Cyclostationary characterization of unintentional stochastic radiations and time-domain detection of stochastic signals with cyclostationary properties

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Outline

• Motivation
• Measurement setup and data analysis
• Clock synchronization component
• Cyclostationary analysis
• Time-domain detection
• Conclusions
Stochastic processes

Autocorrelation function of the almost-cyclostationary process

\[ \rho_X(t, \tau) = \mathbb{E}\{x(t + \tau)x^*(t)\} = \sum_{f_i} R_X^{f_i}(\tau)e^{j2\pi f_it}, \forall f_i \in \mathbb{S} \]

Cyclic autocorrelation function and spectrum

\[ R_X^{f_i}(\tau) = \lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{T/2} R_X(t, \tau)e^{-j2\pi f_it} \, dt \]

\[ S_X^{f_i}(f) = \int_{\mathbb{R}} R_X^{f_i}(\tau)e^{-j2\pi f\tau} \, d\tau \]
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Device under test

- Spartan-6 FPGA LX9 MicroBoard

- Front view
- Back view

- Test mode: filling the DDR memory by “1”
Measurement setup

➢ Time-domain measurement system

✓ Digital oscilloscope

✓ First probe

✓ Observation plane

✓ Object plane

✓ Second probe
Measurement setup

- Langer EMV-Technik RF-R 3-2 magnetic field probes
- Frequency band from 30 MHz up to 3 GHz
Data analysis

➢ Time-domain analysis of EM emissions

✓ Period of the clock signal is 30 ns
Data analysis

➢ Time evolution of the clock signal

✔ Period of clock frequency modulation is 28.6 μs
Data analysis

- Frequency-domain analysis of EM emissions

✓ Clock frequency modulation is used for spreading spectrum
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Clock components

➢ Periodogram of EM emissions
Clock components

- **Amplitude spectrum**

- **Periodogram**

- Fundamental clock frequency is 33.3 MHz
- Frequency deviation is 0.66 MHz
- Triangular waveform frequency is 35 kHz
Clock components

- **Amplitude spectrum**

- **Periodogram**

- Central frequency is 200 MHz
- Frequency deviation is 4 MHz
Clock components

- Amplitude spectrum after clock signal despreading
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Cyclostationary analysis

- Autocorrelation function (ACF)

\[ r_X[m] = \lim_{N \to \infty} \frac{1}{N} \sum_{n=0}^{N-1} x[n] x[n + m] \]

- ACF

- Eye diagram

✓ Cyclostationary signal with period 300 ns
Cyclostationary analysis

➢ Periodic autocorrelation function

\[ \rho_X [n, m] \triangleq \mathbb{E} \left\{ X \left[ n + \frac{m}{2} \right] X \left[ n - \frac{m}{2} \right] \right\} \]

- \( n \) – global time index
- \( m \) – relative time index

✓ Slice of the periodic autocorrelation function
Cyclostationary analysis

➢ Periodic autocorrelation function

✓ Cyclostationary data signal
Cyclostationary analysis

Cyclic autocorrelation function

\[ R^l_X[m] = \frac{1}{N} \sum_{n=-\frac{N-1}{2}}^{\frac{N-1}{2}} \rho_X[n,m] e^{-j\frac{2\pi lm}{N}} \]

\( l \) – cyclic frequency index
Cyclostationary analysis

\[ S^l_X[v] = \frac{1}{N} \sum_{m=-\frac{N-1}{2}}^{\frac{N-1}{2}} R^l_X[m] e^{-j \frac{2\pi vm}{N}} \]

\( v \) – frequency index
Cyclostationary analysis

- ACF
- Eye diagram

✓ Periodic clock signal with period 30 ns
Cyclostationary analysis

➢ Periodic autocorrelation function

✓ Clock signal
Cyclostationary analysis

➤ Cyclic autocorrelation function

✔ Clock signal
Cyclostationary analysis

- Cyclic spectrum

✓ Clock signal
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Time-domain detection

- Scanning area 36 x 24 mm
- Scanning step 3 mm

Starting point for scanning

Reference probe position

Scanning region
Time-domain detection

- Detection of data signal

✓ $H_X$ probe polarization
Time-domain detection

✓ $H_Y$ probe polarization, data signal
Time-domain detection

Detection of clock signal

✓ $H_X$ probe polarization
Time-domain detection

✔ $H_Y$ probe polarization, clock signal
3 mm probe under PCB

✓ $H_X$ probe polarization

✓ $H_Y$ probe polarization

✓ Signals in the probe

✓ Magnetic field vectors
3 mm probe under PCB

✓ $H_X$ probe polarization

✓ $H_Y$ probe polarization

✓ Signals in the probe

✓ Magnetic field vectors
3 mm probe under PCB

- $H_X$ probe polarization
- $H_Y$ probe polarization
- Signals in the probe
- Magnetic field vectors
10 mm probe under PCB

- $H_X$ probe polarization
- $H_Y$ probe polarization
- Signals in the probe
- Magnetic field vectors
10 mm probe above PCB

✓ $H_X$ probe polarization

✓ $H_Y$ probe polarization

✓ Signals in the probe

✓ Magnetic field vectors
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• The experimental results demonstrate the ability of the parameter estimation for the radiated emissions obtained from the measured random signals in the near-field region of the digital device.

• Cyclostationary properties of the radiating stochastic signals allow extracting cyclostationary signatures from the measured data in the near-field region.

• Detection of the signals with predefined cyclostationary signatures in the spatial region of interest gives the spatial energy distribution of the signal corresponding to the chosen radiating source.
Conclusion

• The near-field measurements of stochastic radiation from PCB can be used for the localization of EMI sources with predefined clock frequency.

• The improvement of the localization accuracy could be achieved by parametric identification procedure in addition to the conventional averaging and inverse technique for stochastic EM field.

• The proposed signal processing algorithms for the EMI sources localization and the approach for prediction of the enclose unintentional emissions pattern were verified by experimental measurements.
Acknowledgment

This work was supported by COST action IC1407 “Advanced characterization and classification of radiated emissions in densely integrated technologies (ACCREDIT)”
Thank you for your kind attention!

Questions?