BPM electronics

BI Forum

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BPM Electronics

- Summary
  - BPM electronics specifications
  - BPM electronics schedule
  - Electronics design
    - First Version – Measurements and results
      - Block Diagram
      - Electronics evaluation
      - Phase and position measurements
    - Second Version
      - Redesign
      - Modifications

BPM specifications

- Some specifications (the most critical)
- Translate system numbers to electronics specifications (SNR, Linearity, temperature dependence, etc.)

ID	Name	Value	Comments
DTL.PBI-50	Beam phase measurement: bandwidth	1 MHz	Commissioning, Operations
DTL.PBI-35	Beam position measurement (non-invasive): resolution	20 µm	Commissioning, Operations, nominal beam
DTL.PBI-34	Beam position measurement (non-invasive): accuracy	+-100 µm	Total accuracy error (alignment + electronics). Review from 200 um.
DTL.PBI-45	Beam phase measurement: accuracy	1 °	Difficult, since in time domain means 8 ps and means cable length matched to 2 mm. Measurement accuracy including all sources of measurement errors . Specification valid for 352 MHz
DTL.PBI-46	Beam phase measurement: resolution	0.2 °	@ 352 MHz
SPK.PBI-13	Beam position measurement: resolution for 6.3 mA beam	200 µm	

Resolution: RMS value determined for the system /electronics bandwidth

BPM electronics Specifications

Measured performance of the ESS-SLAC-RTMv1 electronics[1].

Parameter	Value	Comments
Max Input Power	20 dBm	For max attenuation condition and operating bellow 0.1 dB compression point on RF devices
Max RF Chain Gain	27 dB	0 dB on attenuators
Max RF chain attenuation	35 dB	31 dB on attenuators
Center Frequency	352 MHz	Configurable center frequency (300 MHz – 1 GHz)
Bandwidth (3 dB)	11 MHz	
Bandwidth (60 dB)	35 MHz	
Crosstalk	**~50 dB**	Measured for different attenuators value @ 352 MHz
SNR	**~ 41 dBc**	Measured for 16 dB attenuators and 5 dBm input power @ 352 MHz input.
SFDR	~ 57 dBc	Measured for 16 dB attenuators and 5 dBm input power @ 352 MHz input, 22 MHz IF
Nonlinearity	0.1 dB	Over 80 dB input range (-80 dBm to 0 dBm)
Noise Figure	10 dB	Estimated for 5 dB attenuators
Temperature Dependence	TBD	
MTBF	TBD	
Dynamic Range	TBD	Depends on system specifications

BPM electronics Specifications:

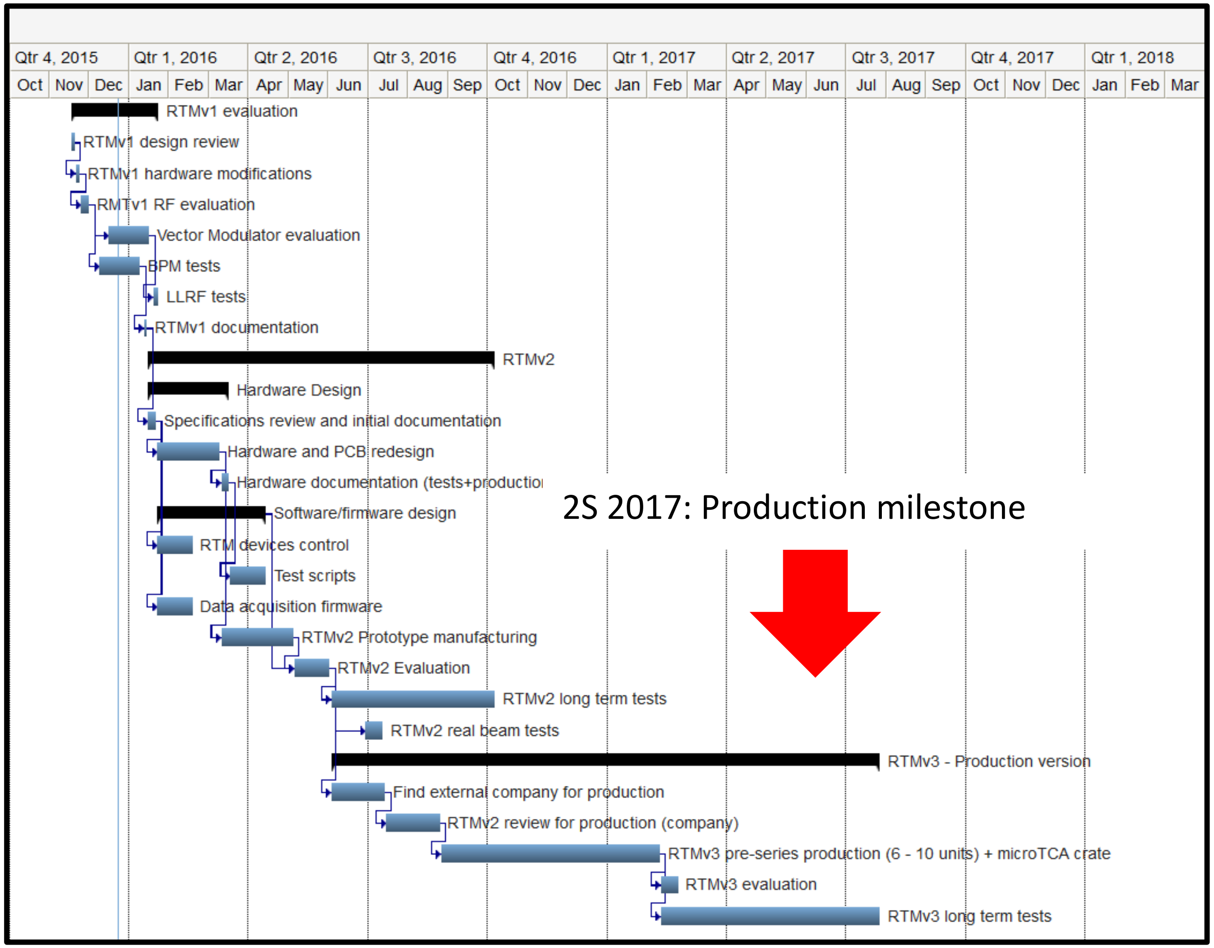
Parameter	Value
Max Input Power	20 dBm
Center Frequency	352 MHz
Bandwidth (3 dB)	1 MHz
Bandwidth (60 dB)	35 MHz
Crosstalk	<-70 dB
SNR	~ 70 dB
Input Power range	-60 to 5 dBm
SFDR	xx dBc
Nonlinearity	xx dB
Noise Figure	10 dB

- SNR specifications will be reviewed
- For BPM application, the SFDR depends on the interest bandwidth

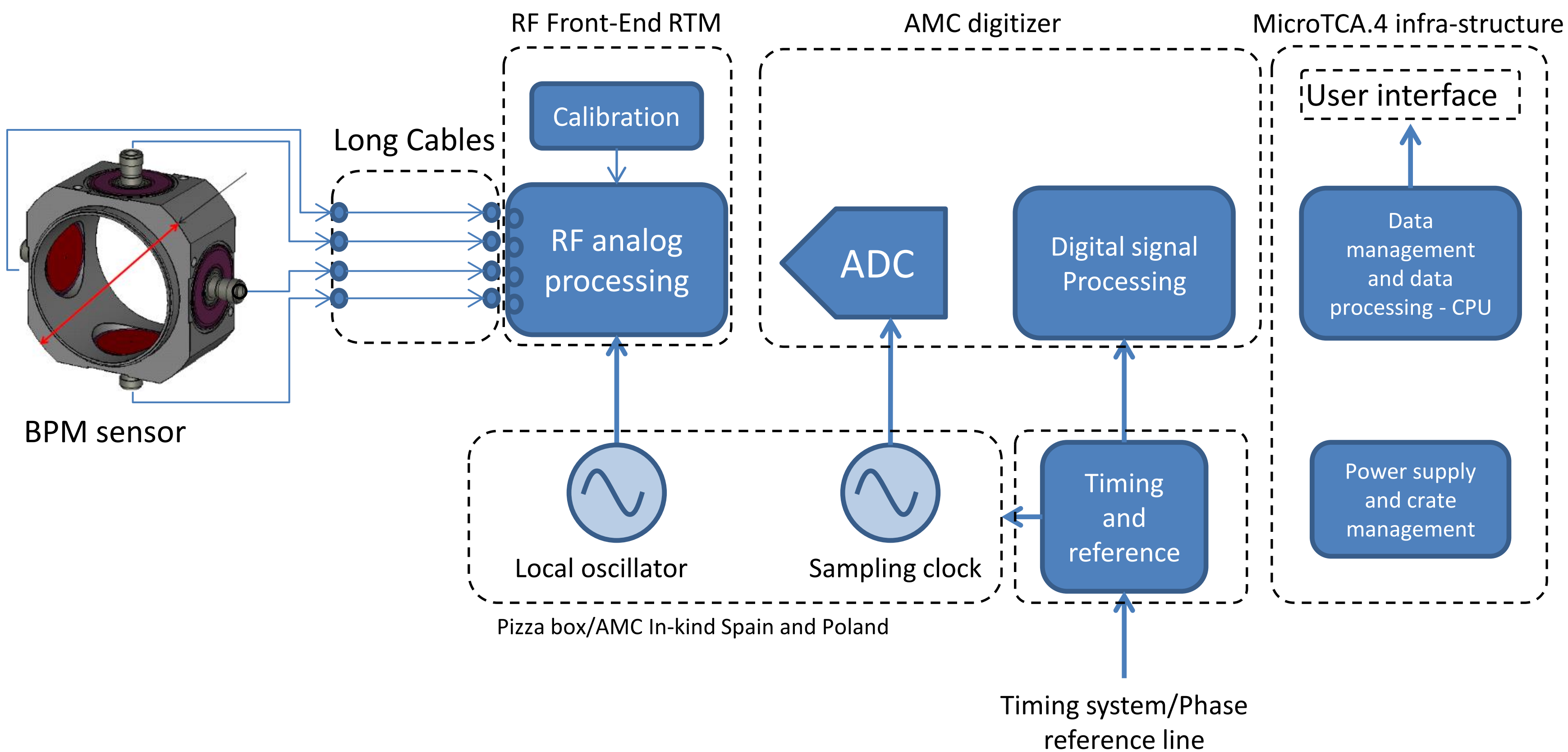
[1] When not specified, the performance is measured for the standard configuration of attenuators (10 dB). Temperature of operation: -20 ºC to 50 ºC.
[2] Nonlinearity is defined as Pout vs Pin deviation from the linear fit of the RF chain linear response for a specific attenuators configuration.

BPM electronics Schedule

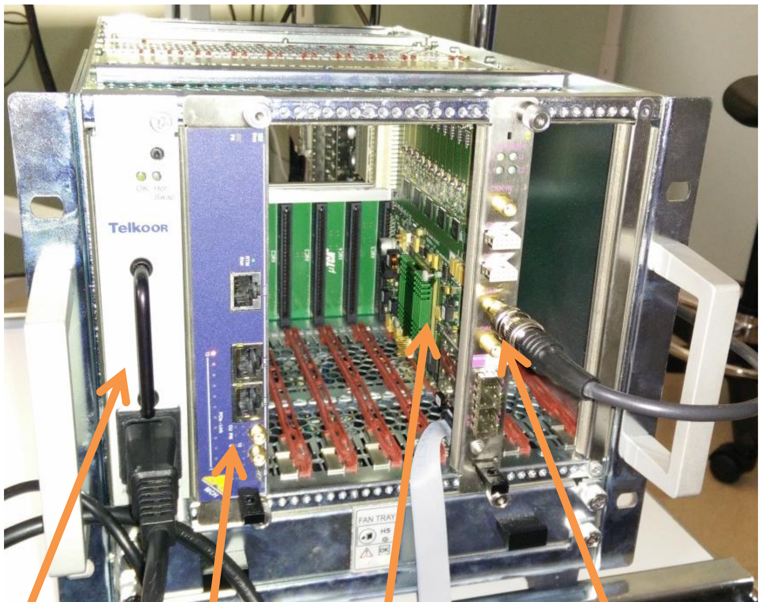
- Schedule
  - Production expected for 2s 2017



BPM system diagram



BPM electronics – microTCA.4 prototype



Power supply unit

microTCA.4 MCH

Struck SIS8300-L2 board

Input clock signals

BPM RTM

Local Oscillator

Input signals

microTCA.4 CPU

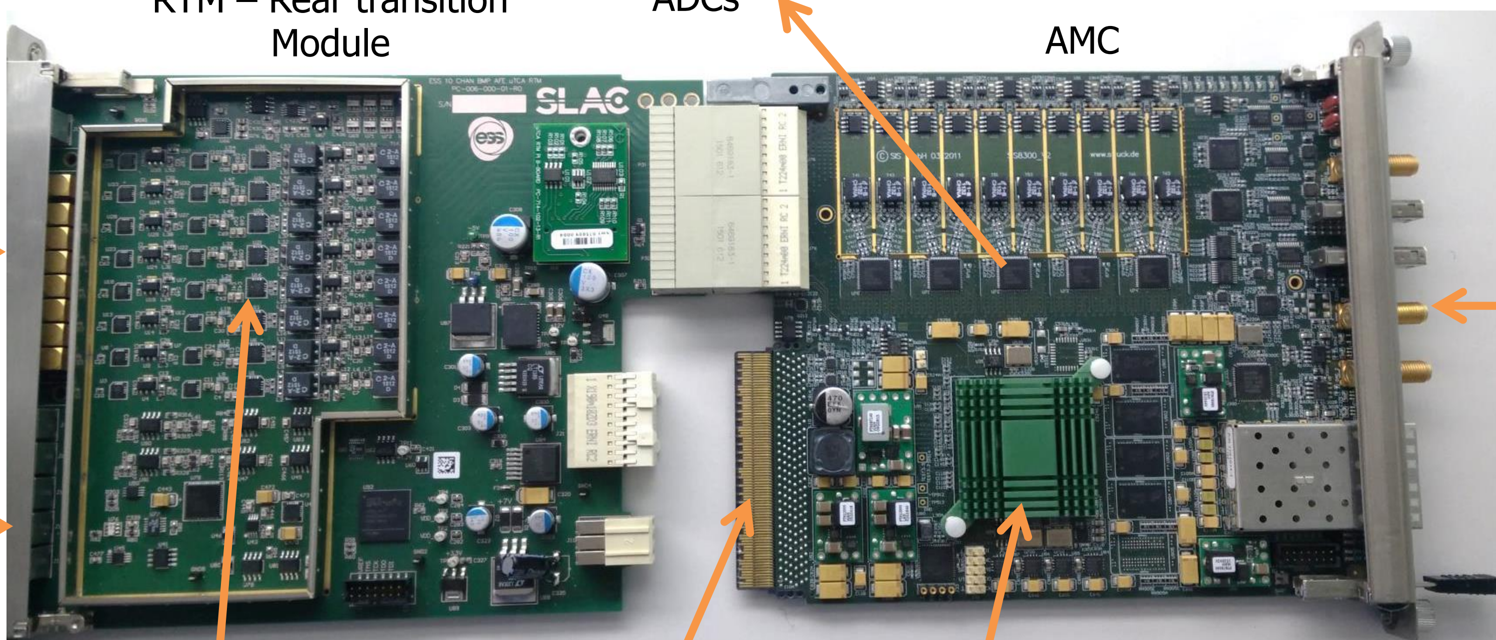
BPM electronics - hardware

Signal inputs

RTM – Rear transition Module

High Speed ADCs

AMC



Local oscillator input

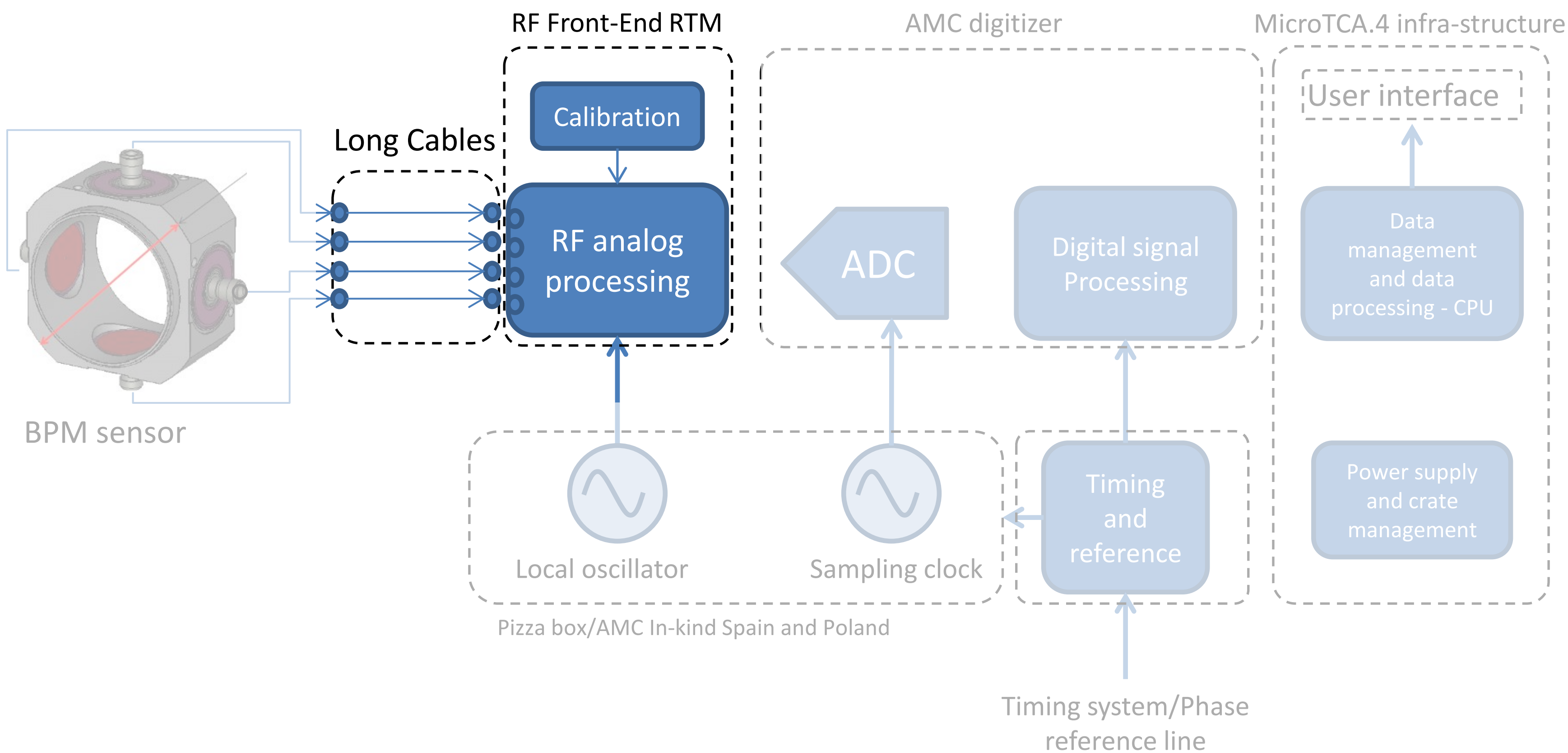
8x RF Channels

PCIe interface: Data available on the CPU

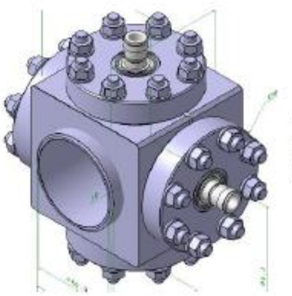
FPGA: Signal processing

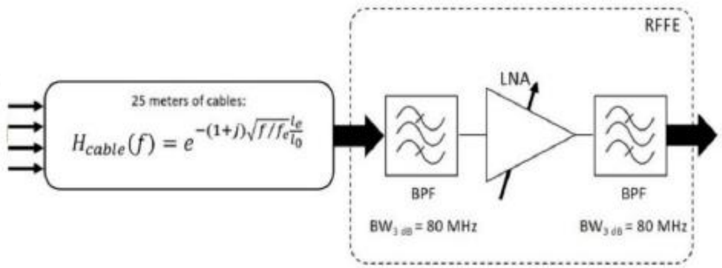
ADC Clock input

BPM system diagram

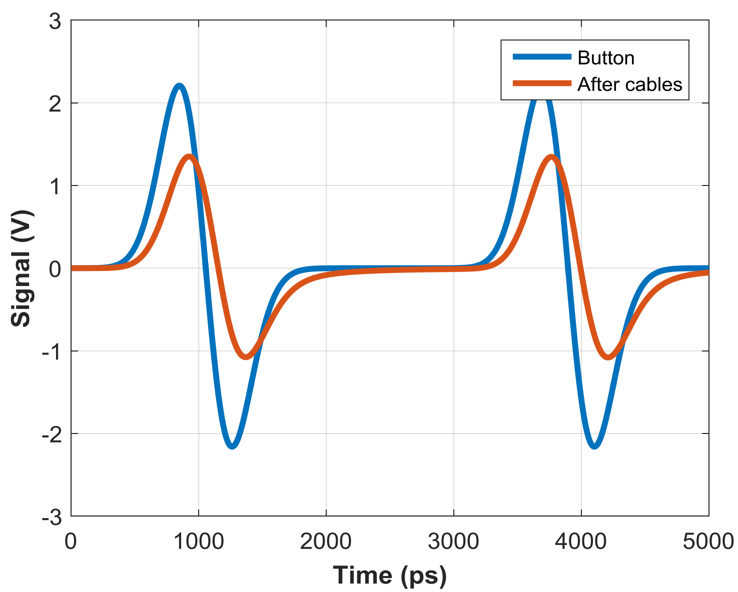


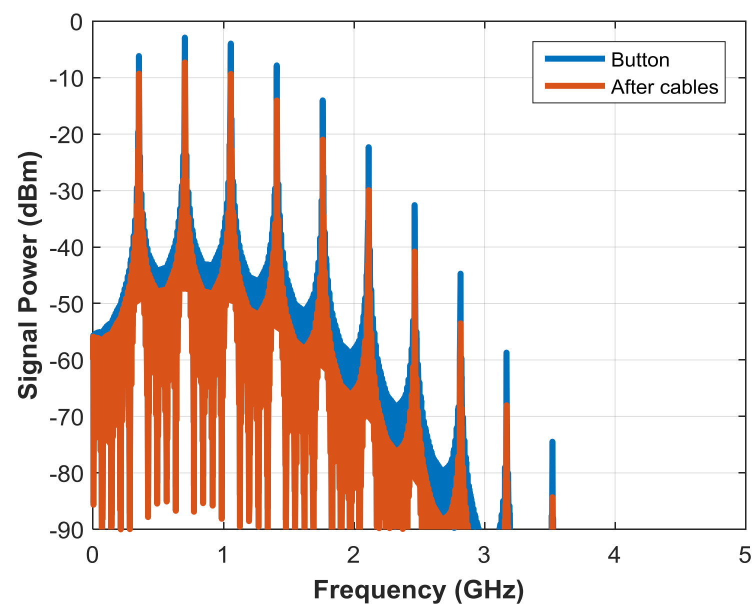
BPM Electronics





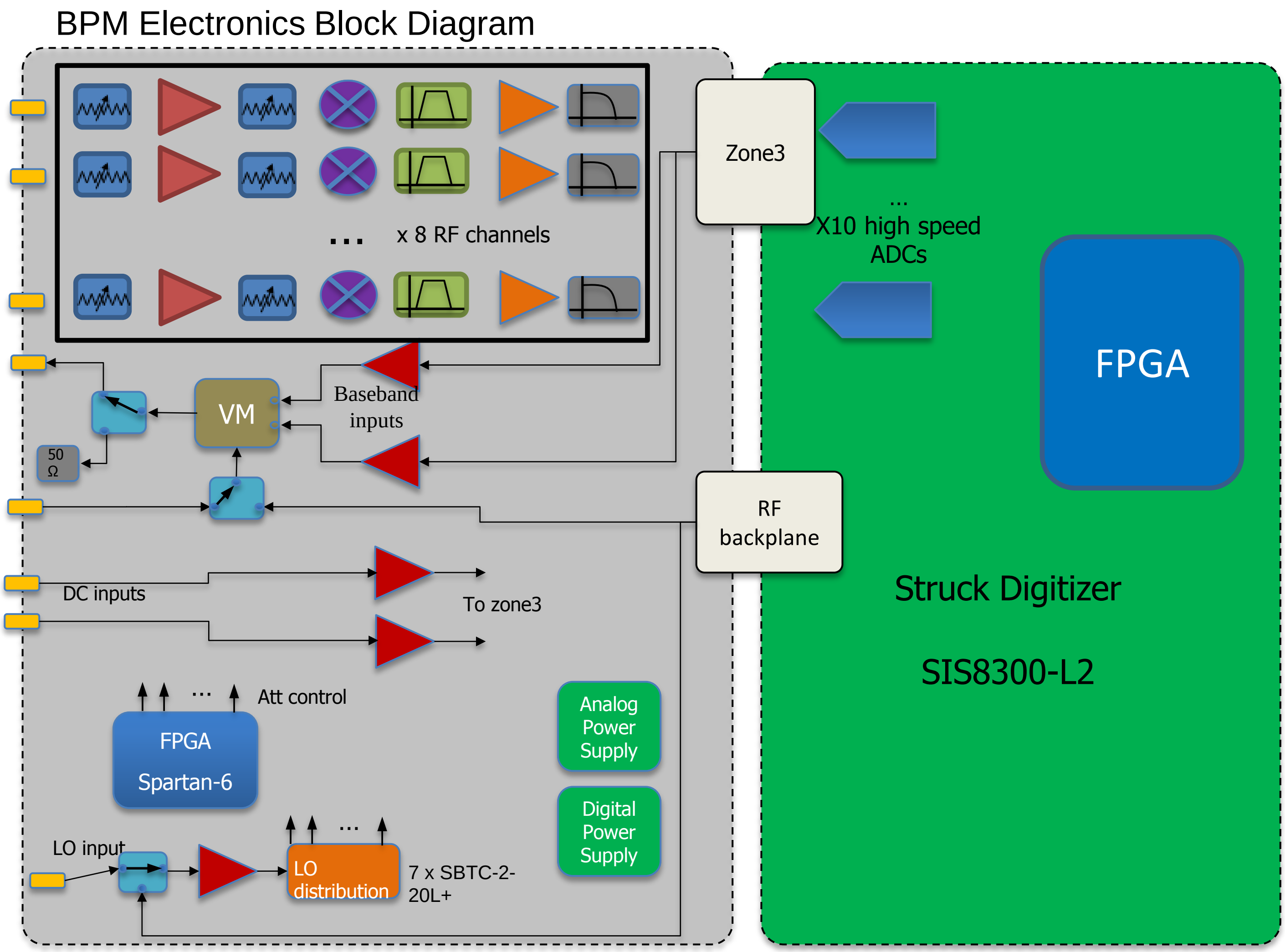
$$V_s(\omega) = \left(\frac{1}{C_b + \frac{1}{j\omega Z_0}} \frac{C_{cov} d_s}{\beta c} \right) e^{-(1+j)\frac{L_c}{L_0}\sqrt{f/fe}} I_{beam}(\omega)$$



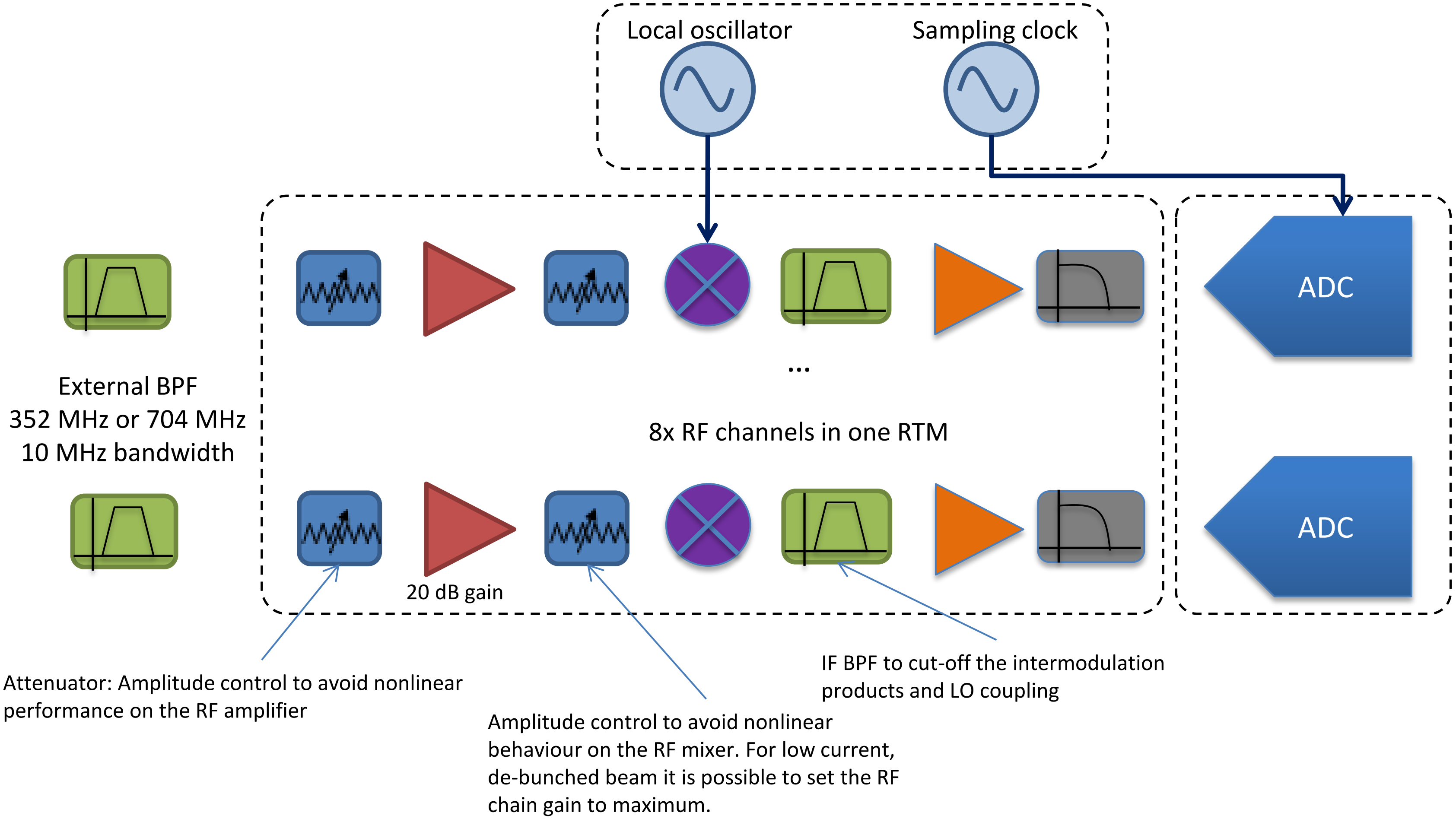


Charge = Q = 62.5 mA/352 MHz ≈ 178 pC

BPM electronics - hardware

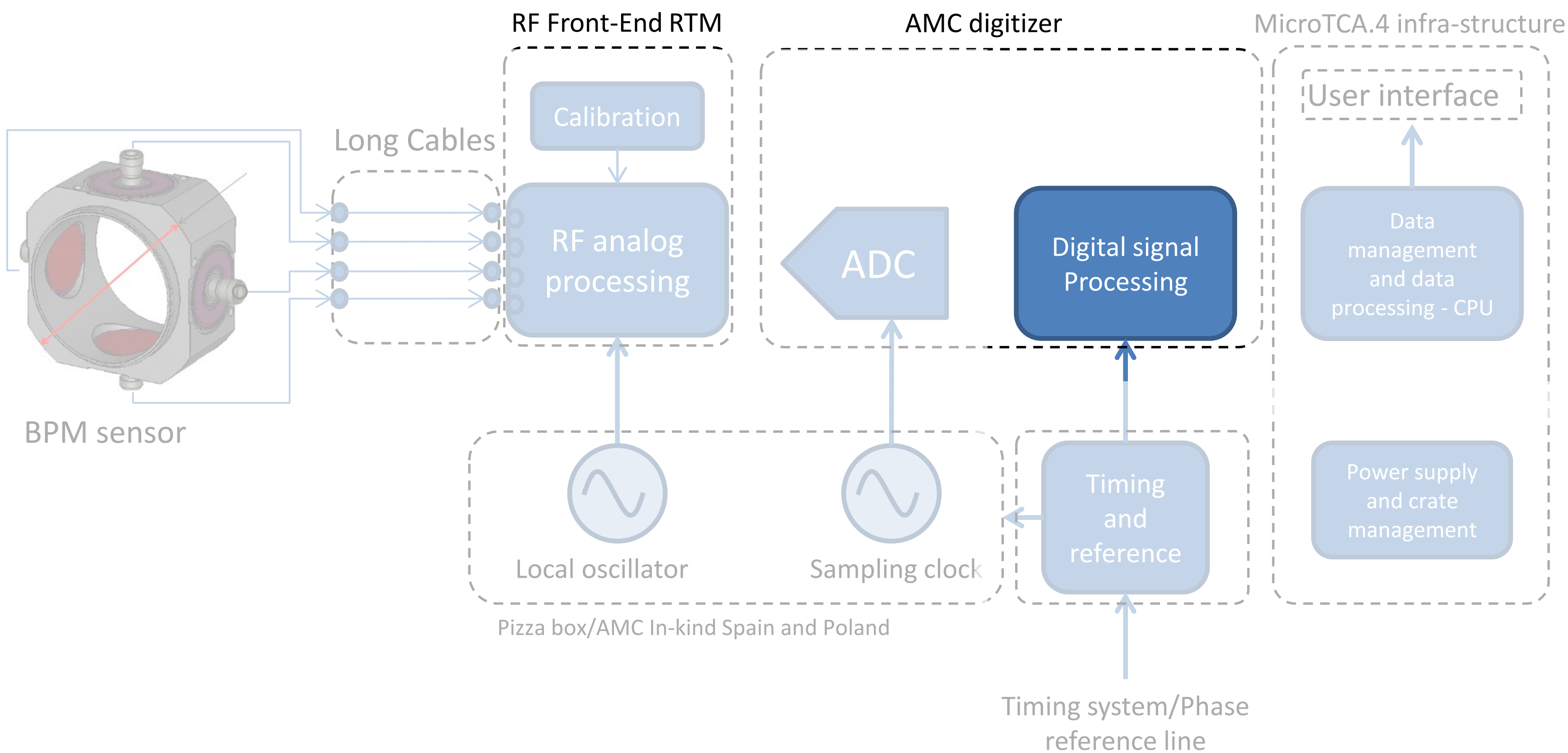


BPM electronics



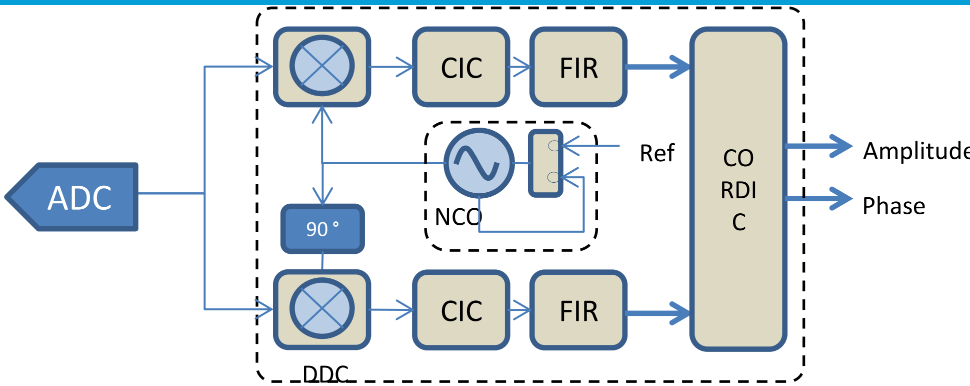
- There is no calibration scheme on the RTM_v1
- There are no Reference Line sampling on the RTM_v1
- The RF chain need modifications to improve the filtering

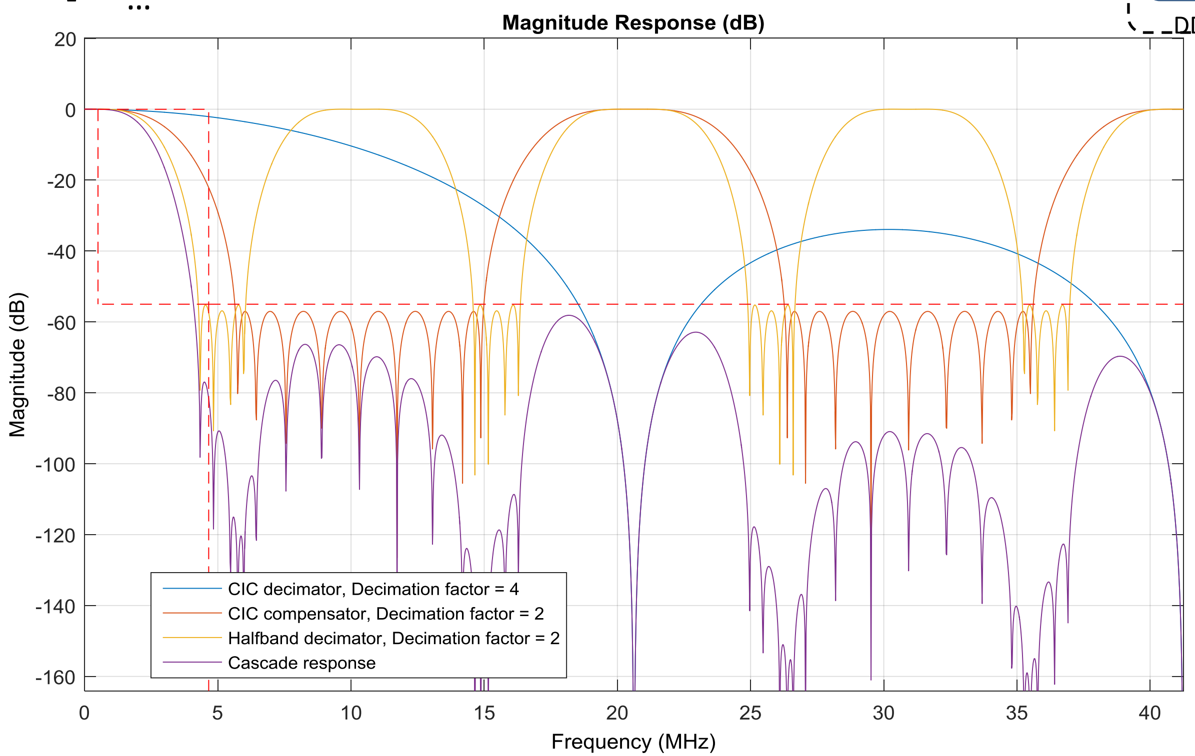
BPM system diagram



BPM Electronics

Specifications:
- Filter bandwidth (1 MHz)
- Passband ripple (0.04 dB – to be determined)
- Stopband attenuation (55 dB)
- Latency (-)
- Number of bits used for the NCO
- …





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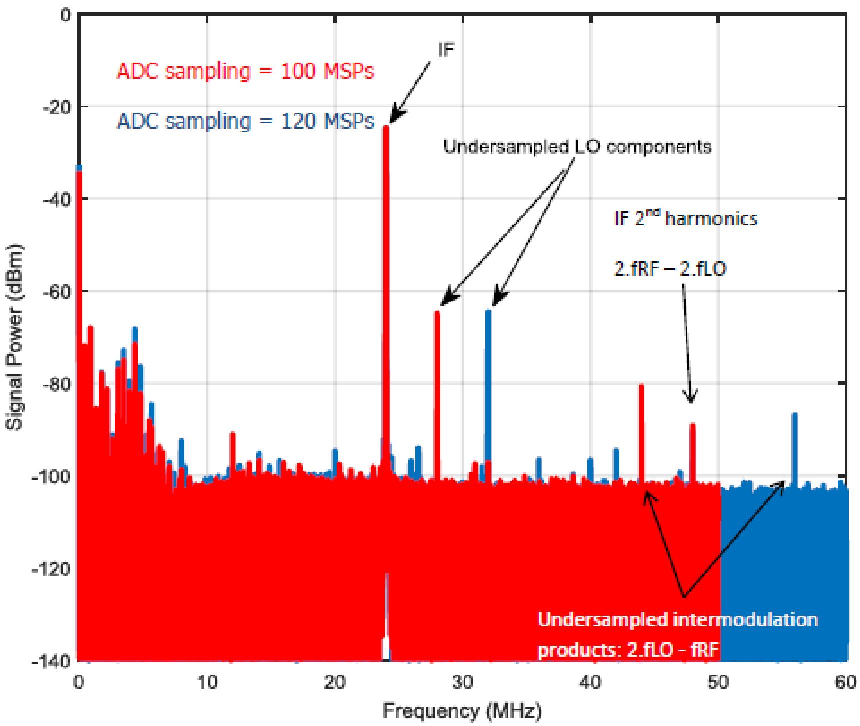
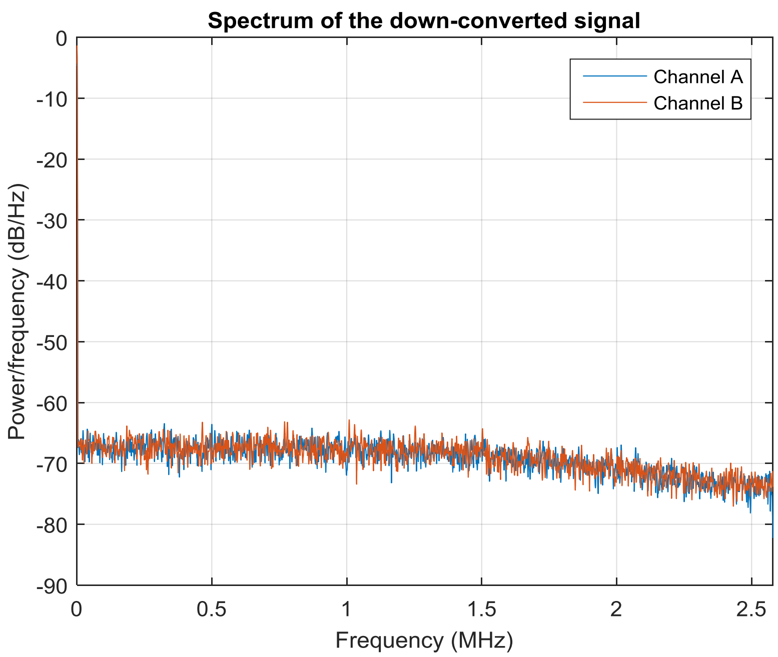
RAW data



Digital Downconverted signal



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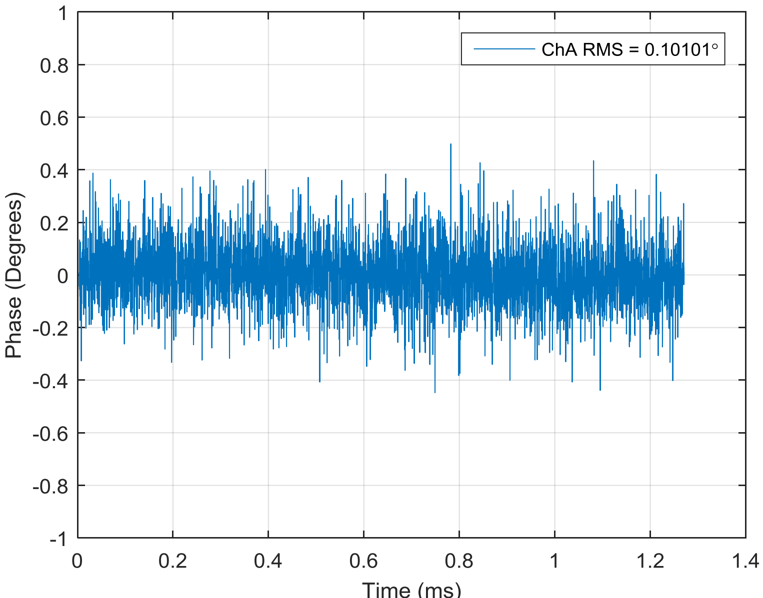
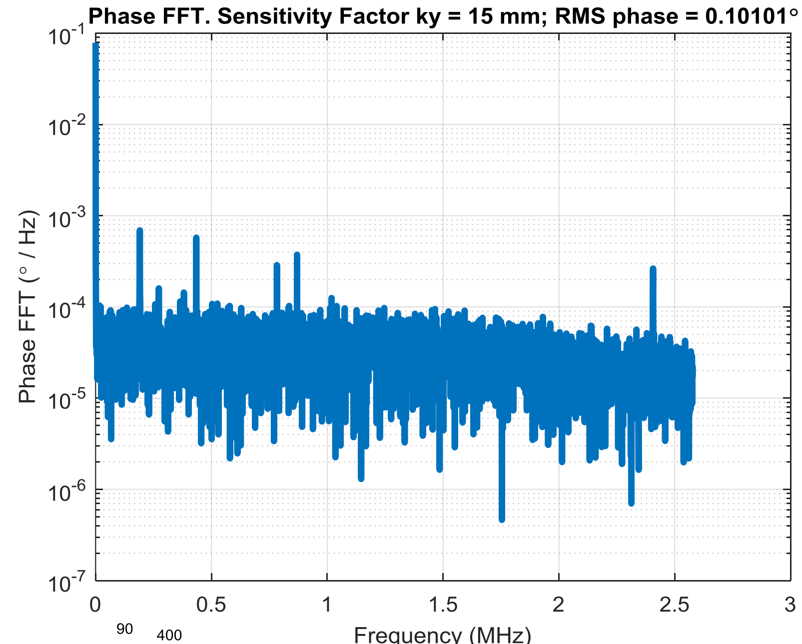
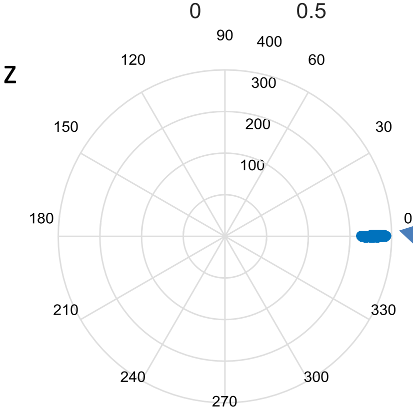




Input Power = 0 dBm

Fsampling = 82.5 MHz; LO = 330 MHz; RF = 352 MHz



Phase and position

$$f_{IF} = f_{RF} - f_{LO} = \frac{M}{N} f_{sampl}$$

$$\frac{M}{N} = 4/15$$

Non-IQ Sampling with a factor of 4/15

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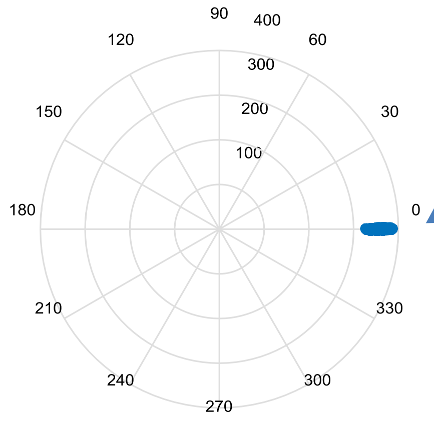
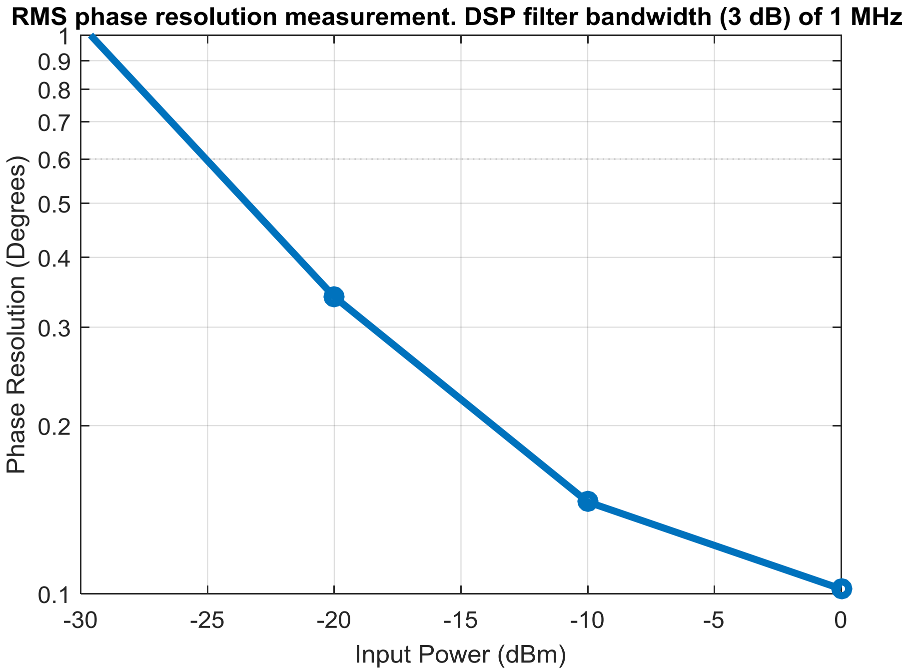


Phase and position for each pulse



- Resolution is mainly function of:
  - Temperature and humidity
  - Flicker noise
  - LO Phase noise
  - Sampling clock Phase noise
  - EMI, etc.
- It can be defined as function of the interest bandwidth:
  - 14 Hz – 1 MHz bandwidth
  - Long term drifts (1 sec - 1 hour → ~0.001 Hz – 1 Hz)

Resolution: RMS value determined for the system bandwidth and during one pulse

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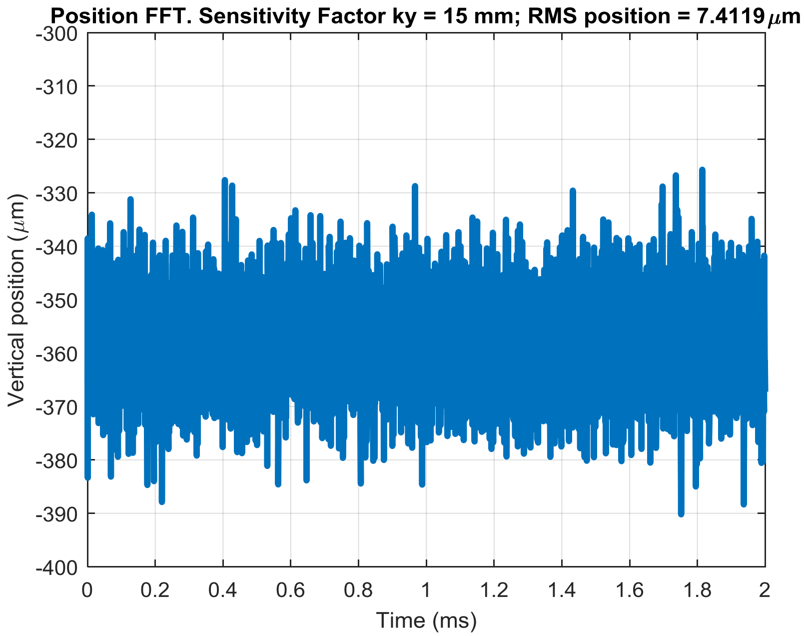
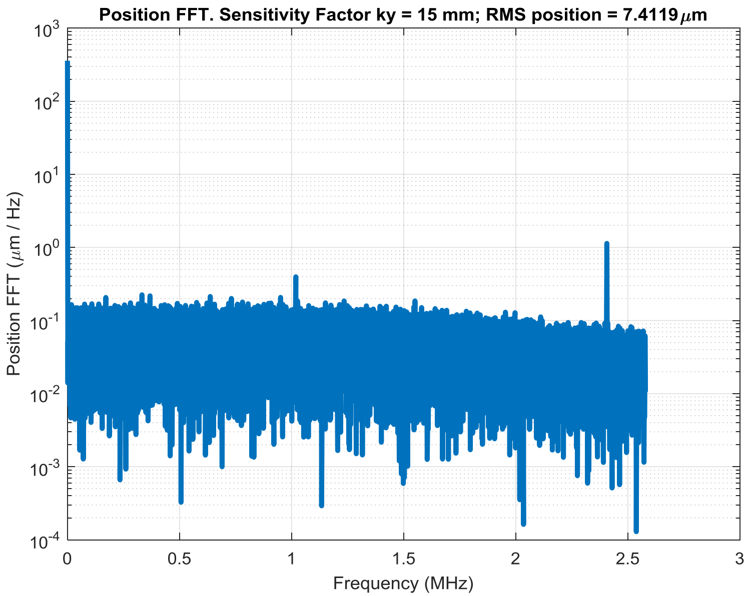


- Beam offset due to bench setup: RF splitters and non-matched cables introduce offset error (accuracy error)



- DSP filter has 1 MHz bandwidth
- DSP filter characteristics can be changed during operation
- Analog filter bandwidth limited to 10 MHz

$$f_{IF} = f_{RF} - f_{LO} = \frac{M}{N} f_{sampl}$$

$$\frac{M}{N} = 4/15$$

Non-IQ Sampling with a factor of 4/15

Input Power = 0 dBm

Fsampling = 82.5 MHz; LO = 330 MHz; RF = 352 MHz

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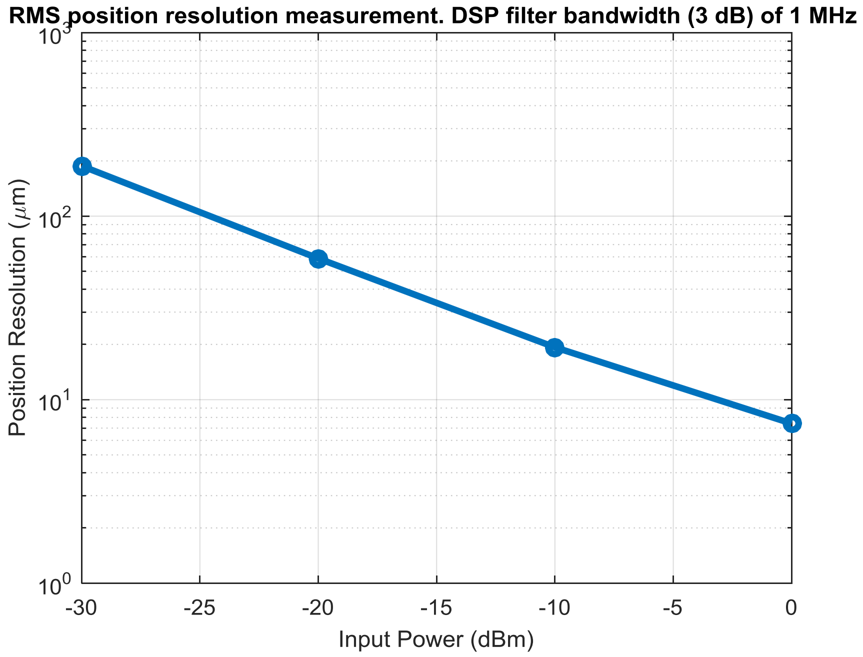
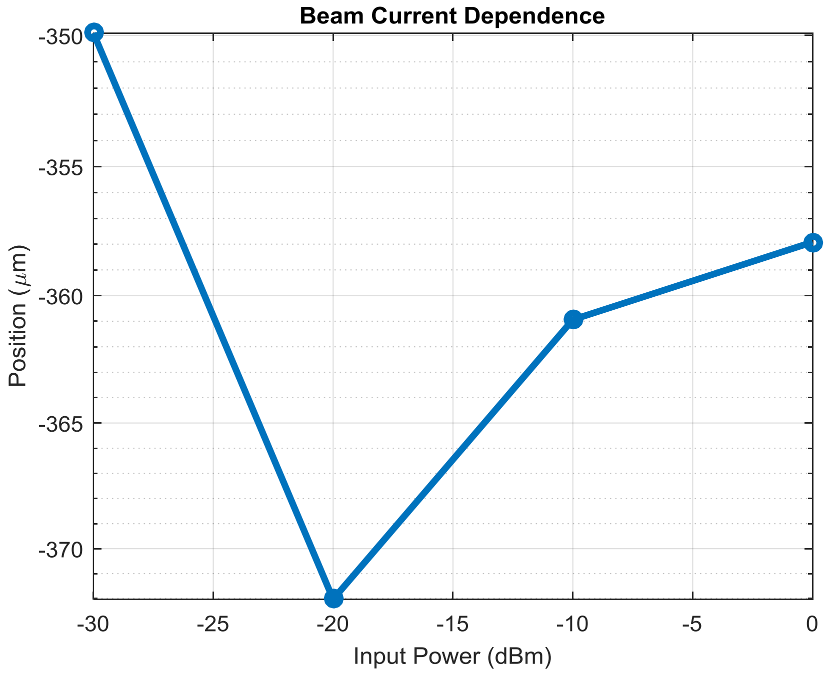


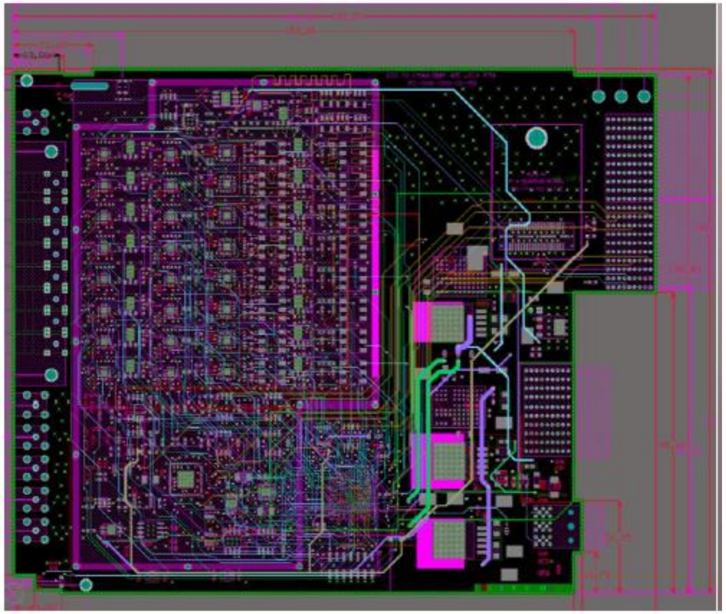


- The resolution was measured for specific attenuation on the RFFE

- Inaccuracy as function of the beam current

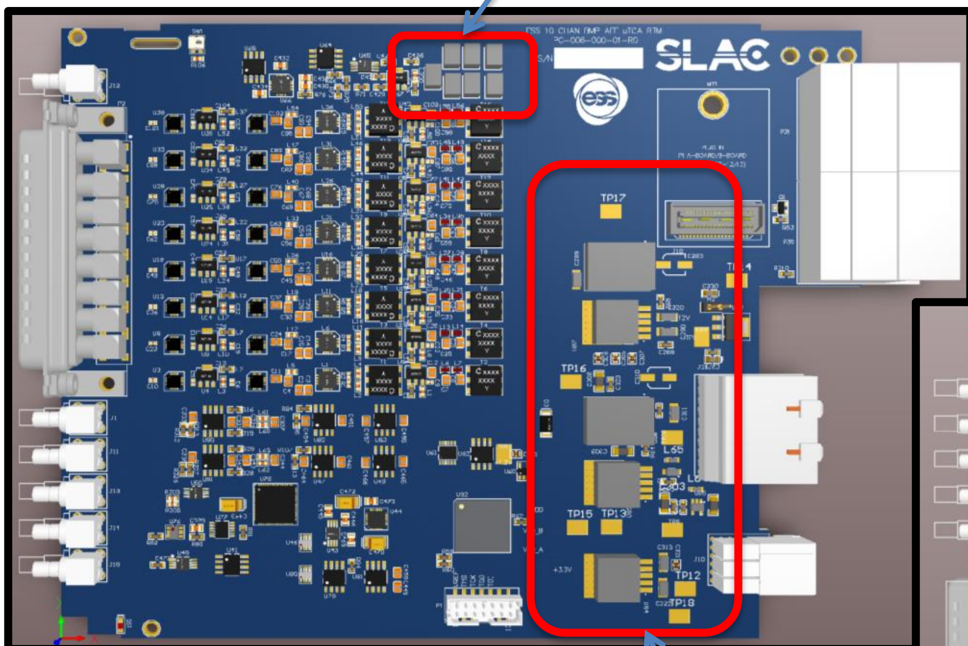
BPM Electronics – RTMv2

Issue	status	Description
Include another DC-DC converter for the 3V3 branch.	fixed	Using Linear regulators dissipates more than 30W on the board
Use the LTM8033 DC-DC converter for the 3V3 and 5V branches	fixed	Power supply efficiency improved
Use Low Dropout voltage regulators LT1764	fixed	Power supply efficiency and reduce power consumption
Use the voltage converter LT1931A to generate the negative voltage needed	fixed	The current solution is big and poor in terms of EMI
Modify the Vector Modulator, including reference voltages and others.	fixed	The design must be corrected
Include one voltage regulator for the FPGA. Use the LT1763 if possible	fixed	Improve switching noise on the supply nets
Modify the mechanical guide on the back connector to satisfy the RTM standard requirements	fixed	The part number is not correct
Change the power splitters for higher bandwidth ones (Mini-circuits SBTC-2-10+)	fixed	Increase the LO distribution scheme bandwidth
Insert pull-up resistors on the I2C lines	fixed	
Fix errors on the Altium schematic compilation	fixed	
Change the ATC capacitors	fixed	Changed for RF capacitors that can be found in stock at distributors
Match LO traces length	fixed	Match in phase the traces length for the LO distribution signals
Fix errors on the Altium PCB layout compilation	fixed	
Change the TH test probe joints for SMT ones	fixed	Suggestion from the PCB manufacturer
PCB without fiducials and no panel border	-	Suggestion from the PCB manufacturer
Change the PAD in some devices. Use "via in pad"	fixed	Suggestion from the PCB manufacturer
Change the layout of U69-U76	fixed	Suggestion from the PCB manufacturer
Other modifications suggested by the manufacturer, including changing pads, and hole sizes	fixed	Suggestion from the PCB manufacturer

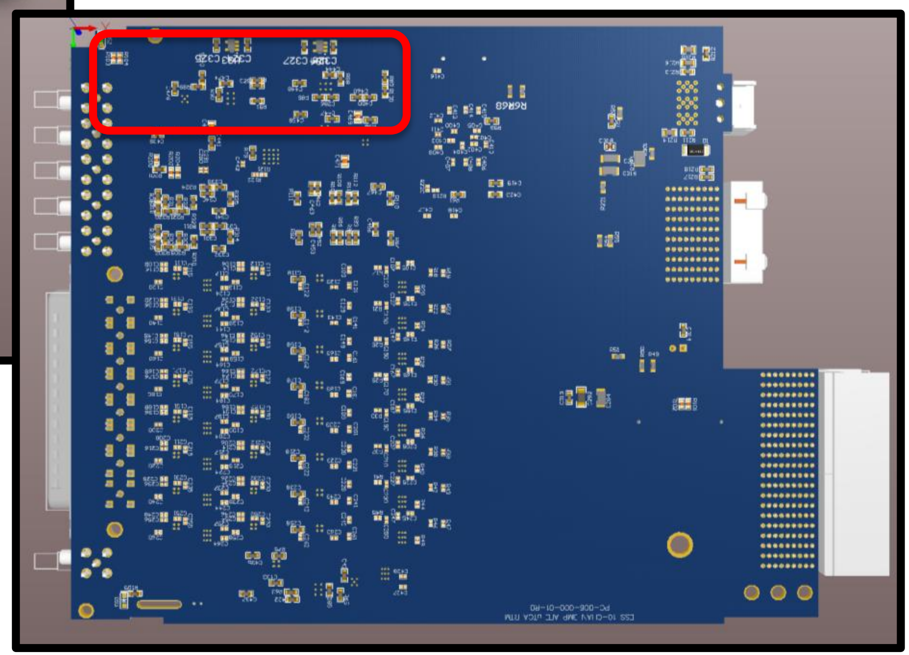


BPM Electronics – RTMv2

LO distribution scheme. Operation for 352 MHz and 704 MHz



Stable and low noise reference voltages

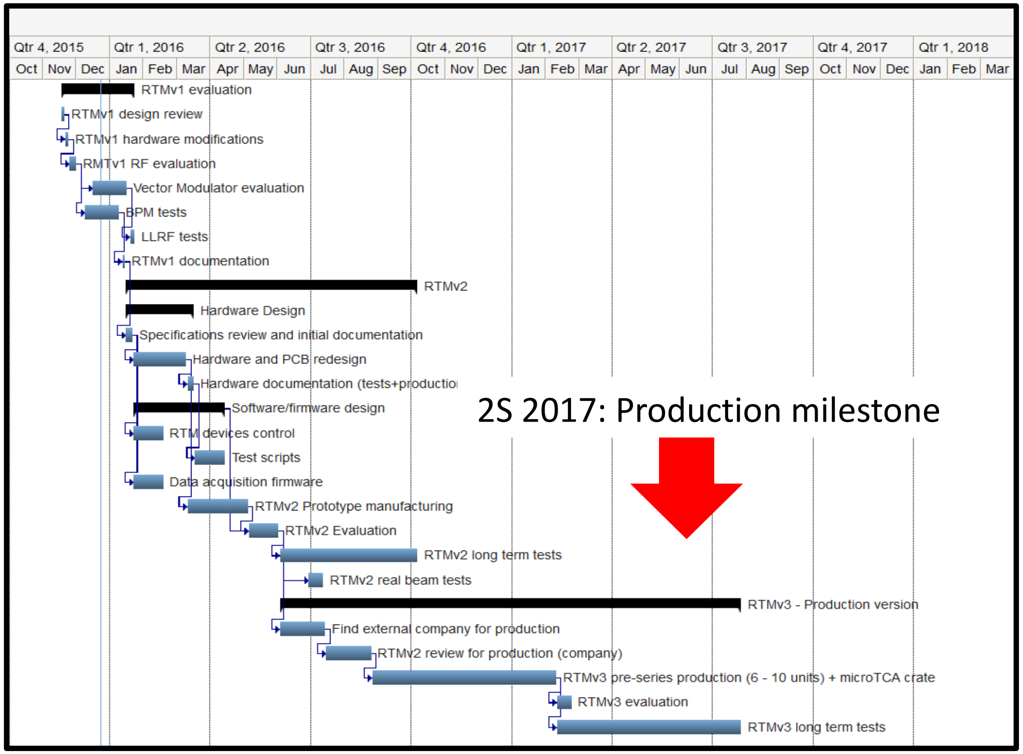


Power supply noise, efficiency and thermal dissipation improvements

- It is not possible to add more RF channels to this version due to power consumption limitations of the MicroTCA.4 standard (30 W)

BPM Electronics - Summary

- Results from the first prototype → In-house redesign finished. RTMv2 ready for manufacturing in some weeks.
- Future plans:
  - Internal review to determine the need for upgrades such as calibration schemes and phase reference line sampling.
  - Schedule and other activities according to slide 4



BPM Electronics - Summary

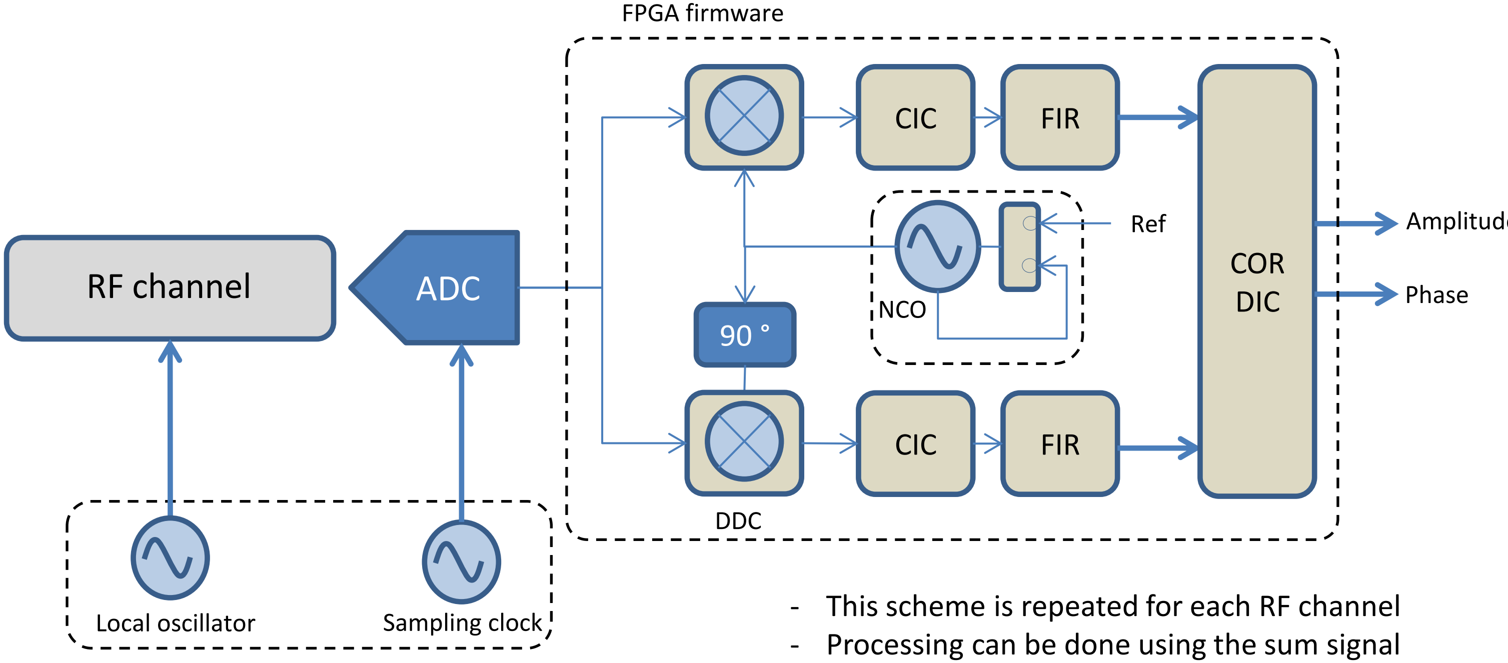
- Thanks!

BPM specifications

- Some specifications (the most critical)
- Translate system numbers to electronics specifications (SNR, Linearity, temperature dependence, etc.)

ID	Name	Text	Clarification	Unit	Min.	Norm.	Max.	Phase	TBD
MEBT.PBI-60	Transverse beam position measurement: accuracy	The beam position with respect to the beam theoritical axis shall be measured with an accuracy of better than ± 200 um averaged over the beam pulse*	* This gives the total error budget including alignment of the monitor axis with respect to the theoritical beam axis whose position is given by the general ESS coordinate system and error of the measurement with respect to the monitor axis	micro-meter	-200		200	Commissioning, start-up, operations	
DTL.PBI-50	Beam phase measurement: bandwidth	The beam phase measurement system shall have a bandwidth of at least 1 MHz		MHz				Commissioning, Operations	
DTL.PBI-35	Beam position measurement (non-invasive): resolution	The position of the beam centroid shall be measured with a resolution of better than 0.05 mm		mm			0,05	Commissioning, Operations	20 µm
DTL.PBI-34	Beam position measurement (non-invasive): accuracy	The position of the beam centroid shall be measured with an accuracy of better than +/- 0.2 mm with respect to the theoretical beam axis, averaged over the beam pulse	This includes errors of fiducialization, errors on the electrical center and other errors	mm	-0,2		0,2	Commissioning, Operations	Maybe 0.1 mm!
DTL.PBI-45	Beam phase measurement: accuracy	The beam phase with resepct to the RF reference shall be measured with an accuracy of better than +/- 1 degree of the bunching frequency of 352.21 MHz	Measurement accuracy including all sources of measurement errors and assuming on-axis beam. The processing frequency may be different from the bunching frequency.	degree	-1		1	Commissioning, Operations	
DTL.PBI-46	Beam phase measurement: resolution	The beam phase with resepct to the RF reference shall be measured with a resolution of better than 0.2 degree of the bunching frequency of 352.21 MHz	The processing frequency may be different from the bunching frequency	degree			0,2	Commissioning, Operations	
DTL.PBI-54	Beam phase measurement: beam position and phase correlation	The error in the beam phase measurement induced by the beam centroid position changes shall be less than +/-0.5 degree		degree	-0,5		0,5	Commissioning, Operations	
SPK.PBI-11	Beam position measurement: Precision for nominal beam	Any position measurement of the nominal beam in this section shall have a precision* better than 25 um	*The precision is the random component of the uncertainty of the measurement that has a zero-mean	um			25	Design	XX 20 µm
SPK.PBI-13	Beam position measurement: Precision for 6.3 mA beam	Any position measurement of the low-charge (6.3 mA) beam in this section shall have a precision of at most 250 um		um			250	Design	200 µm

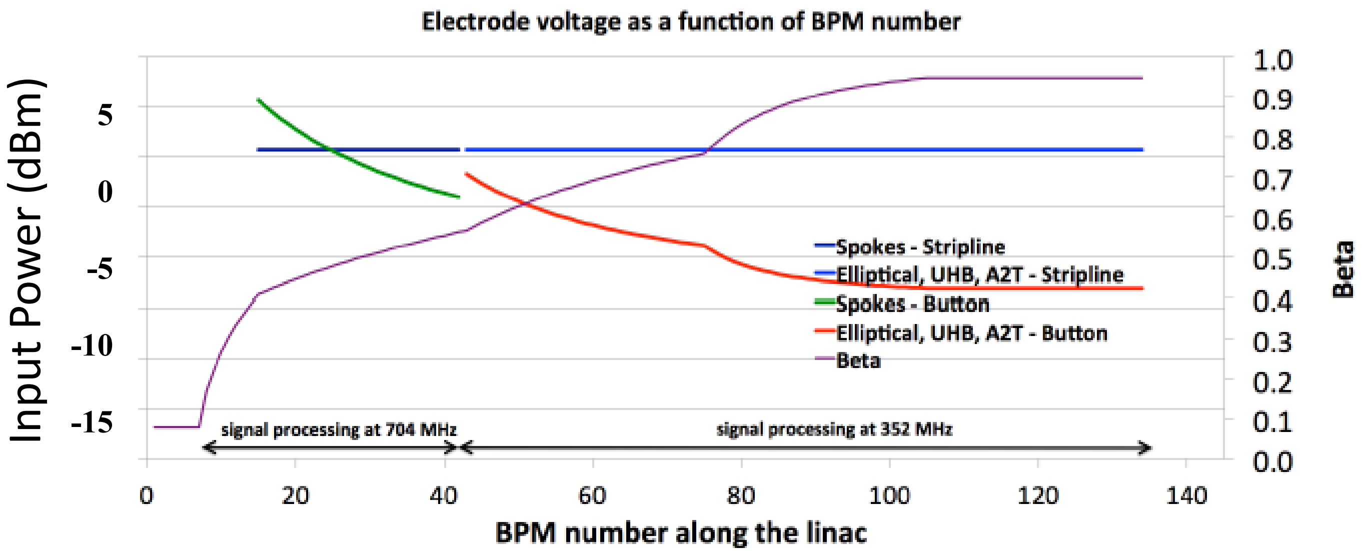
BPM electronics - DSP



- This scheme is repeated for each RF channel
- Processing can be done using the sum signal
- Position is calculated using the delta over sum
- It is also possible to have different decimation rates. For example, 10 Hz output for long term phase monitoring (specification SPK.PBI-34)

- Near-IQ has advantages when compared to IQ. The nonlinear high order harmonics can be pushed out of the interest bandwidth
- Work with the LLRF team to use common firmware block when possible

BPM Electronics



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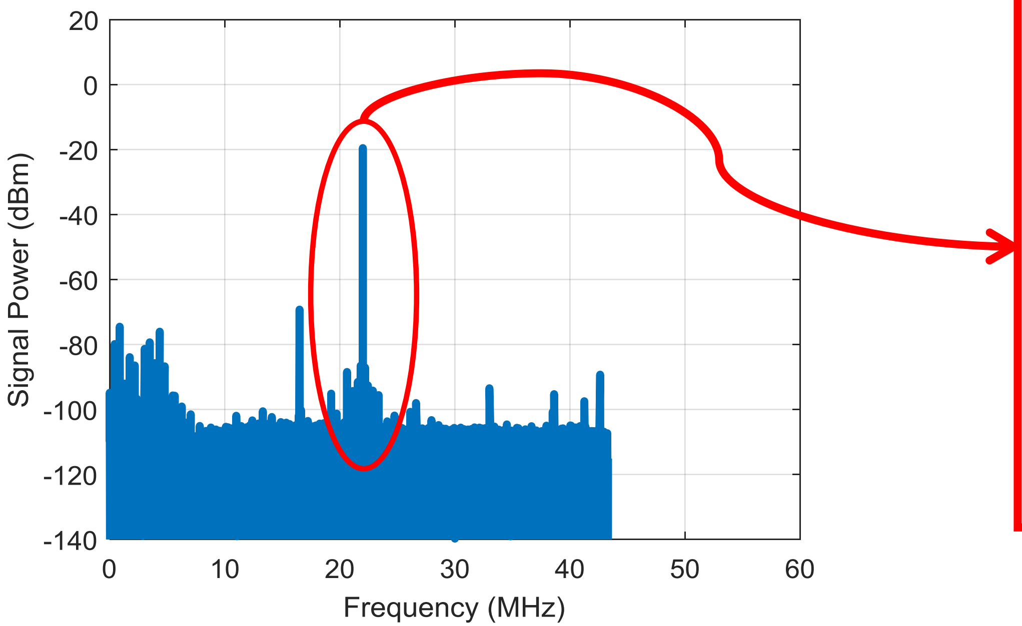

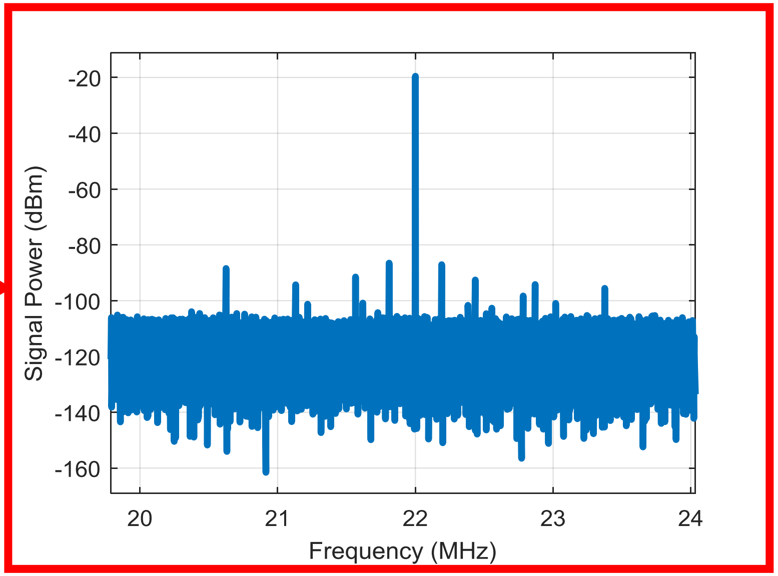

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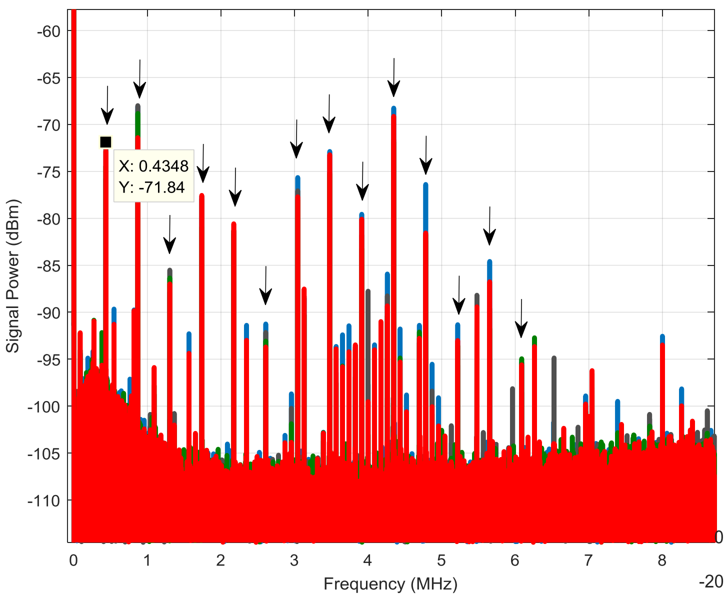

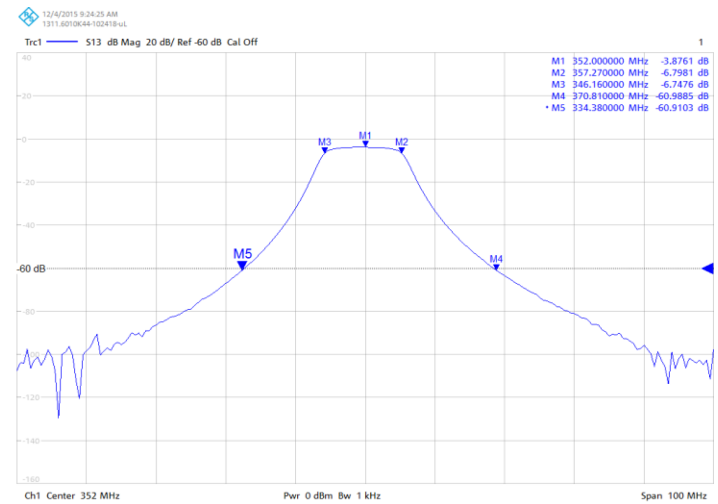

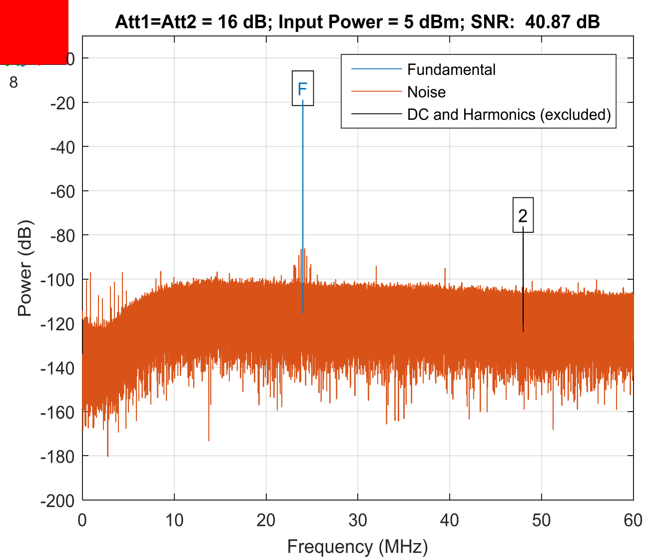

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