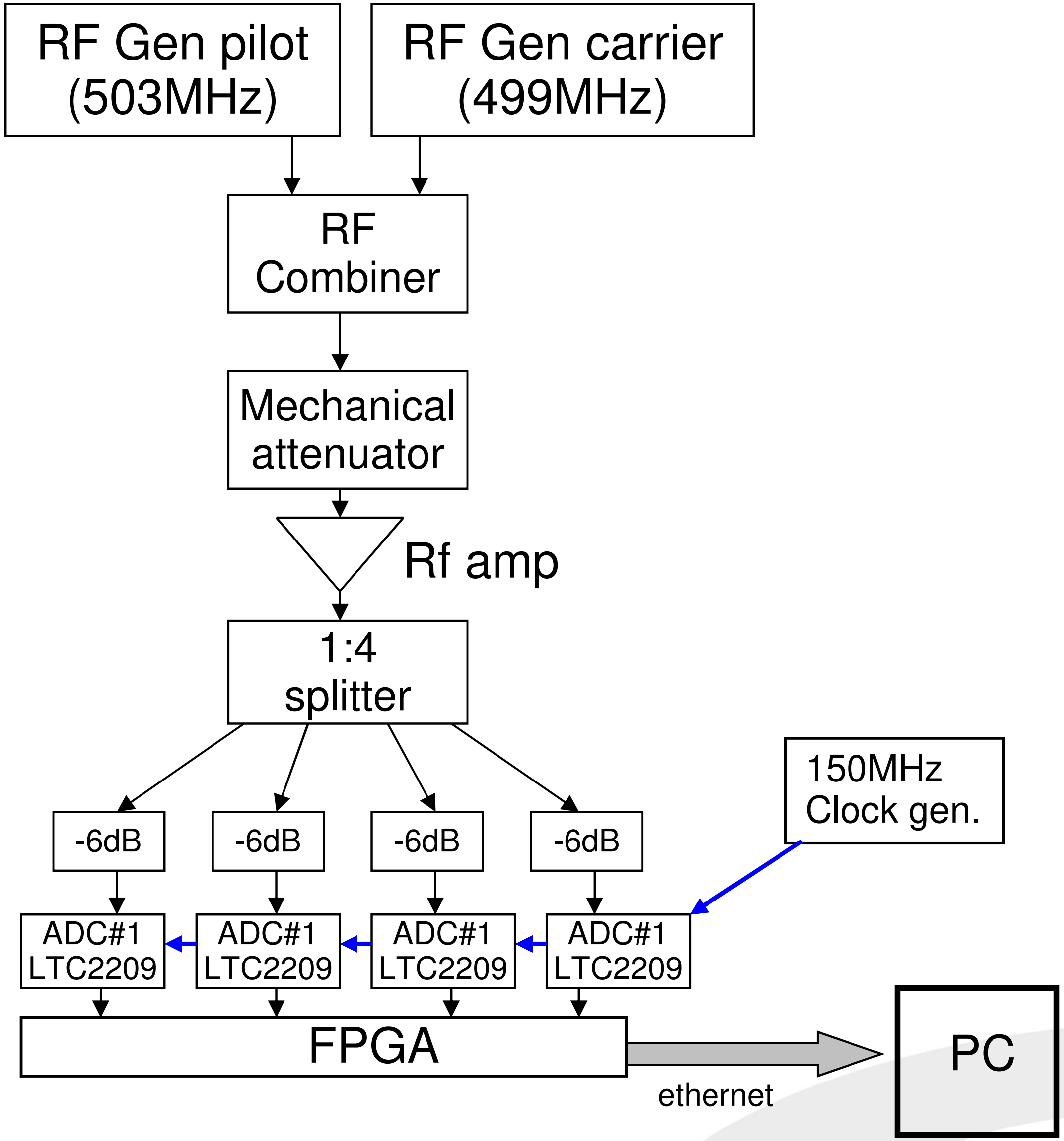
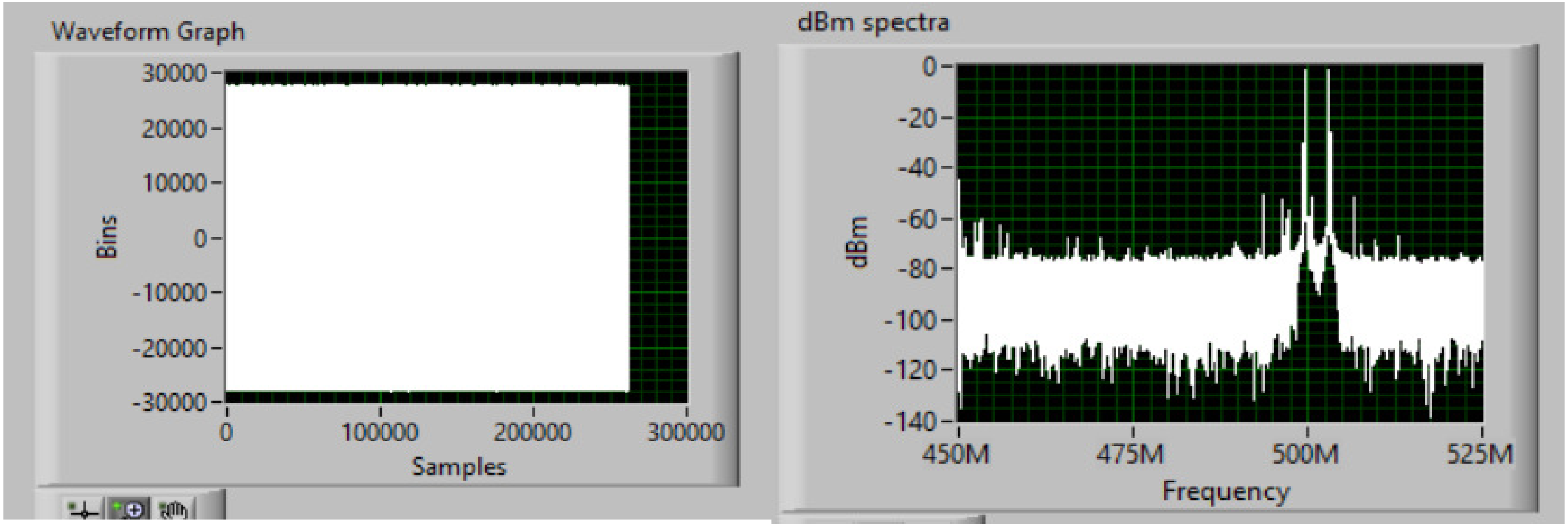
# ADC Measurement system diagram





# Data Acquisition system software

The acquisition software acquires 2.6Msamples of raw data from the ADC @150Ms/s. Then it computes an FFT on these data and it finds the peaks for the two tones. The amplitudes of these peaks are used to calculate the positions respectively for the carrier (@499.654 MHz) and for the pilot tone (@503.123 MHz)



# ADC tests: LTC 2209 ADC characteristics

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**CONVERTER CHARACTERISTICS** The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at $T_A = 25°C$. (Note 4)

| PARAMETER | CONDITIONS | | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|
| Integral Linearity Error | Differential Analog Input (Note 5) | ● | | ±1.5 | ±5.5 | LSB |
| Differential Linearity Error | Differential Analog Input | ● | | ±0.3 | ±1 | LSB |
| Offset Error | (Note 6) | ● | | ±2 | ±10 | mV |
| Offset Drift | | | | ±10 | | µV/°C |
| Gain Error | External Reference | ● | | ±0.2 | ±2 | %FS |
| Full-Scale Drift | Internal Reference<br>External Reference | | | ±30<br>±15 | | ppm/°C<br>ppm/°C |
| Transition Noise | External Reference | | | 3 | | $LSB_{RMS}$ |

2209fb

Note 5: Integral nonlinearity is defined as the deviation of a code from a “best fit straight line” to the transfer curve. The deviation is measured from the center of the quantization band.

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# ADC tests:
# position algorithm considerations

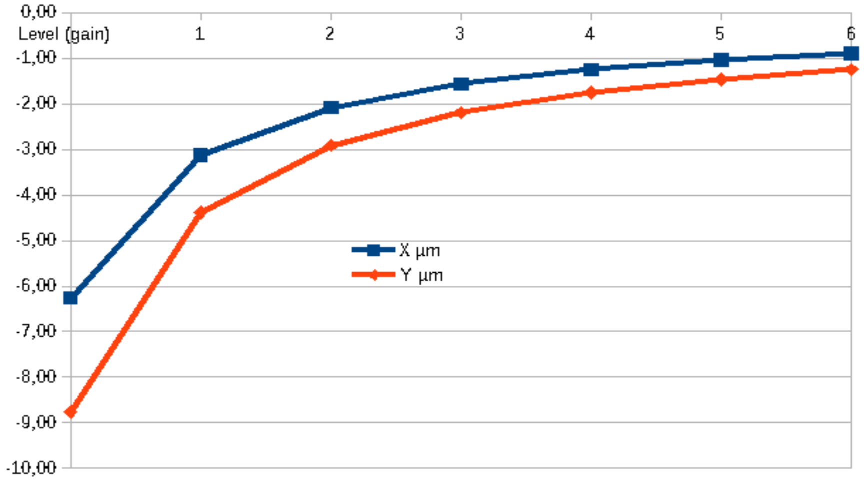
ADC offset definition: with 0 (no) input signal the ADCs have to read 0 (zero) code
In practice this never happens!.
What does it means? What are the effects?

| Level (gain) | ADC A | ADC B | ADC C | ADC D | | zero A | zero B | zero C | zero D | | X µm | Y µm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 4000 | 4000 | 4000 | 4000 | | 8 | 6 | 2 | 5 | | -6,26 | -8,76 |
| 2 | 8000 | 8000 | 8000 | 8000 | | 8 | 6 | 2 | 5 | | -3,13 | -4,38 |
| 3 | 12000 | 12000 | 12000 | 12000 | | 8 | 6 | 2 | 5 | | -2,08 | -2,92 |
| 4 | 16000 | 16000 | 16000 | 16000 | | 8 | 6 | 2 | 5 | | -1,56 | -2,19 |
| 5 | 20000 | 20000 | 20000 | 20000 | | 8 | 6 | 2 | 5 | | -1,25 | -1,75 |
| 6 | 24000 | 24000 | 24000 | 24000 | | 8 | 6 | 2 | 5 | | -1,04 | -1,46 |
| 7 | 28000 | 28000 | 28000 | 28000 | | 8 | 6 | 2 | 5 | | -0,89 | -1,25 |

$$X = 20000 * \frac{((adcA - zeroA) + (adcD - zeroD)) - ((adcB - zeroB) + (adcC - zeroC))}{(adcA - zeroA) + (adcB - zeroB) + (adcC - zeroC) + (adcD - zeroD)}$$

$$Y = 20000 * \frac{((adcA - zeroA) + (adcB - zeroB)) - ((adcC - zeroC) + (adcD - zeroD))}{(adcA - zeroA) + (adcC - zeroC) + (adcB - zeroB) + (adcD - zeroD)}$$

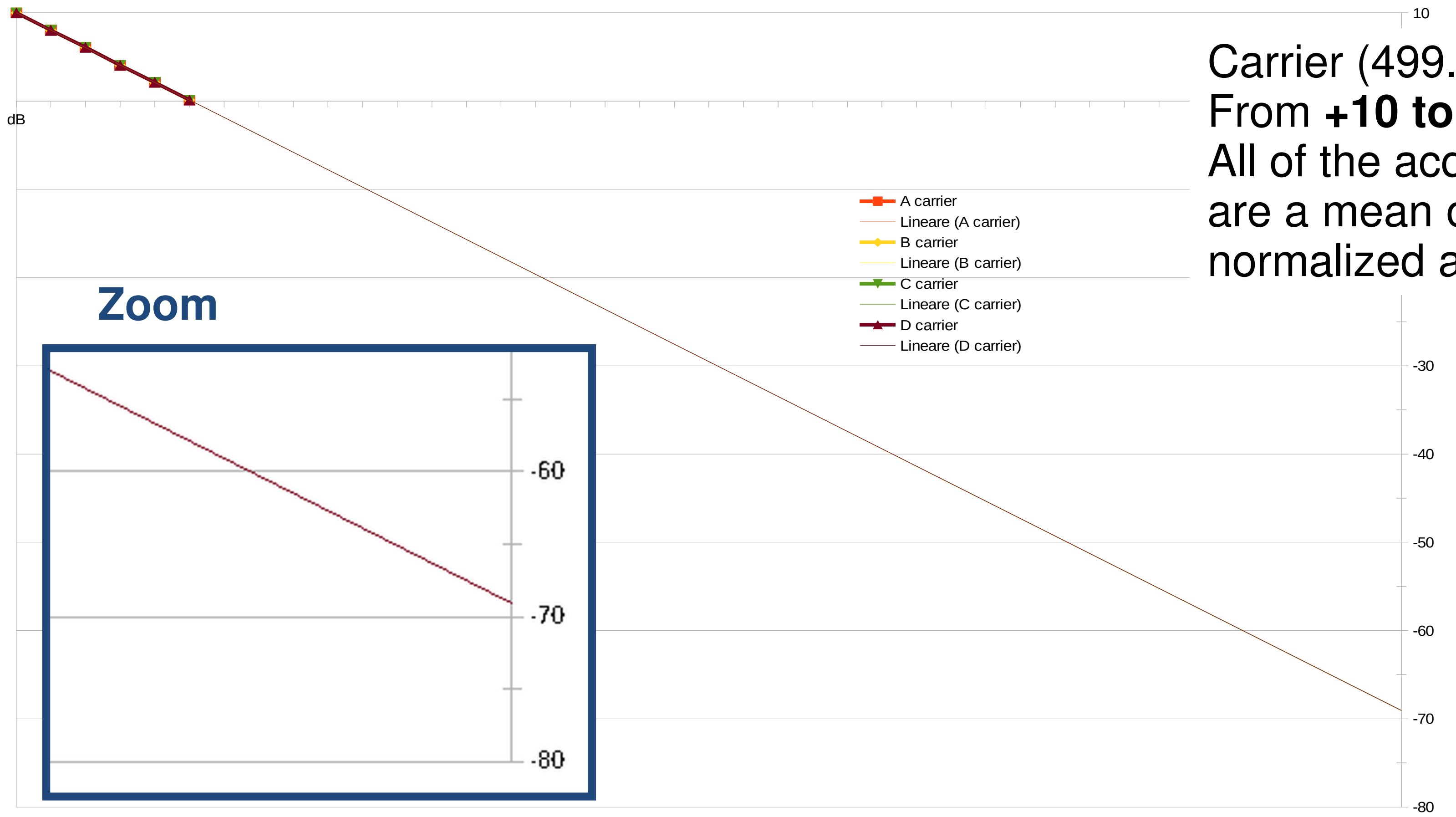
With these data is possible to evaluate the weight of a **little** offset (compared to the whole signal) as specified as the typical integral non-linearity value in ADC datasheet.




The sum over difference algorithm is sensitive to the ADC offset.

# ADC tests:
# Zero Offset measure

Zero Offset is the effective ADC value for 0 (no) signal input.
The way to measure is to use a “best fit straight line” to the transfer curve.
Due to a measure method (using dB attenuators) a logarithmic scales have been used.
That means that no zero intercept point between axes exists.
Then a max -80dB point was chosen.

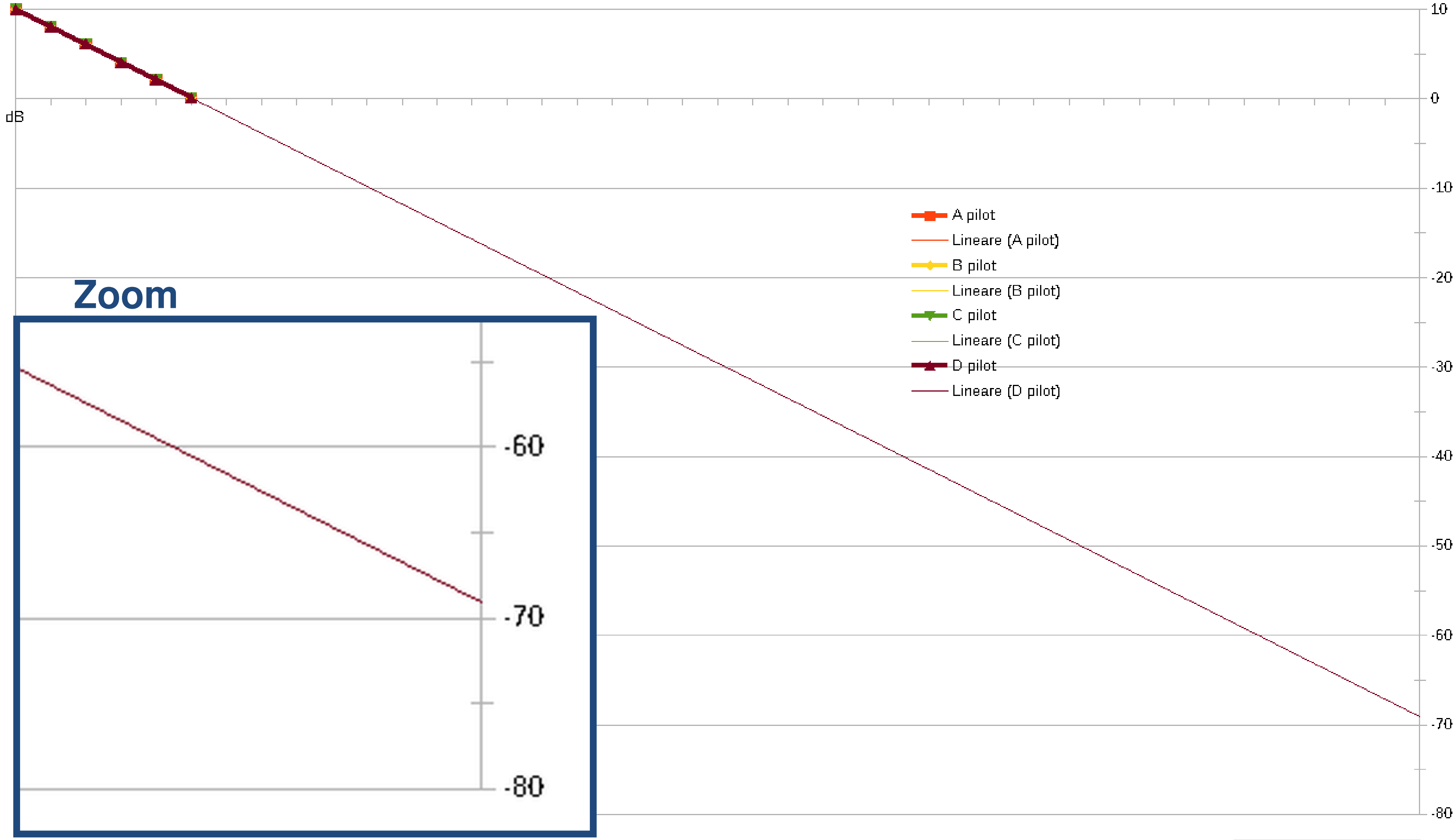



Carrier (499.654 MHz)
From **+10 to 0 dBm**
All of the acquired points are a mean of 20 points normalized at +10

# ADC tests: Zero Offset measure

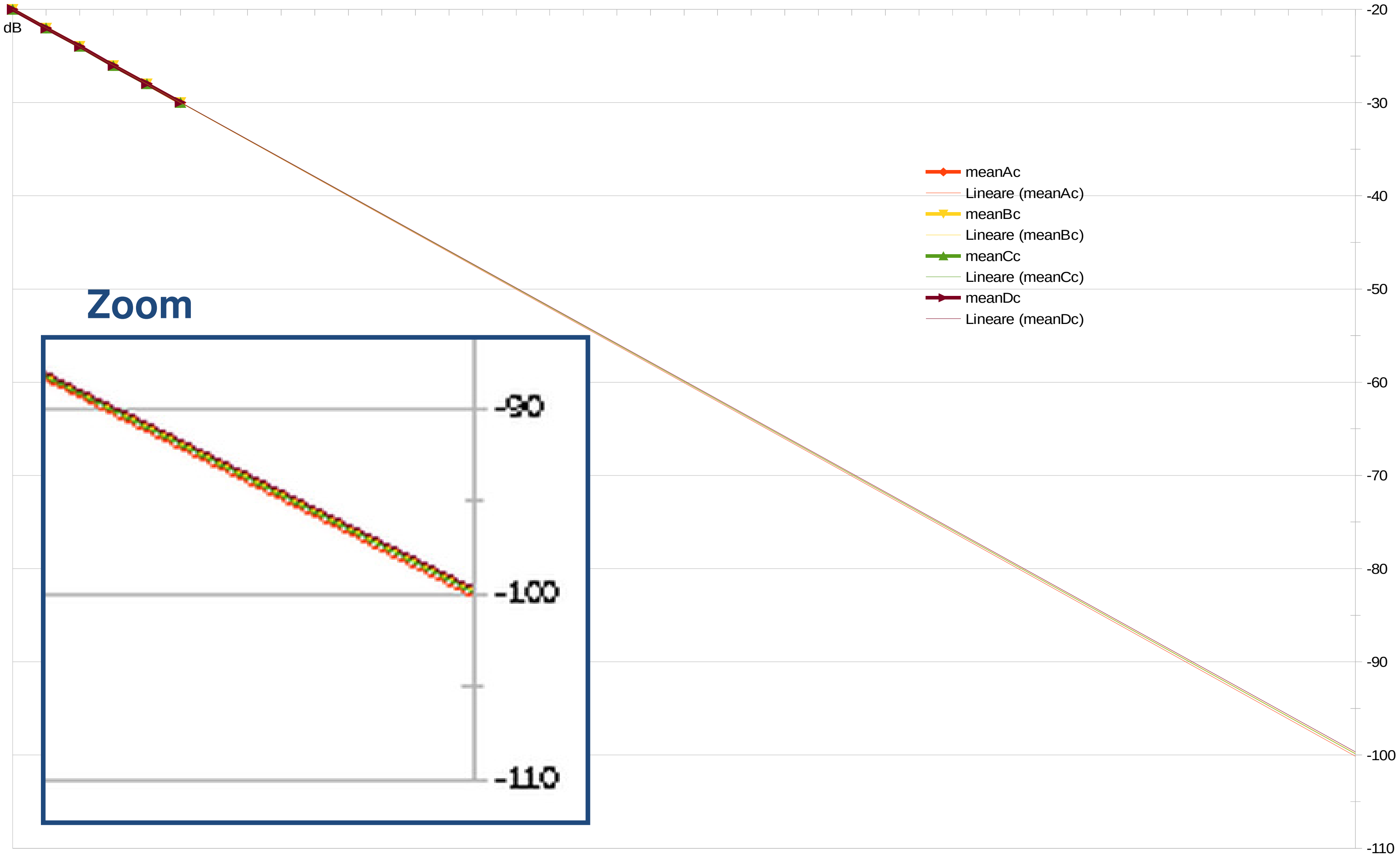
Pilot (503.123) **From +10 to 0 dBm**

All of the acquired points are a mean of 20 points normalized at +10



# ADC tests:
# Zero Offset measure

Carrier (499.654 MHz) From **-20 to -30 dBm --- Same mechanical steps as +10 to 0**
All of the acquired points are a mean of 20 points normalized at -20



# ADC tests:
# Zero Offset measure

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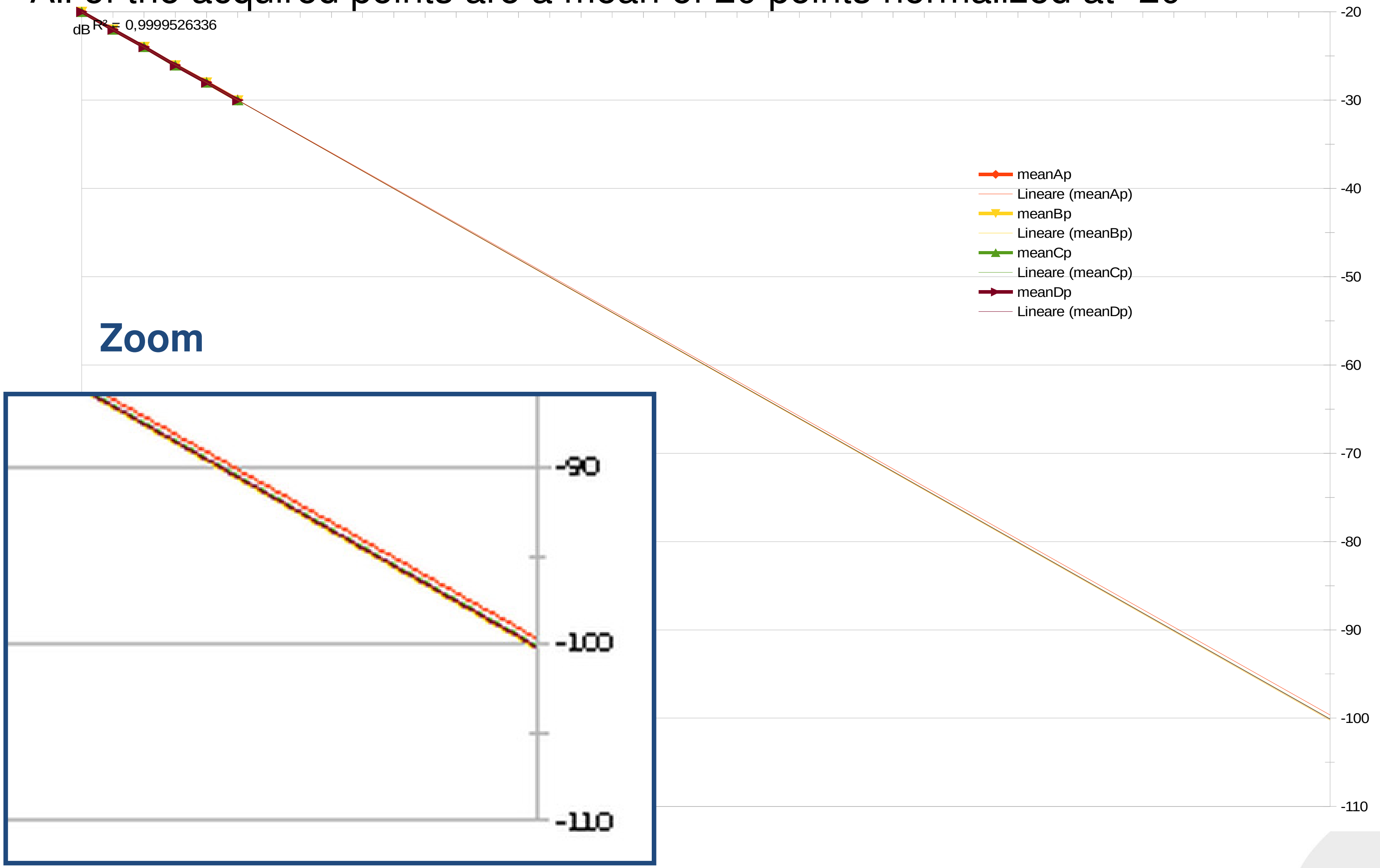
Pilot (503.123 MHz) From **-20 to -30 dBm --- Same mechanical steps as +10 to 0**
All of the acquired points are a mean of 20 points normalized at -20



# ADC tests:
# Zero Offset and integral nonlinearity

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The line fitting shows that the ADC integral linearity is **affected by the input level**.
The ADC integral linearity affects the ADC zero offset.
Then the position calculated is affected by ADC input level.

| 0 to -10 dBm, step-2, mean20 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **meanAc** | **meanBc** | **meanCc** | **meanDc** | **meanAp** | **meanBp** | **meanCp** | **meanDp** | **Xc** | **Yc** | **Xp** | **Yp** |
| 0,1894 | 0,1904 | 0,1898 | 0,1893 | 0,2049 | 0,2060 | 0,2054 | 0,2048 | -38,14 | 18,85 | -37,92 | 18,64 |
| 0,1508 | 0,1516 | 0,1511 | 0,1507 | 0,1630 | 0,1638 | 0,1633 | 0,1629 | -38,27 | 18,63 | -37,80 | 18,80 |
| 0,1209 | 0,1216 | 0,1212 | 0,1208 | 0,1307 | 0,1314 | 0,1310 | 0,1306 | -38,53 | 18,79 | -37,93 | 18,89 |
| 0,0954 | 0,0960 | 0,0956 | 0,0954 | 0,1031 | 0,1036 | 0,1033 | 0,1030 | -38,56 | 18,50 | -37,44 | 19,18 |
| 0,0764 | 0,0768 | 0,0766 | 0,0764 | 0,0828 | 0,0832 | 0,0829 | 0,0827 | -38,61 | 18,14 | -36,86 | 19,63 |
| 0,0607 | 0,0610 | 0,0608 | 0,0607 | 0,0656 | 0,0660 | 0,0658 | 0,0656 | -38,88 | 18,04 | -36,88 | 19,92 |
| | | | | | | | **RMS:** | **0,24** | **0,30** | **0,46** | **0,46** |

A possible solution is to use (also) the pilot tone amplitude to keep the ADC inputs levels constant when the carrier signal (from machine) is varying.

| SAME LEVEL (±27K pk-pk), 0 to -10 dBm carrier, step -2 ,mean 20, pil step3 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **meanAc** | **meanBc** | **meanCc** | **meanDc** | **meanAp** | **meanBp** | **meanCp** | **meanDp** | **Xc** | **Yc** | **Xp** | **Yp** |
| 0,1895 | 0,1905 | 0,1899 | 0,1894 | 0,2054 | 0,2064 | 0,2058 | 0,2052 | -38,10 | 18,85 | -37,92 | 18,65 |
| 0,1505 | 0,1513 | 0,1508 | 0,1504 | 0,2312 | 0,2324 | 0,2317 | 0,2311 | -38,09 | 18,84 | -37,67 | 18,82 |
| 0,1202 | 0,1208 | 0,1204 | 0,1201 | 0,2607 | 0,2620 | 0,2612 | 0,2605 | -37,99 | 18,84 | -37,70 | 18,76 |
| 0,0934 | 0,0939 | 0,0936 | 0,0934 | 0,2897 | 0,2912 | 0,2903 | 0,2895 | -38,03 | 18,65 | -37,77 | 18,70 |
| 0,0747 | 0,0751 | 0,0749 | 0,0747 | 0,3285 | 0,3303 | 0,3292 | 0,3283 | -38,01 | 18,78 | -37,80 | 18,61 |
| 0,0590 | 0,0593 | 0,0592 | 0,0590 | 0,3672 | 0,3692 | 0,3680 | 0,3670 | -38,10 | 19,23 | -37,84 | 18,61 |
| | | | | | | | **RMS:** | **0,04** | **0,18** | **0,08** | **0,08** |

# ADC tests: Conclusions

- Direct RF undersampling with high speed ADC is actually the best cost/benefits solution to acquire the signals for a BPM system.
- But the high speed ADC like LTC 2209 have some intrinsic behaviours that have to be considered. These behaviours may influence the beam current dependence.
- Some techniques and some strategies in Automatic Gain Control and/or in the pilot tone compensation are required to reduce at the minimum possible the effects due to integral non-linearity of the ADCs.
- The “modular approach” for a BPM system can help to better understand the behaviours of each part.

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# Thank you!


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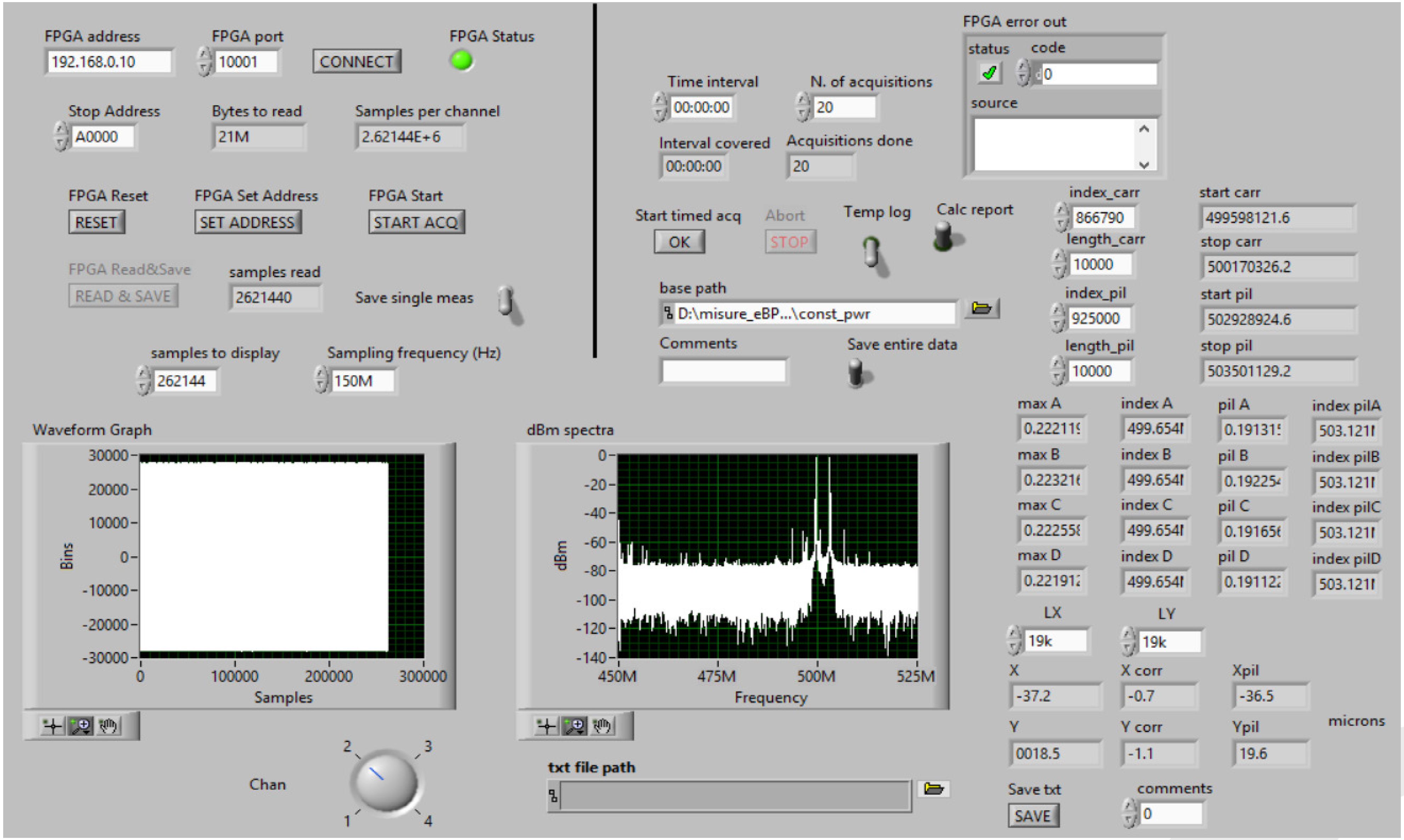
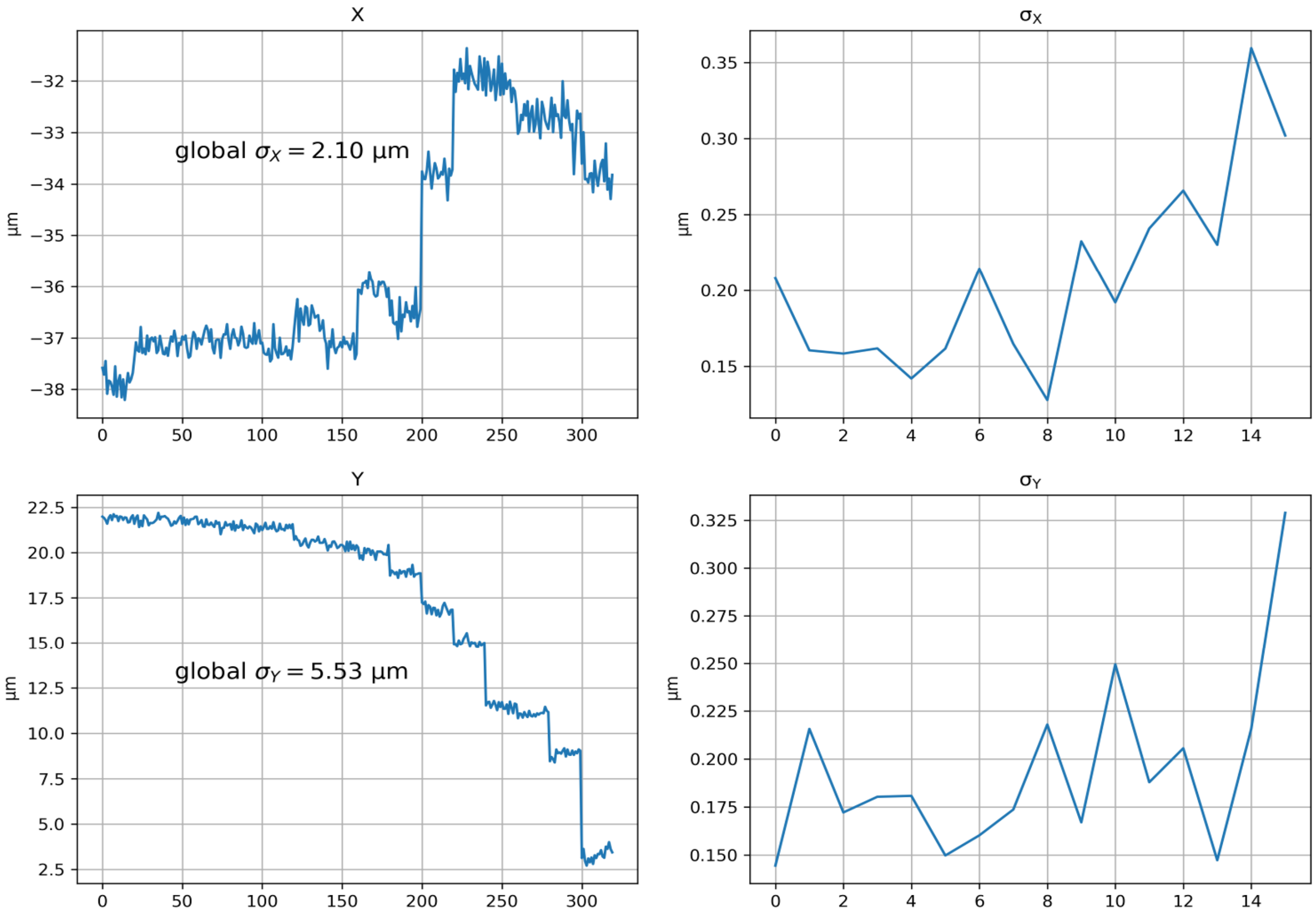
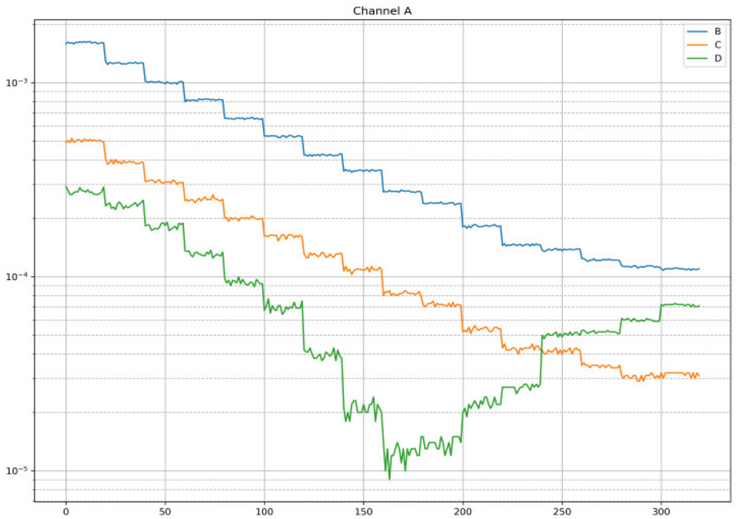


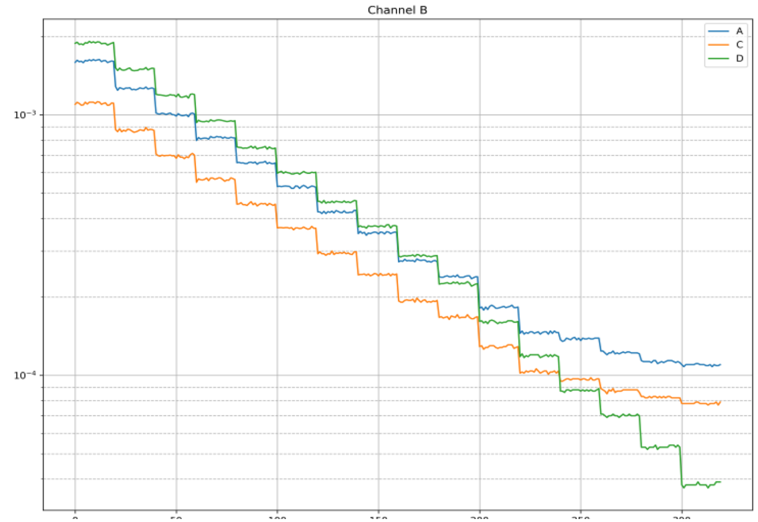
# Single Tone -6 to -36

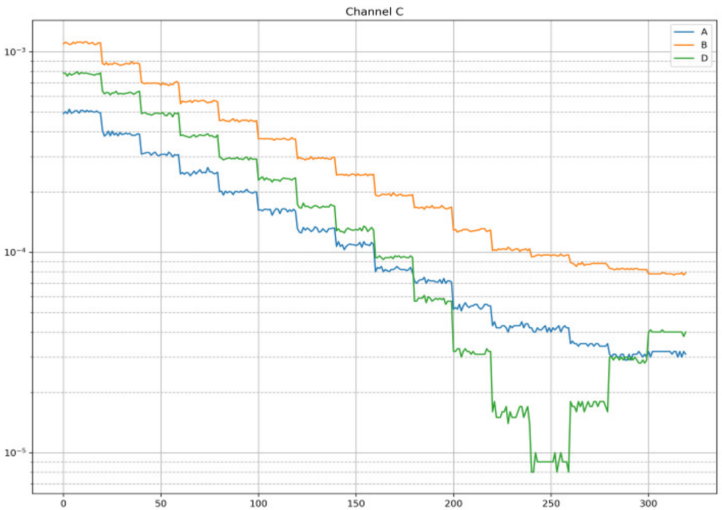
Carrier position: 499 MHz from -6 dBm to -36 dBm

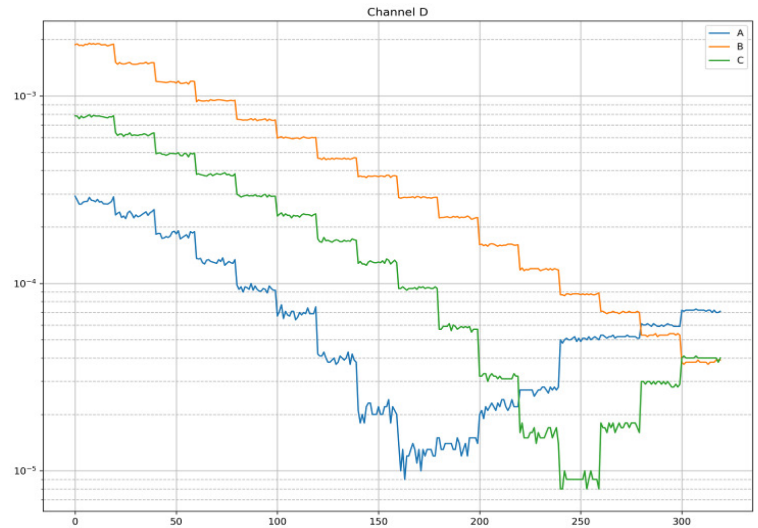


# Single Tone -6 to -36



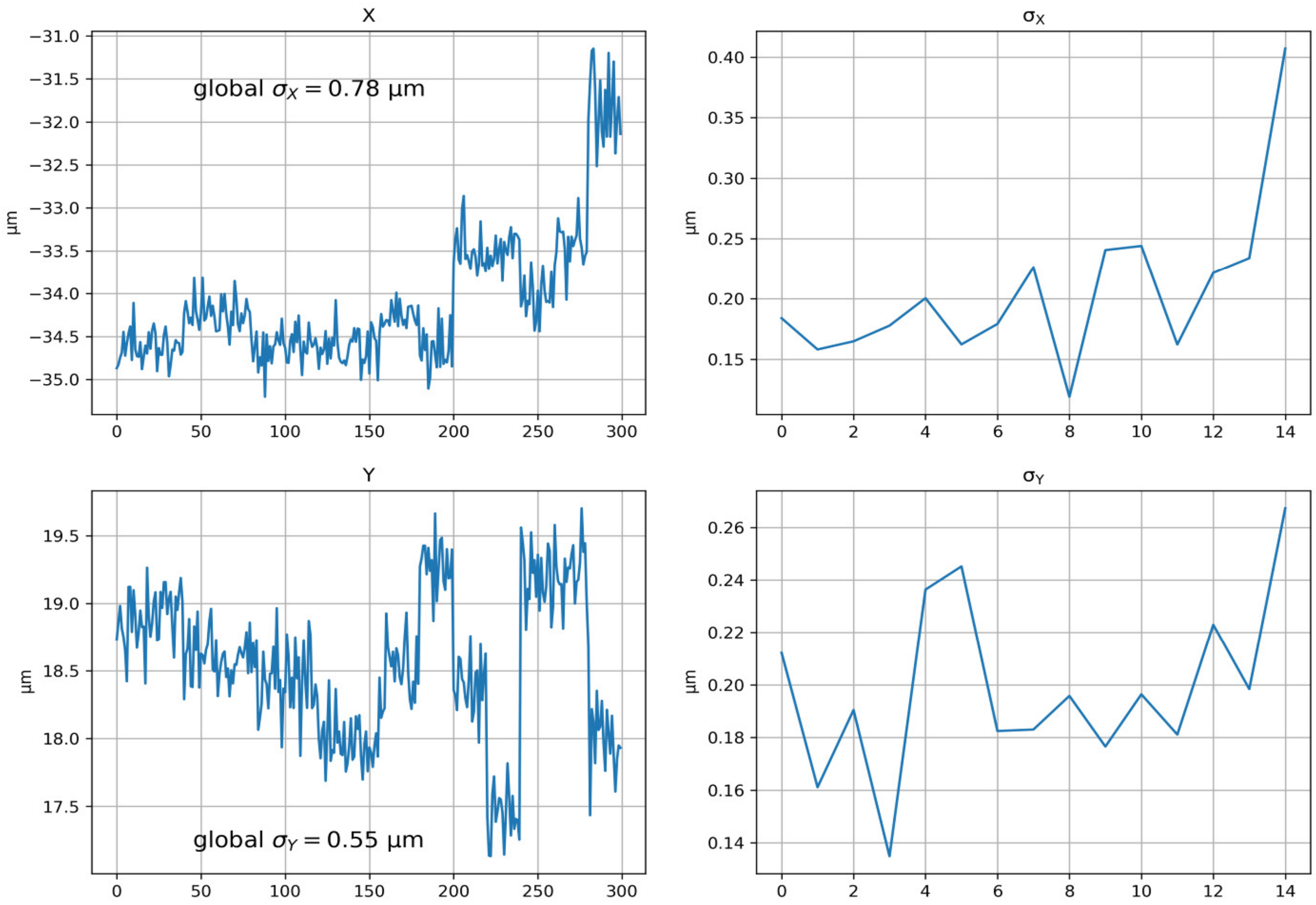



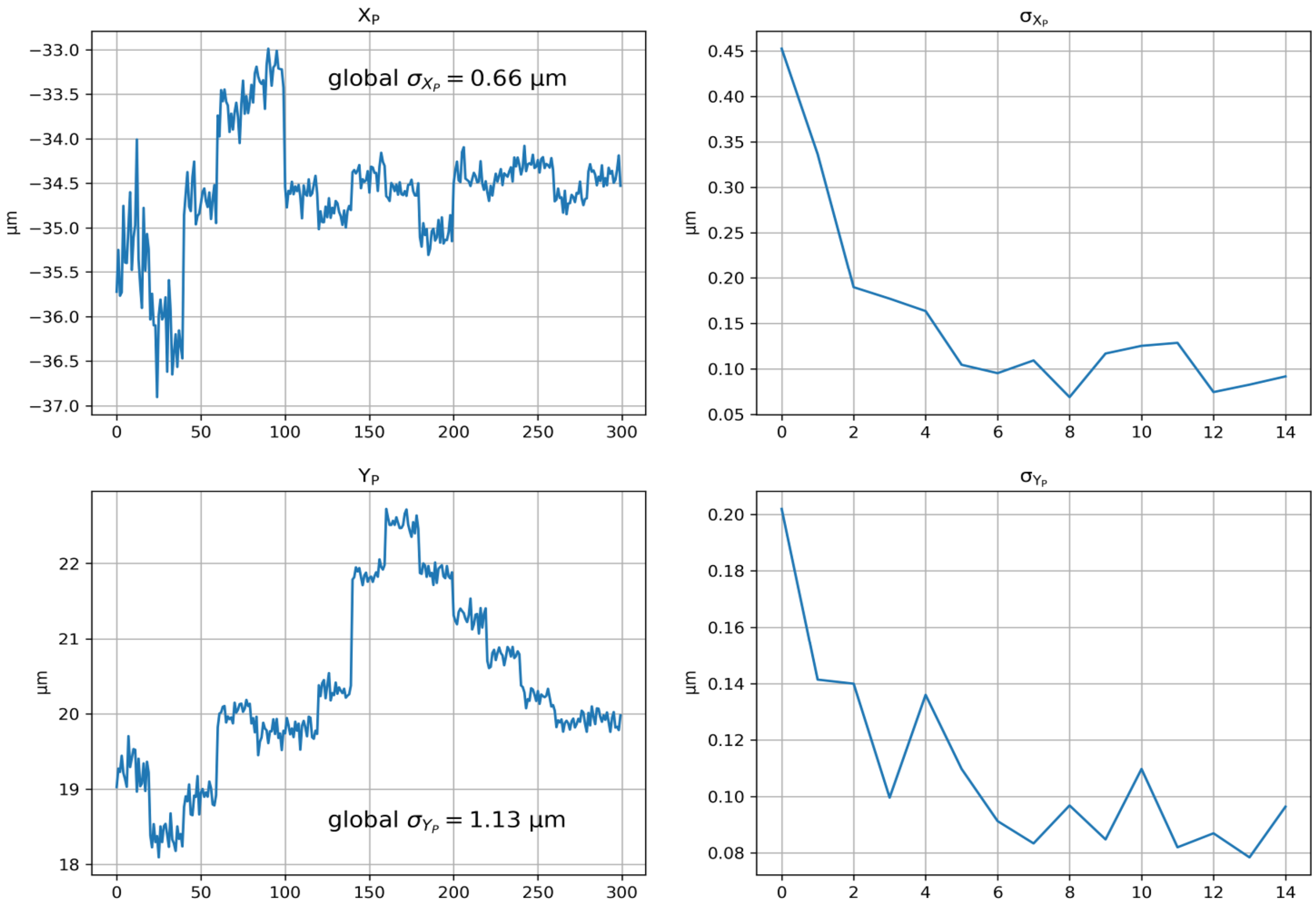
# Dual Tone Constant Power -6 to -36

Carrier position: 499 MHz from -2 dBm to -30 dBm



# Dual Tone Constant Power -6 to -36

Pilot position: 503 MHz from -30 dBm to -2 dBm



# Dual Tone Constant Power -6 to -36