IC 1407 ACCREDIT

Measurements and evaluation of the cyclostationary characteristics for stochastic radiations from the Round Robin DUT

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Technische Universitaet Muenchen

TECHNISCHE UNIVERSITÄT MÜNCHEN

07.02.2018

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Outline

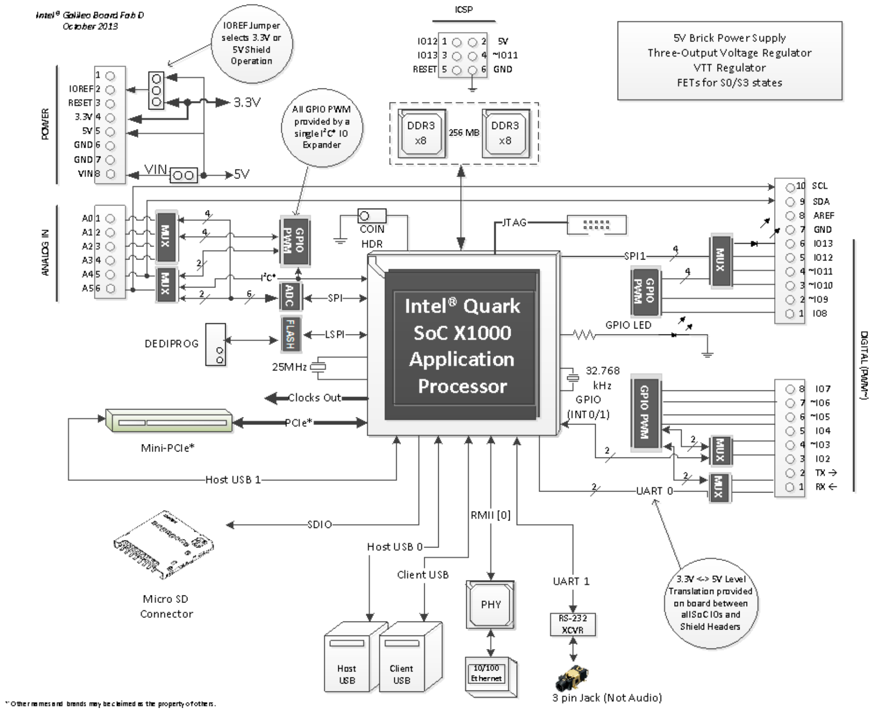
- **Motivation The Intel® Galileo Board**
- **Localization of the physical radiated sources of the DUT**
- **Frequency, time and spatial characterization of the physical radiated sources**
- **Cyclostationary sources characterization in the near-field**
- **Far-field analysis of the DUT’s physical radiated sources**
- **Conclusion**

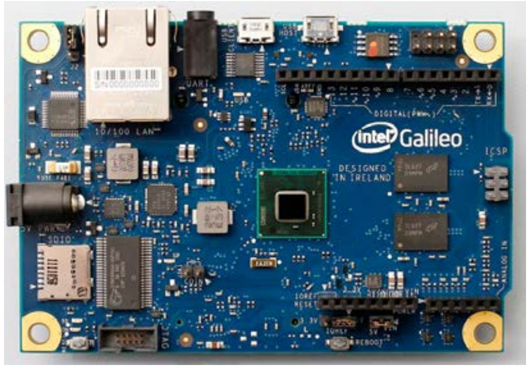
Motivation

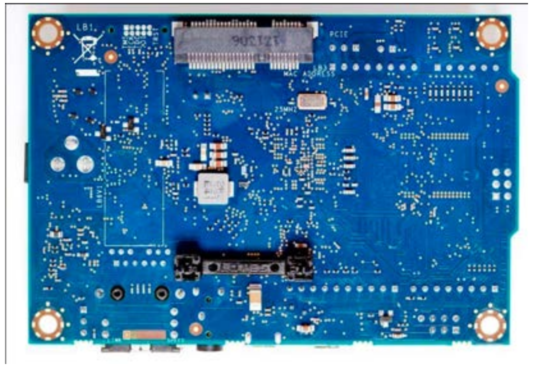
- Electromagnetic radiation of the DUT
  - ✓ stochastic: data transferring, thermal noise, jitter
  - ✓ periodic deterministic: frequency synthesizer, power supply units, etc.
- Characteristics of stochastic signals
  - ✓ auto- and cross-correlation functions
  - ✓ cyclic cross-correlation cumulant functions
- Characteristics of periodic deterministic signals
  - ✓ Fourier series expansion
  - ✓ Power of spectral components

Device under test

➤The Intel® Galileo Board







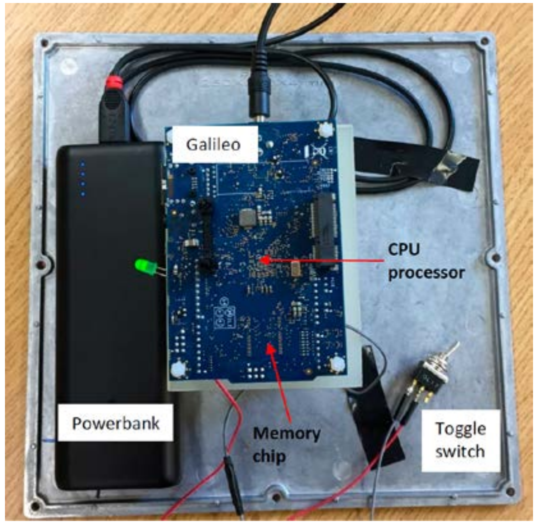
✓400MHz 32-bit Intel® Pentium processor

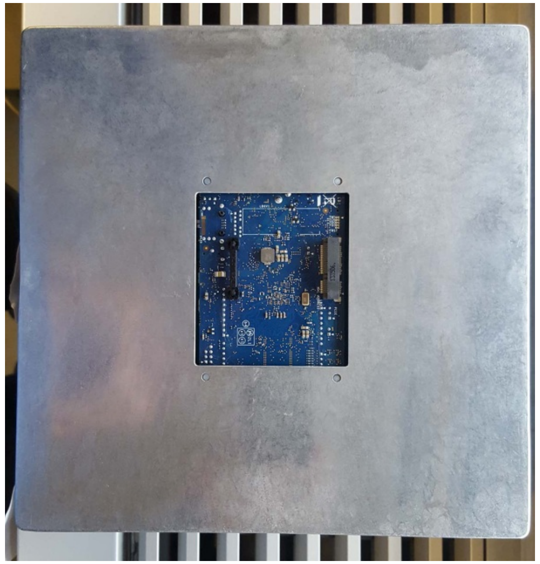
✓10/100 Ethernet connector

✓Full PCI Express* mini-card slot

✓USB 2.0 Host connector

Device under test



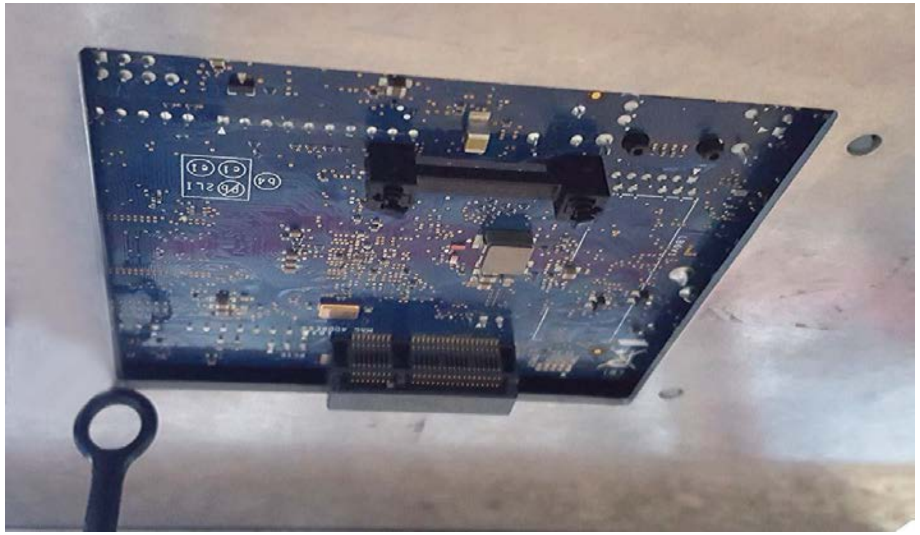


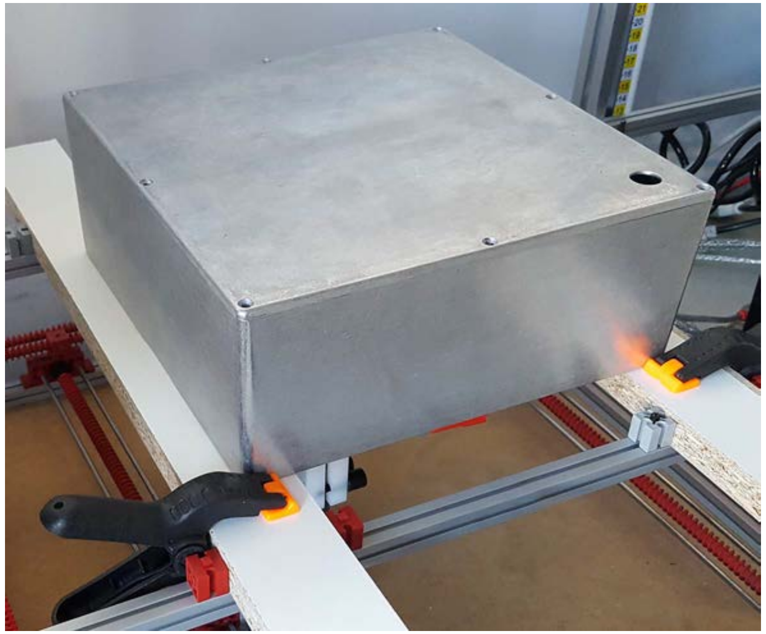
➢ Test modes

✓Memory test OFF

✓Memory test ON. Memory intensive process where random integer numbers are generated and will be saved in a random element in a large array allocated in the memory

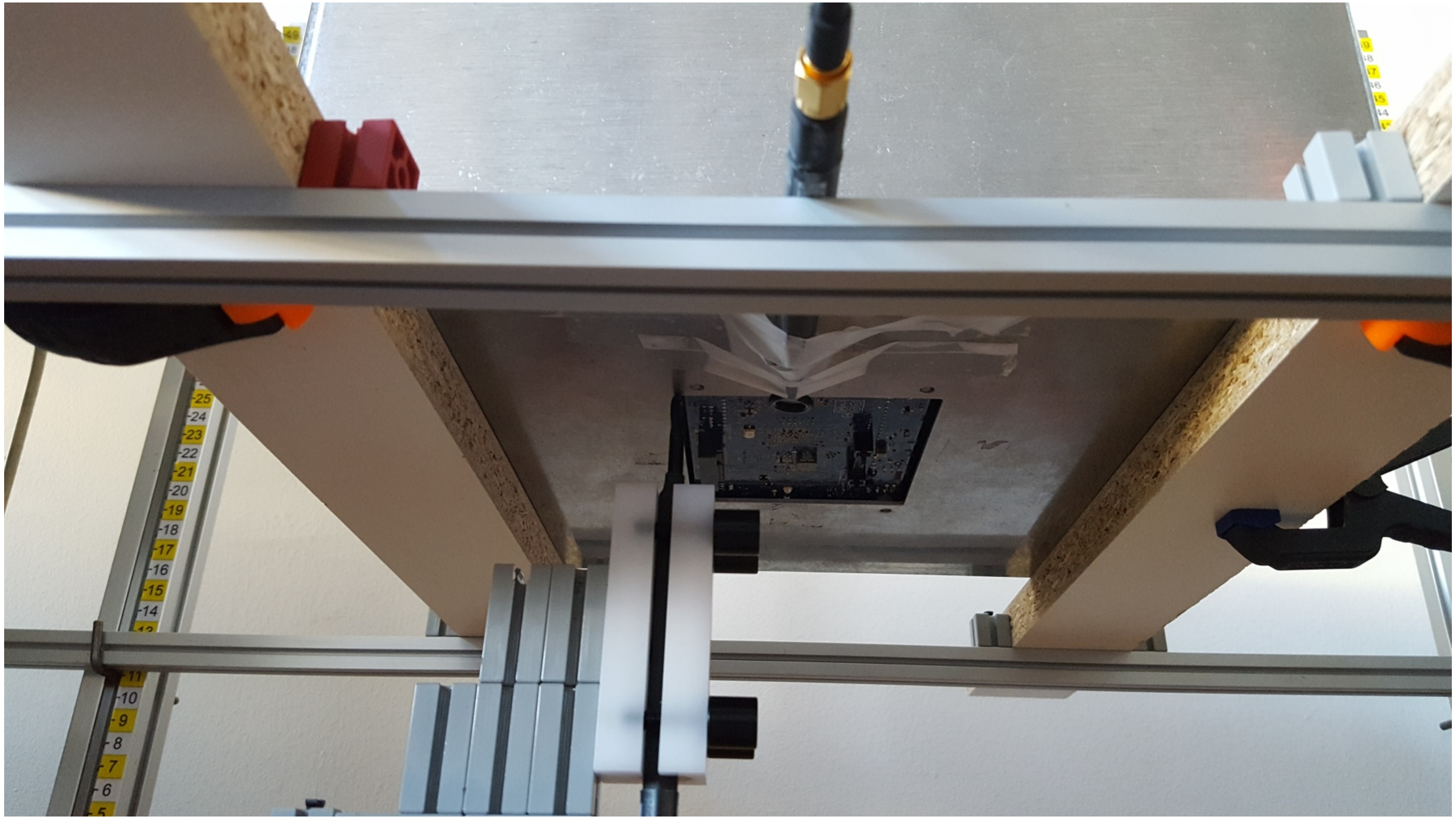
Near-field measurement setup



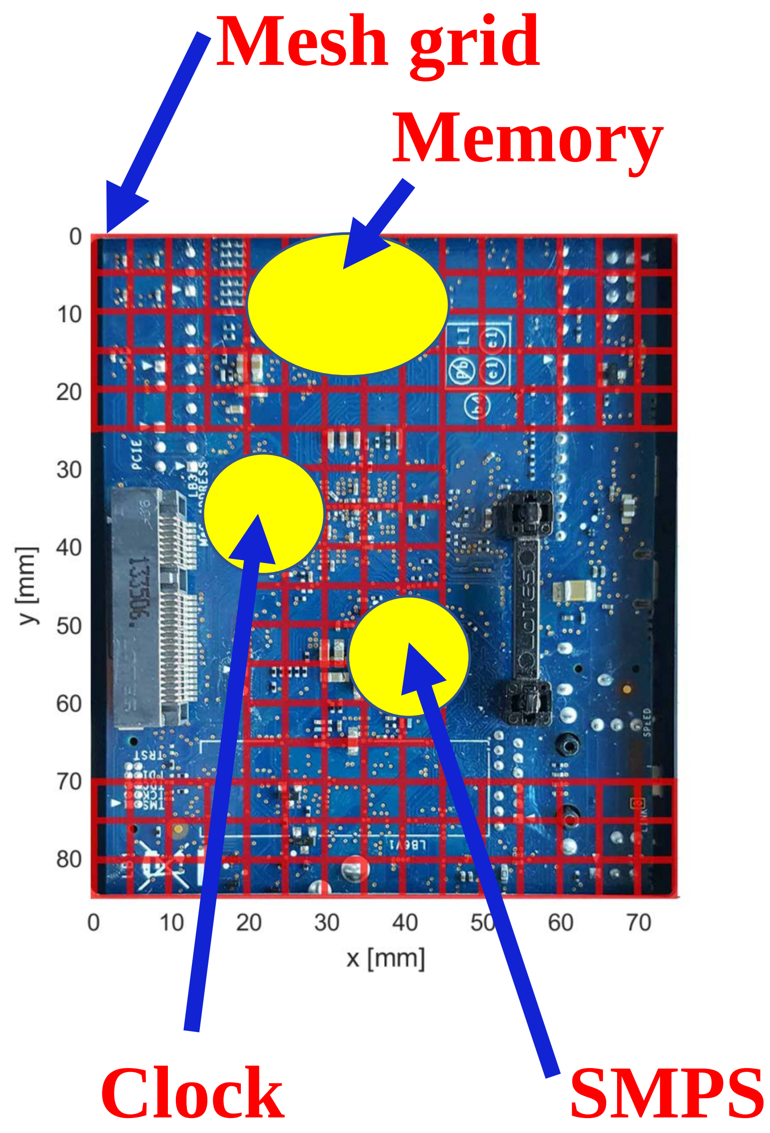


- ✓Langer near-field 10 mm probe
- ✓Two polarization of the probe: H_X and H_Y
- ✓Scanning area 75 x 85 mm
- ✓5 mm scanning step
- ✓4 mm distance between PCB and probe
- ✓13 GHz Oscilloscope LeCroy SDA 813Zi-A
- ✓2.5 GSa/s sampling frequency
- ✓5 MSa data length

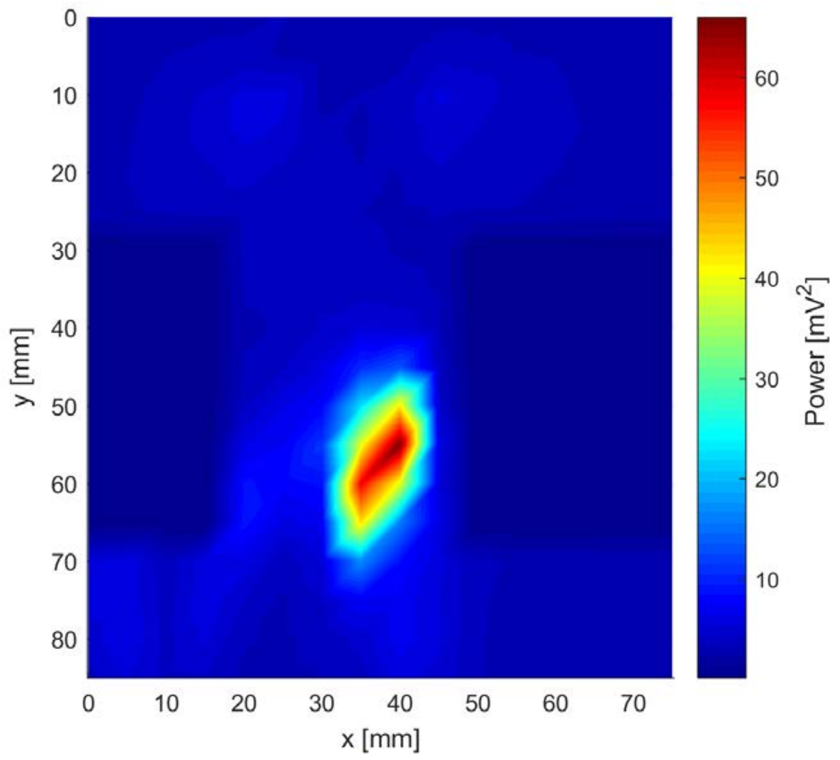
Near-field measurement setup



Power hot spots of the DUT

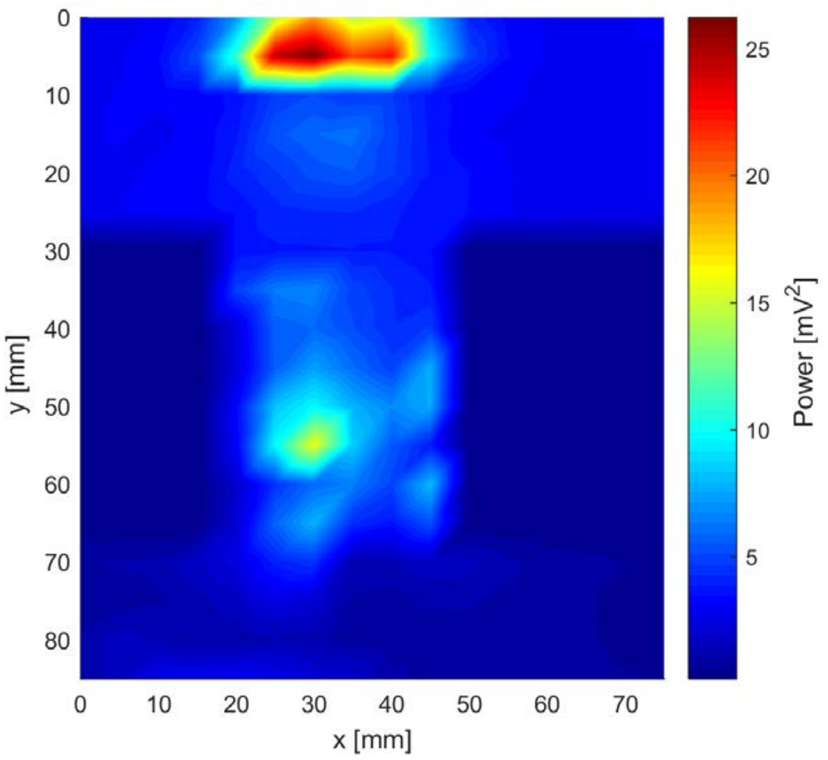


➢ H_X polarization



✓ Power level 63 mV^2

➢ H_Y polarization



✓ Power level 27 mV^2

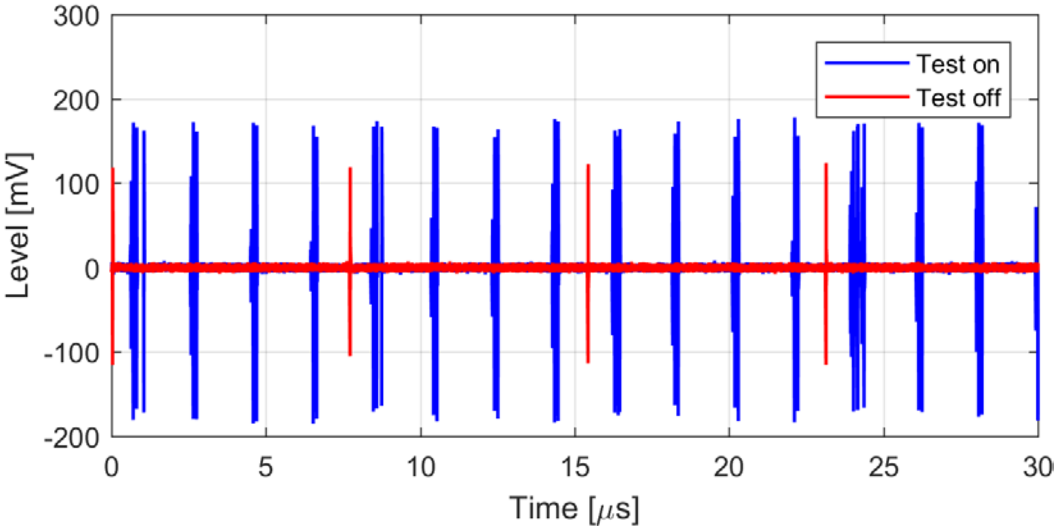
Memory hot spot

✓Measured signals are nonperiodic

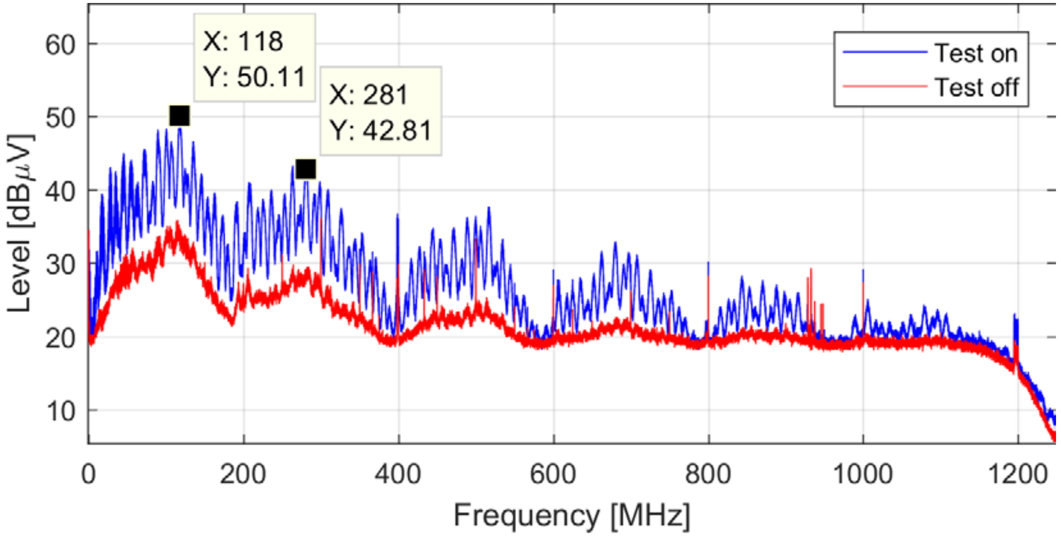
✓Memory test signals are random

✓ Maximum of the PS at 118 MHz

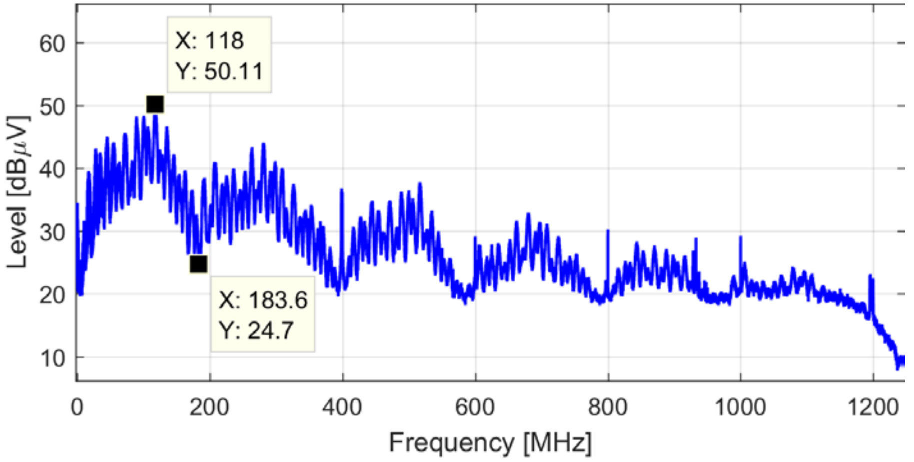
➢ Measured signals



➢ Power spectrum



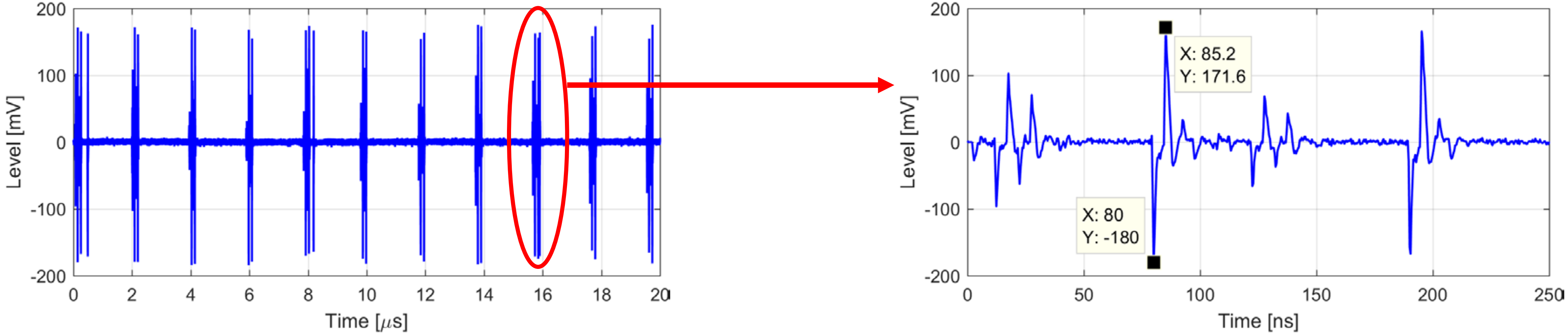
Memory test on



✓Bit duration is 5.2 ns

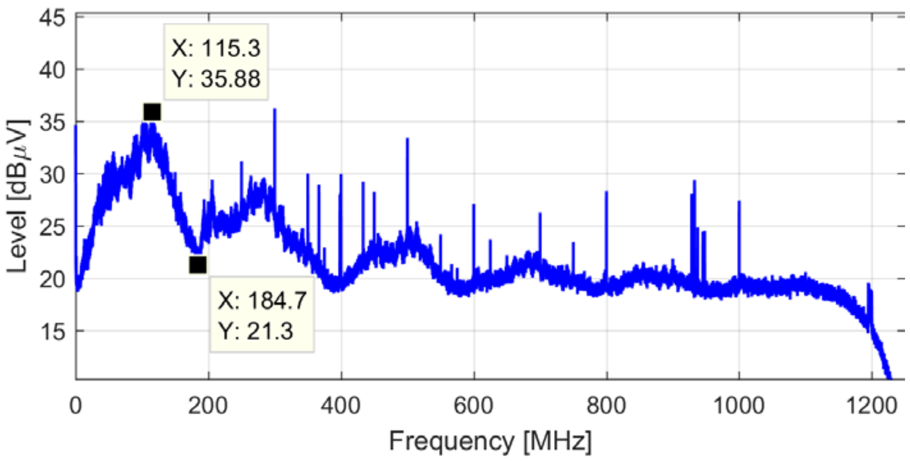
✓The shape of pulses is identical

✓Memory test process is cyclostationary

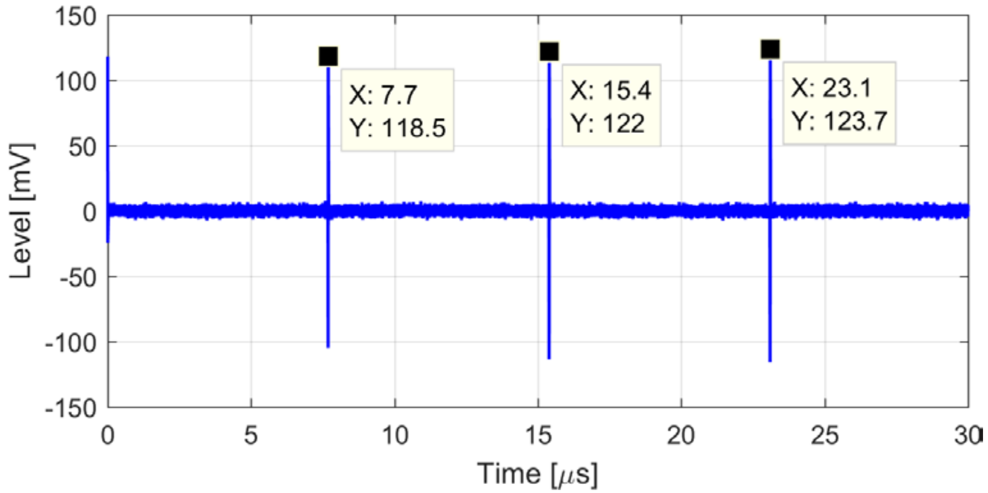


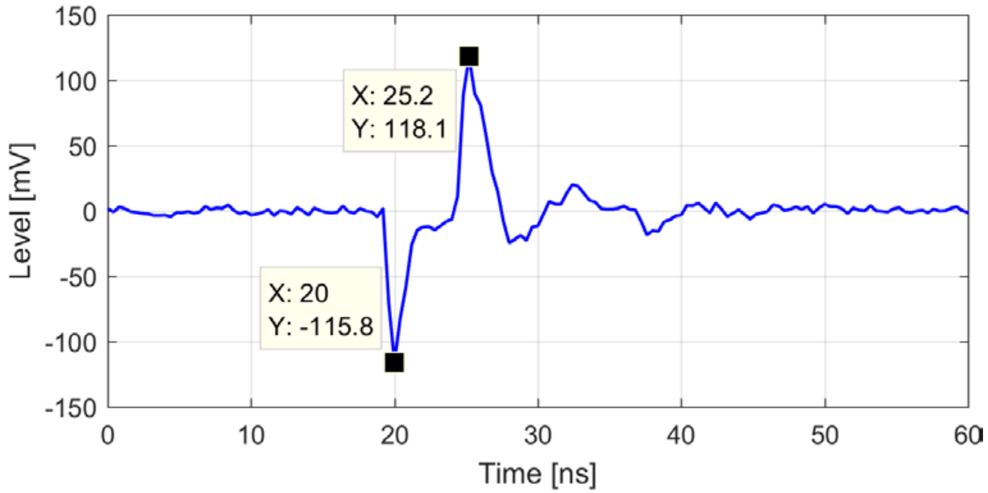
cost

Memory test off

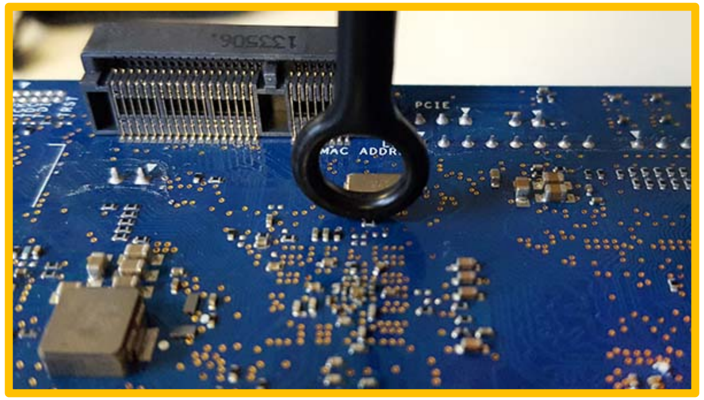


- ✓Pulse duration is 5.2 ns
- ✓Sequence of single pulses
- ✓Period of signal is 7.7 mks





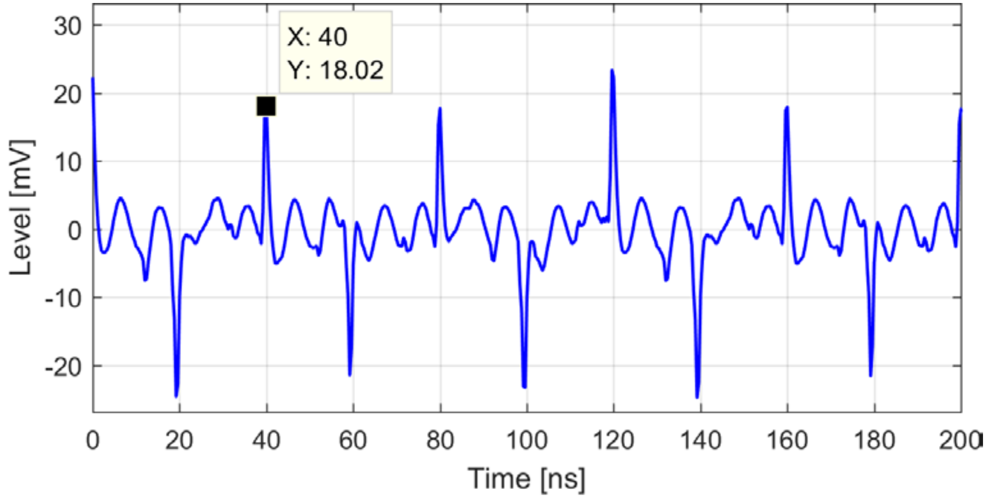
Signal of the clock frequency synthesizer



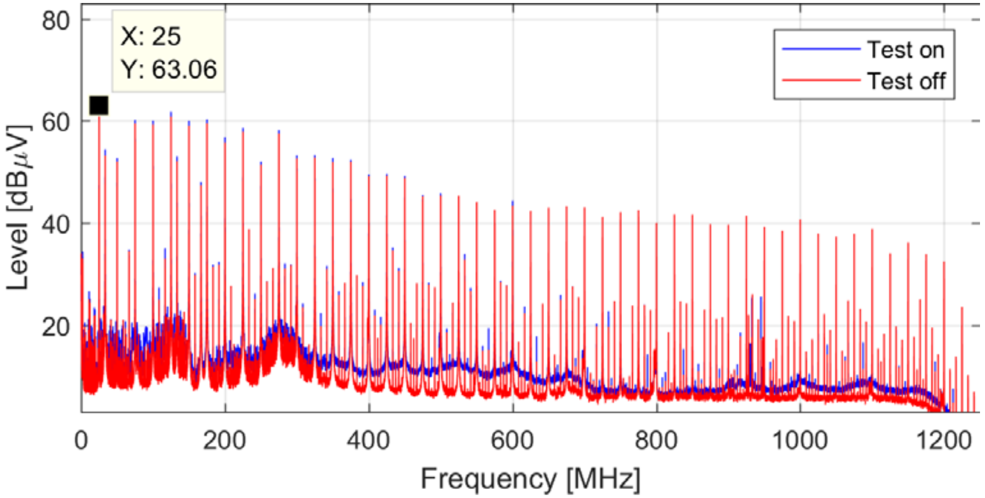
✓Period of signal 40 ns

✓Frequency bandwidth up to 1.25 GHz

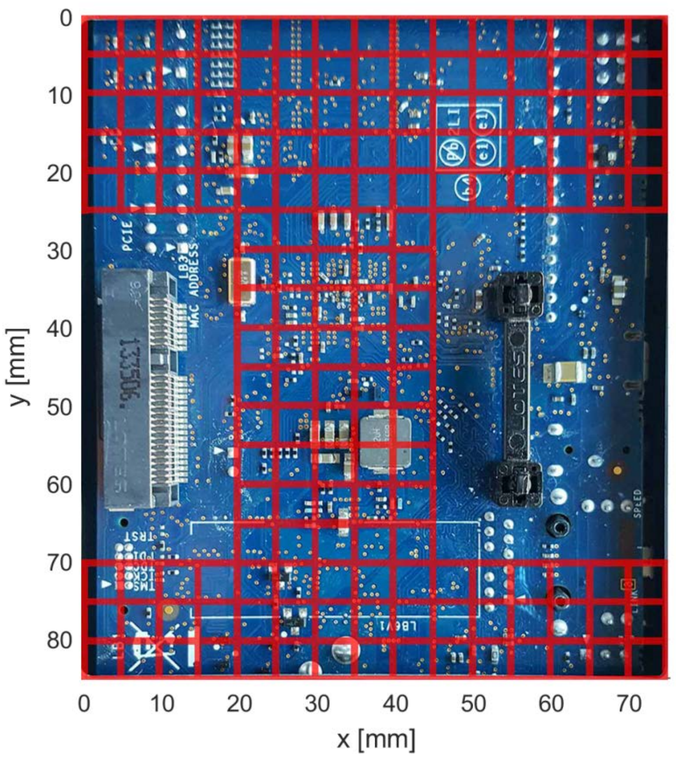
➢ Measured signals



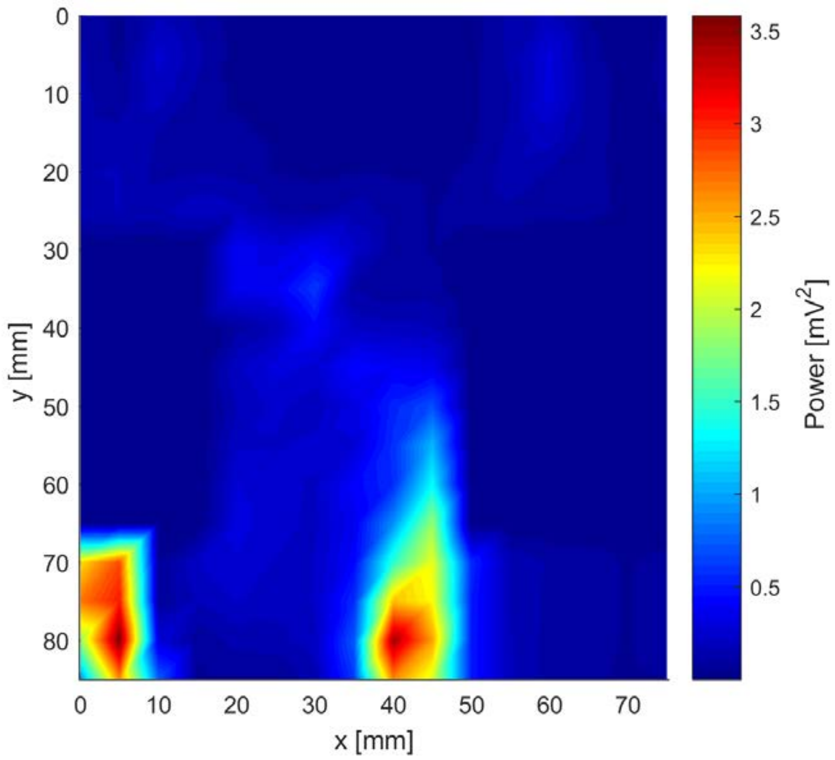
➢ Power spectrum



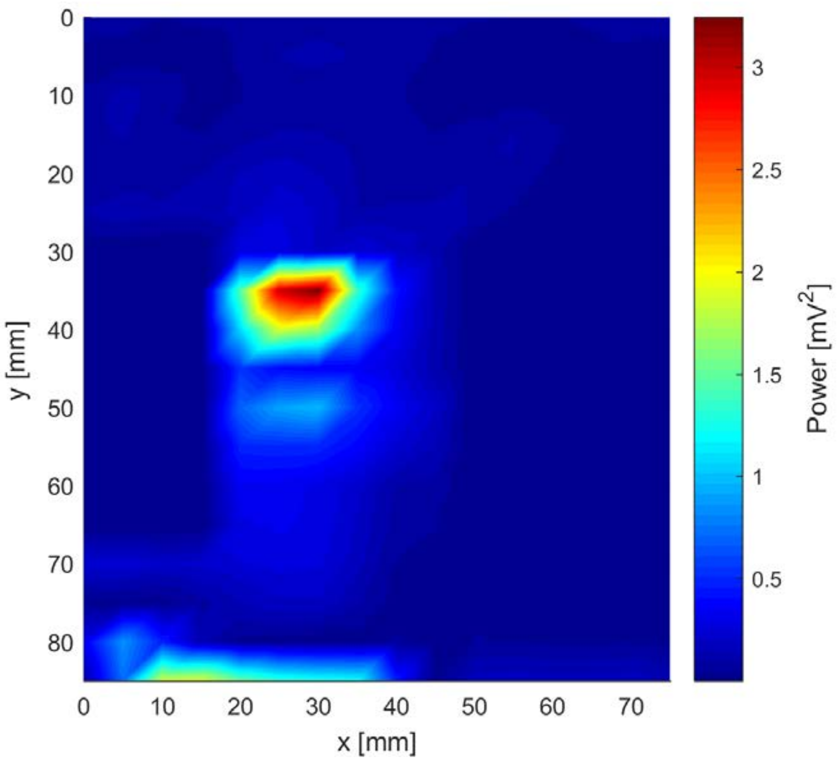
Spatial distribution of the clock signal



➢ H_X polarization



➢ H_Y polarization



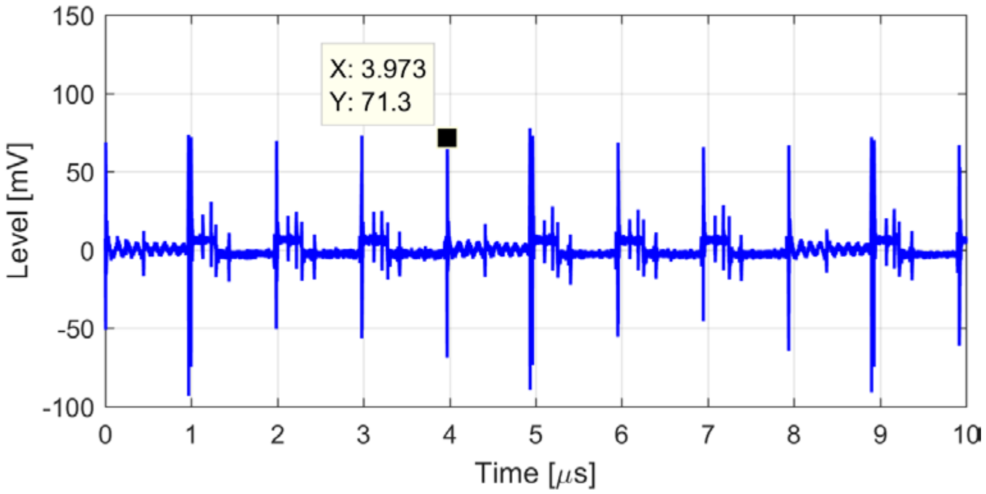
✓ Power level 3.5 mV^2

Signal of the switched mode power supply

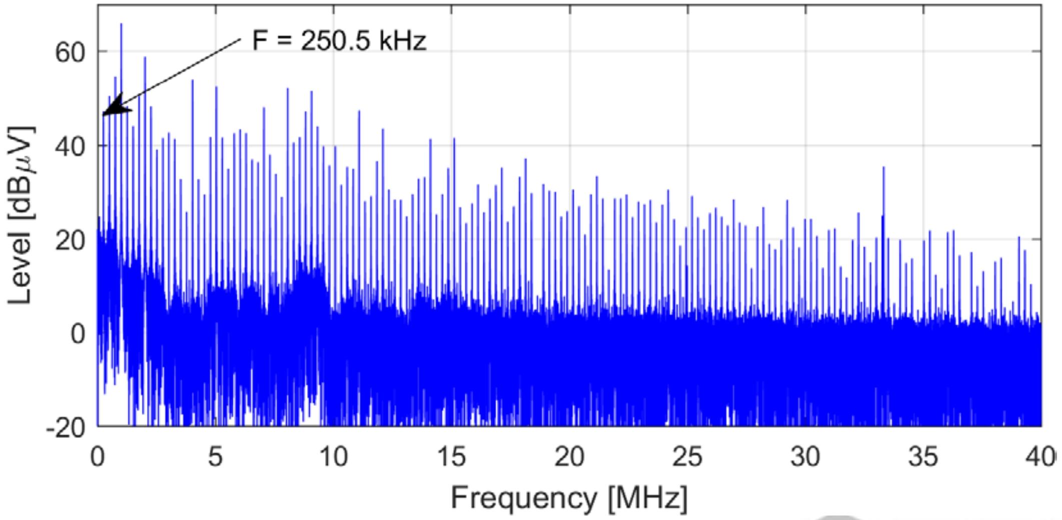
✓Period of signal ~ 4 mks

✓Frequency bandwidth up to 40 MHz

➢ **Measured signals**



➢ **Power spectrum**



Cyclostationary sources characterization

The periodic sample mean function of the cyclostationary process

$$m_x(\alpha,t) = \lim_{N\to\infty}\frac{1}{2N+1}\sum_{n=-N}^{N} x\,(t+nT) = \sum_{k=-\infty}^{\infty} e^{\frac{j2\pi kt}{T}} \lim_{\Delta\to\infty}\frac{1}{\Delta}\int_{-\frac{\Delta}{2}}^{\frac{\Delta}{2}} x\,(\zeta)\, e^{-j2\pi\alpha k\zeta}\, d\zeta$$

Nonlinear inertialess shifted transformation of the signal

$$z(t,\tau) = x(t-\tau/2)x(t+\tau/2\,)$$

Cyclic autocorrelation function

$$R_x(\alpha,\tau) = \lim_{\Delta\to\infty}\frac{1}{\Delta}\int_{-\frac{\Delta}{2}}^{\frac{\Delta}{2}} z(t,\tau)\, e^{-j2\pi\alpha t}\, dt$$

Cyclostationary sources characterization

Non-periodic second order cyclic cumulant function

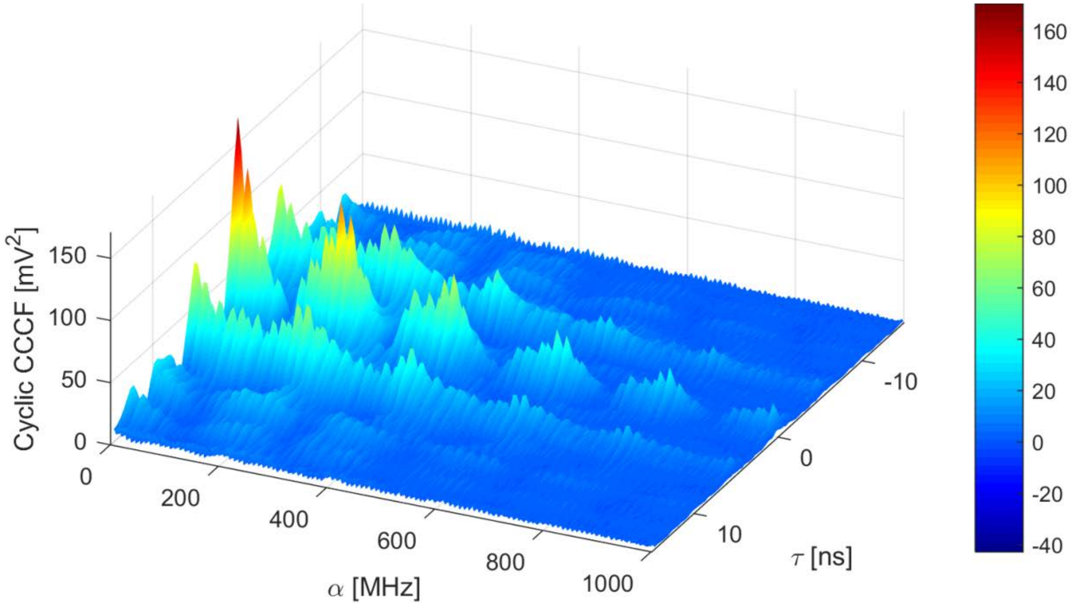
$$C_{\chi}(\alpha,\tau)=\lim_{\Delta\to\infty}\frac{1}{\Delta}\int_{-\frac{\Delta}{2}}^{\frac{\Delta}{2}}\left[x\left(t-\frac{\tau}{2}\right)-m_{\chi}\left(\alpha,\left(t-\frac{\tau}{2}\right)\right)\right]\left[x\left(t+\frac{\tau}{2}\right)-m_{\chi}\left(\alpha,\left(t+\frac{\tau}{2}\right)\right)\right]e^{-j2\pi\alpha t}\,dt$$

Cyclic cross-correlation cumulant function (cyclic CCCF)

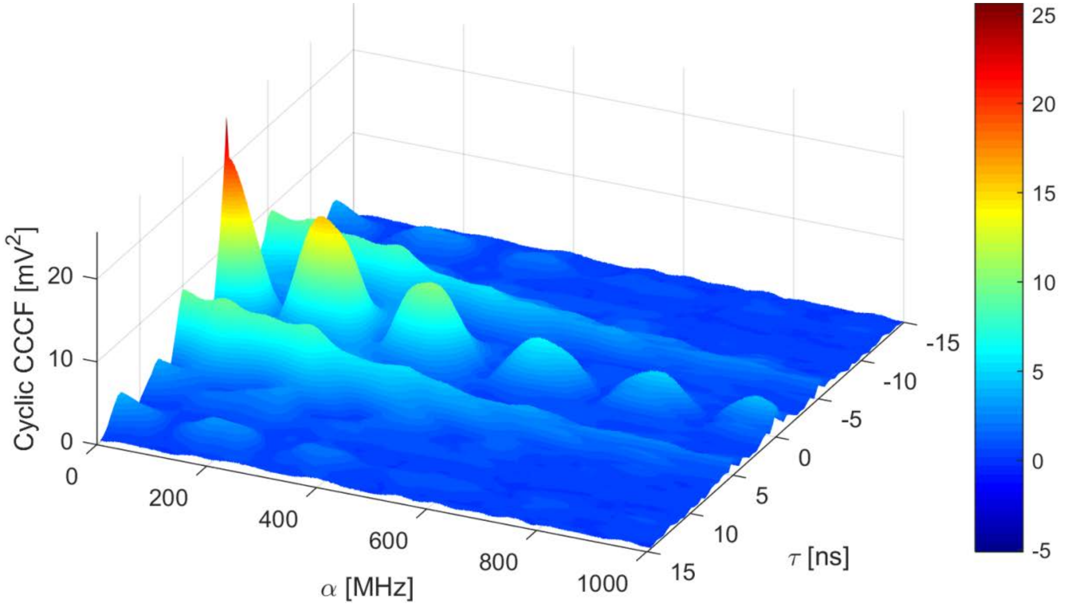
$$C_{yx_{mn}}(\alpha_1,\tau)=\lim_{\Delta\to\infty}\frac{1}{\Delta}\int_{-\frac{\Delta}{2}}^{\frac{\Delta}{2}}\left[y\left(t-\frac{\tau}{2}\right)-m_{y}\left(\alpha_1,\left(t-\frac{\tau}{2}\right)\right)\right]\left[x_{mn}\left(t+\frac{\tau}{2}\right)-m_{x_{mn}}\left(\alpha_1,\left(t+\frac{\tau}{2}\right)\right)\right]e^{-j2\pi\alpha_1 t}dt$$

Cyclic auto-correlation cumulant functions

- Memory test on



- Memory test off

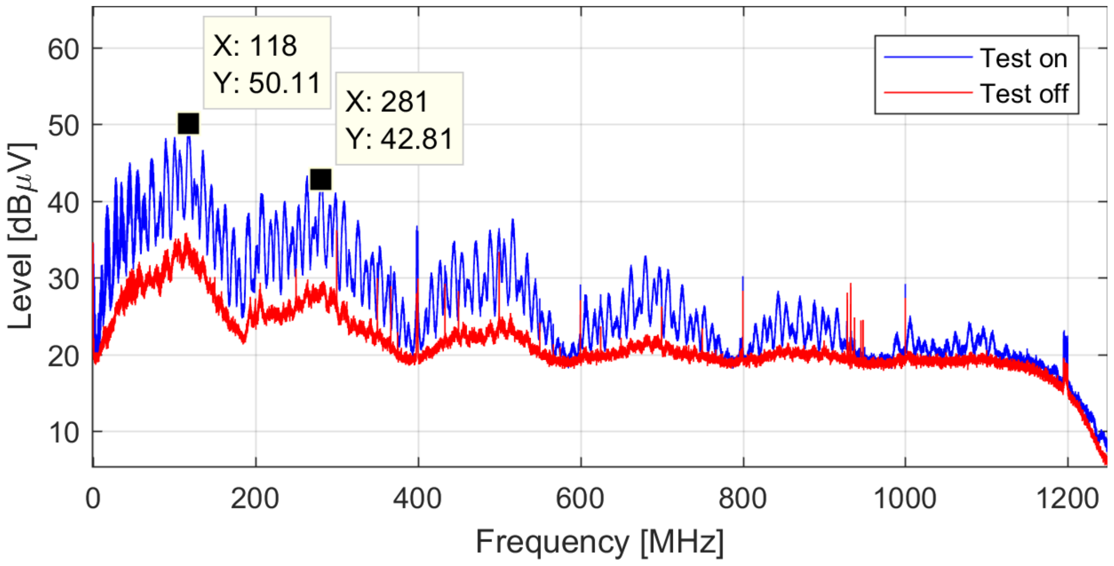


✓ Power level 165 mV^2

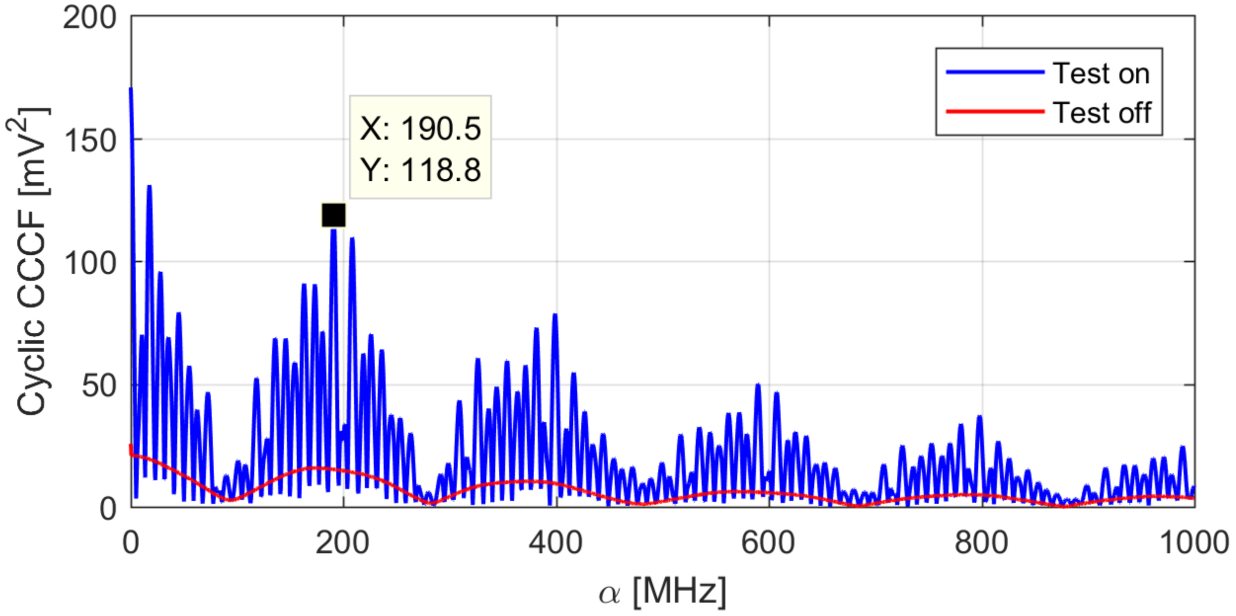
✓ Power level 25 mV^2

Cyclic auto-correlation cumulant functions

➢ **Power spectrum**



➢ **Cyclic ACCF**

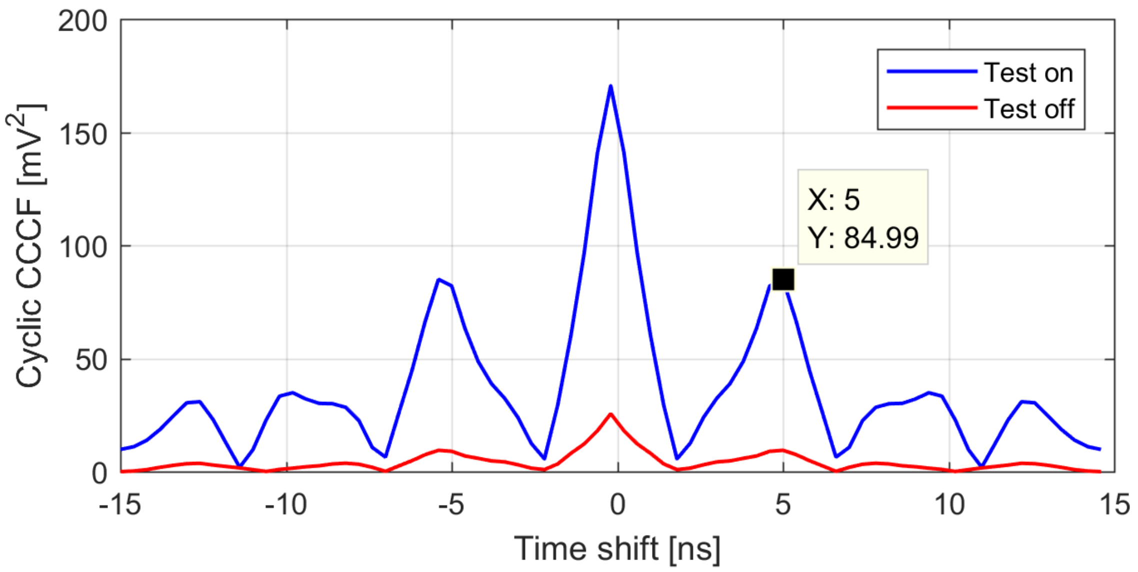


✓ **Maximum of cyclic ACCF corresponds to the cyclic frequency 190.5 MHz**

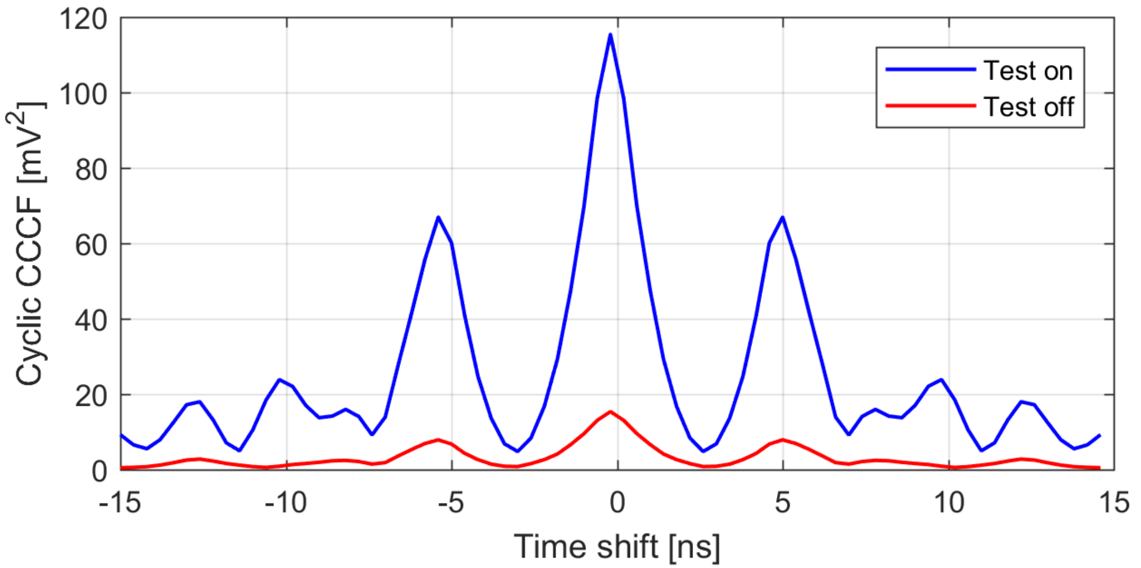
✓ **Cyclic frequency is suppressed in the power spectrum**

Cyclic auto-correlation cumulant functions

➢ Cyclic frequency α = 0



➢ Cyclic frequency α = 190.5 MHz

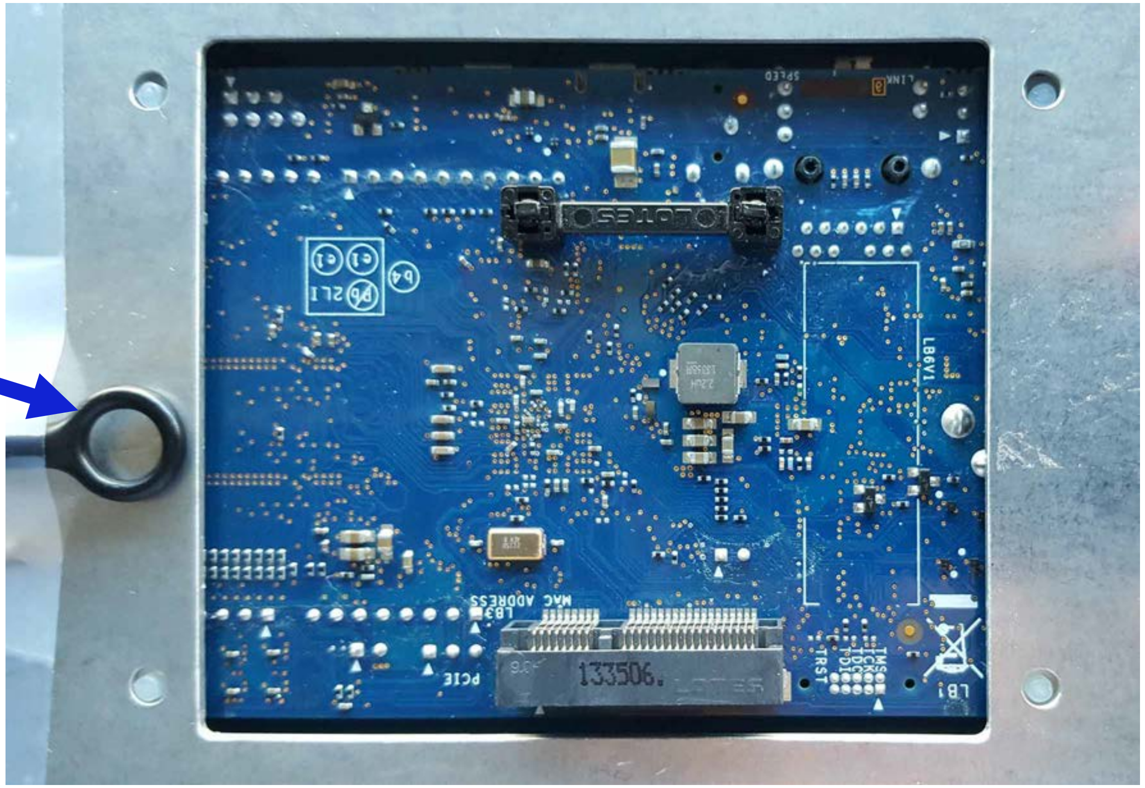


✓Correlation interval corresponds to the pulse duration 5.2 ns

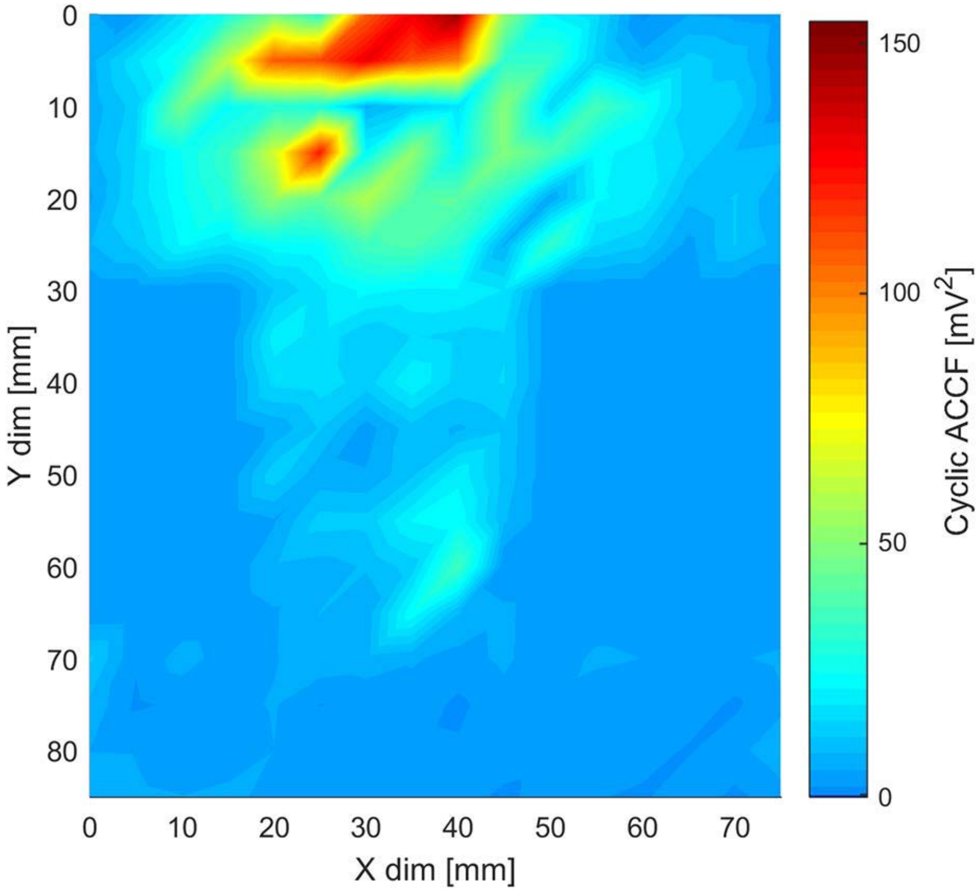
✓Both slices are nearly identical

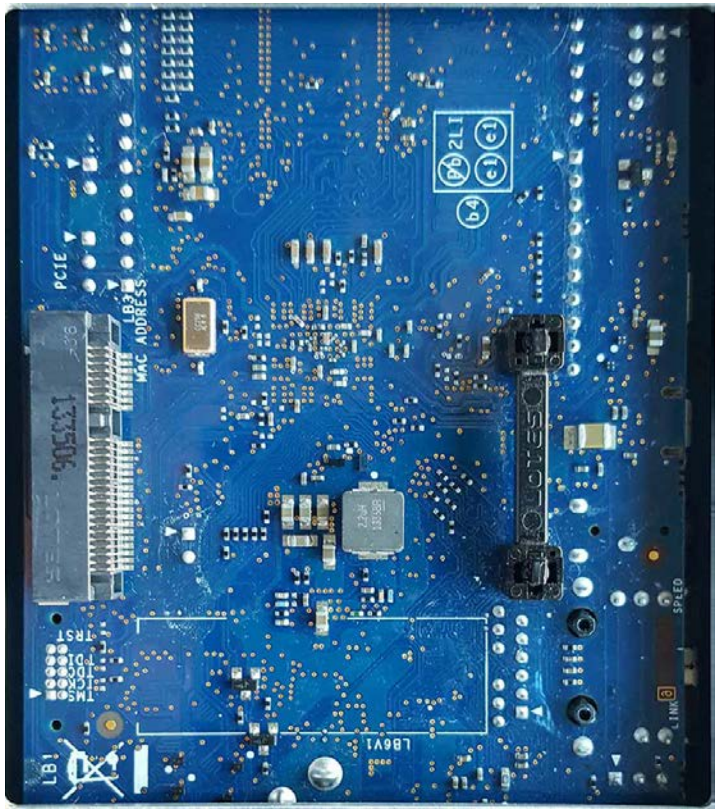
Spatial distribution of the cyclic CCCF

Reference probe

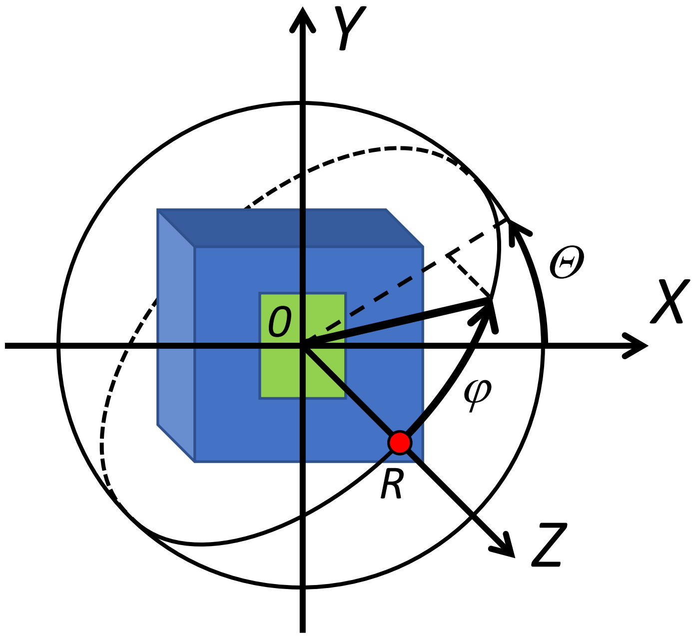


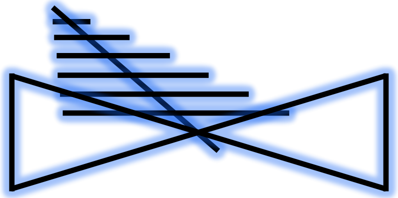
Spatial distribution of the cyclic CCCF



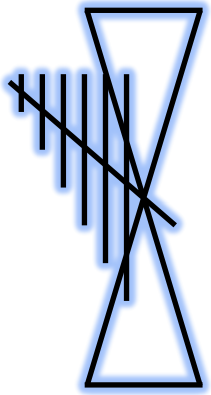


Far-field measurement setup

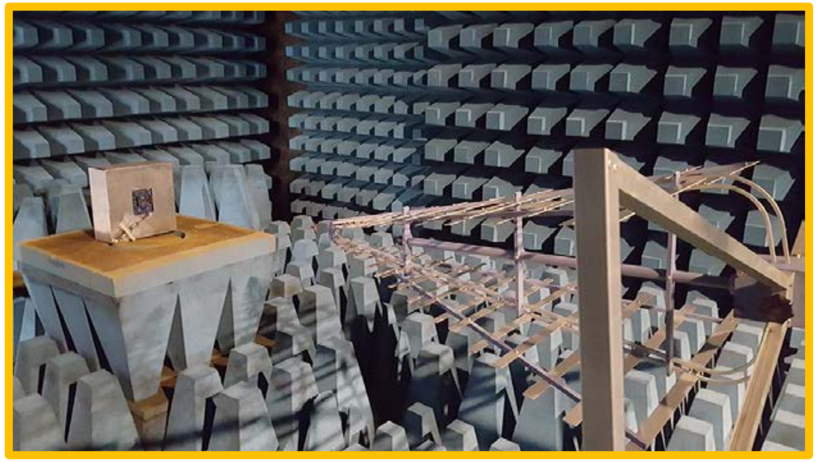




H_X polarization



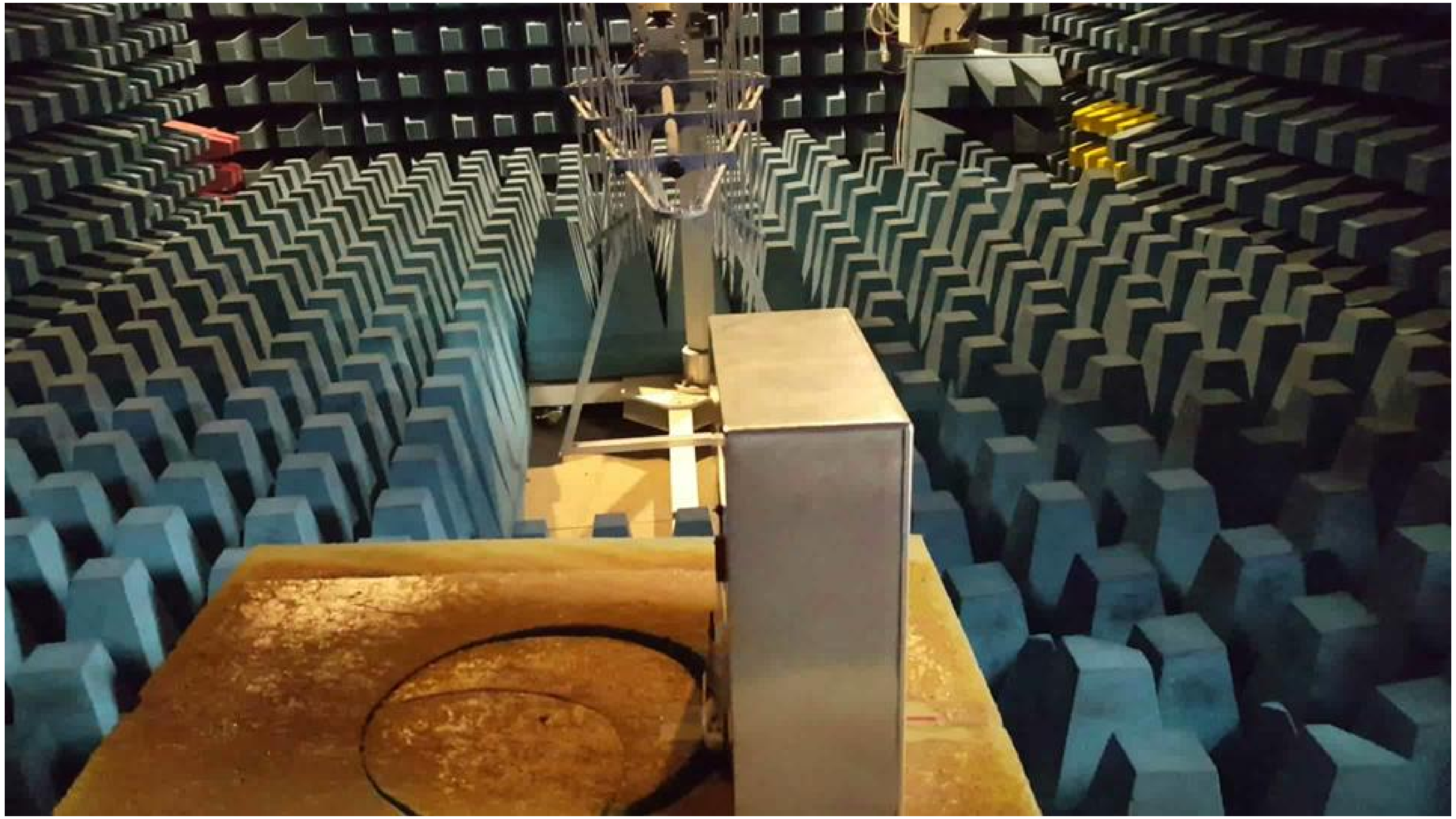
H_Y polarization



✓ H_X polarization

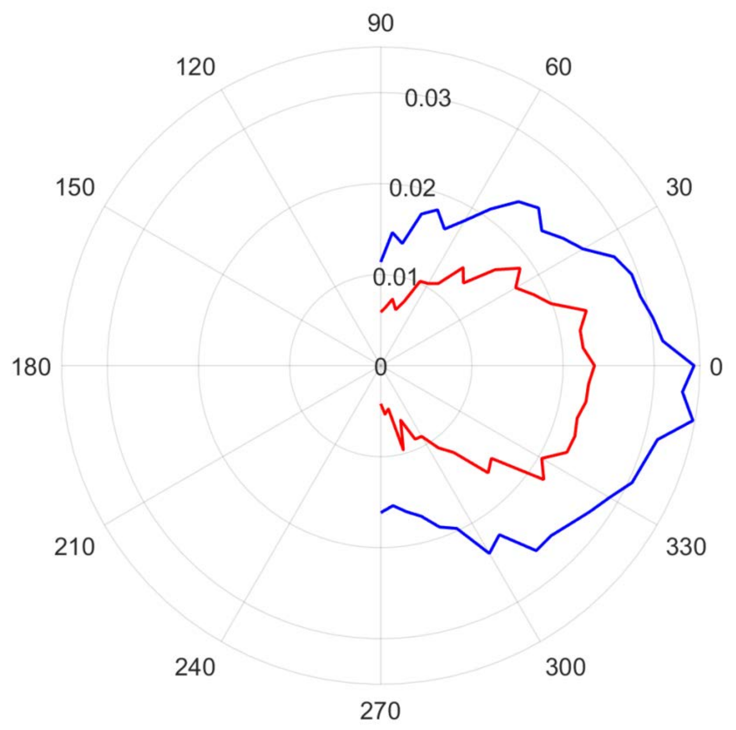
✓ H_Y polarization

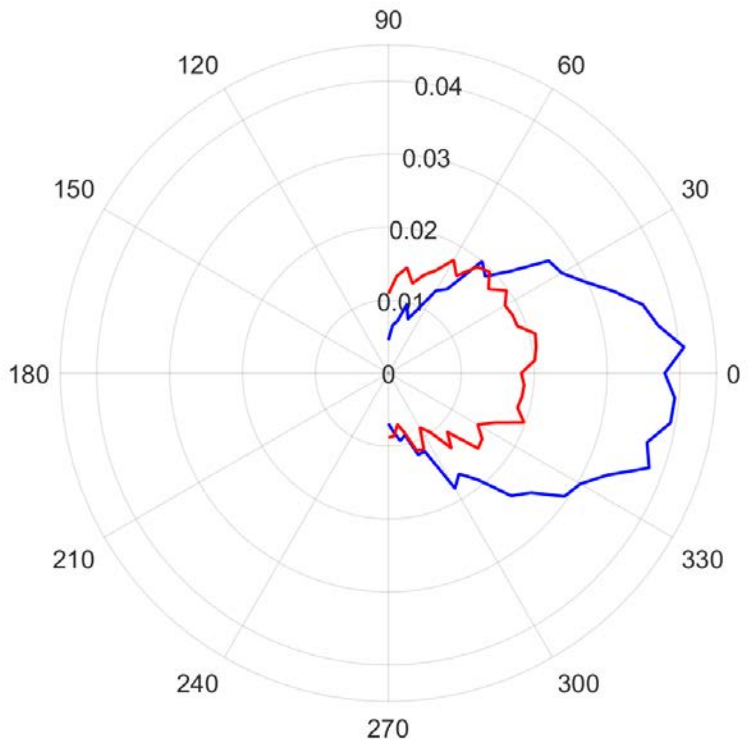
Far-field measurements



Far-field measurements

➢ **Power of the clock signal, test on**



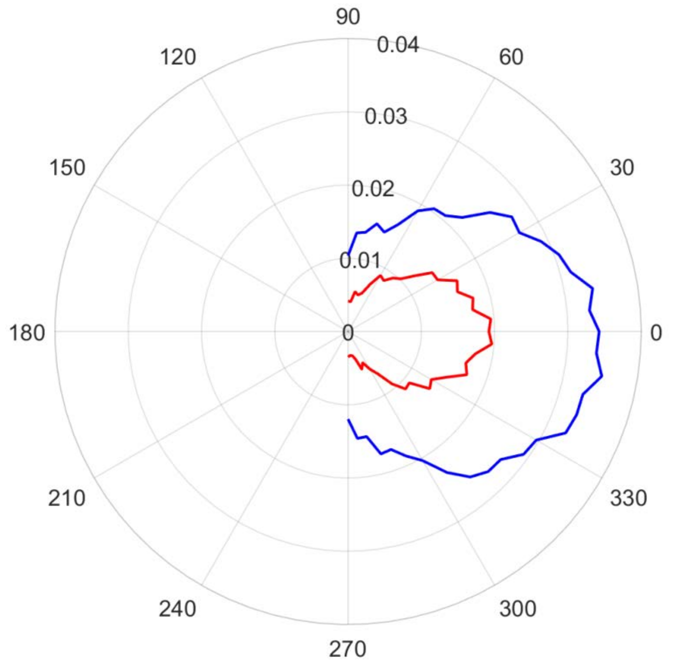


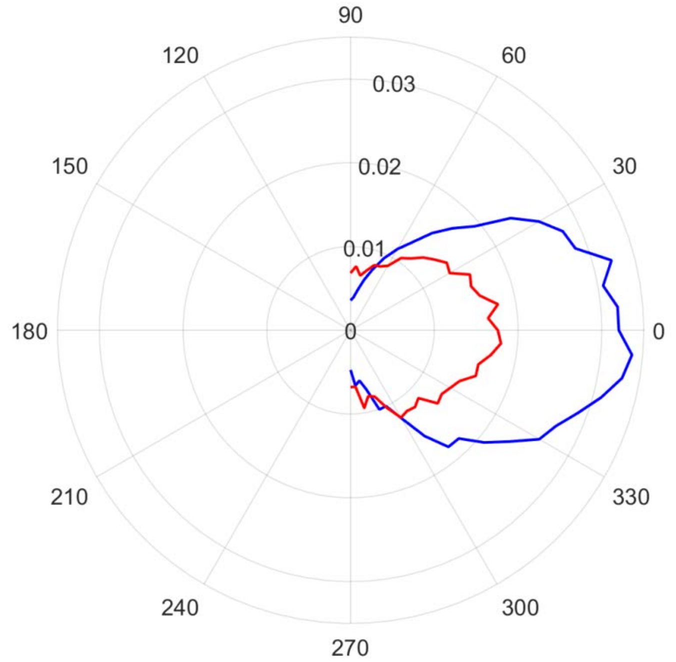
- ✓ ***Distance 1 m***
- ✓ ***Θ = 0º***

- ✓ ***Distance 1 m***
- ✓ ***Θ = 90º***

Far-field measurements

➢ **Power of the clock signal, test off**





- ✓ ***Distance 1 m***
- ✓ ***Θ* = 0º**

- ✓ ***Distance 1 m***
- ✓ ***Θ* = 90º**

Conclusion

- Localization of the physical radiated sources of the DUT was performed
- Frequency, time and spatial characterization of the physical radiated sources have been obtained
- Characterization of the random data signals reveals hidden cyclic frequencies of the sequence
- Far-field analysis of the DUT’s physical radiated sources was accomplished in anechoic chamber

Publications

- **EMC Europe 2018 Symposium, August 27-30, Amsterdam, Netherlands**
- **2018 Baltic URSI Symposium, May 14-17, Poznań, Poland**
- **2nd URSI AT-RASC, 28 May – 1 June, Gran Canarias**
- **European Microwave Week 2018, September 23-28, Madrid, Spain**