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Submission Title: [A Crystal-less OFDM-based WBAN System]
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Abstract: [According to the WBAN requirements, an OFDM-based design is introduced, including the system behavior and specification. Besides, a crystal-less approach is proposed to reduce power consumption and achieve tiny area integration.]

Purpose: [Provide a possible solution for WBAN application.]

A Crystal-less OFDM-Based WBAN System

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March, 2009

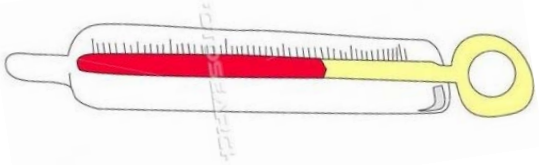
Outline

- Wireless body area network (WBAN)
- Requirements
- Proposed crystal-less OFDM-based system
  - System specification
  - Crystal-less approach
- Simulation and prototype
- Conclusion

Wireless Body Area Network

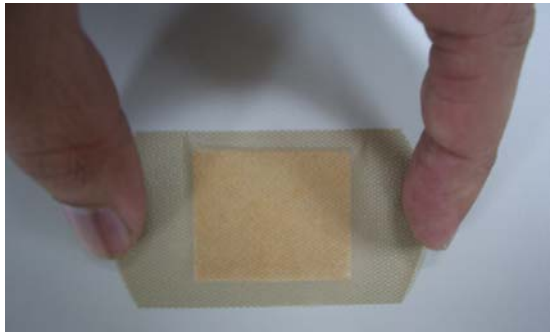
-Sensor network
-Multi-users
-Operation Environments

CPN



Requirements for WBAN

- Reliable transmission
  - High tolerance to multipath
  - Robust to external interference
  - Coexistence
- Low power
  - Long duration operation
- Tiny area integration
  - Comfortable monitoring



Proposed System Specification

- Application example: ECG monitoring
- Frequency band: 1395M Hz ~ 1400M Hz (WMTS)
- Signal bandwidth: 4M Hz
- Modulation: QPSK + OFDM
- Max data rate: 4.85M bps
- Information rate: 8k bps (16 bits 500 samples/sec.)
- Distance: 3 m
- WSN numbers: 12(sensor nodes) * 10(users)
- Multiple access: TDM
- Working duration: 7 days continuous monitoring

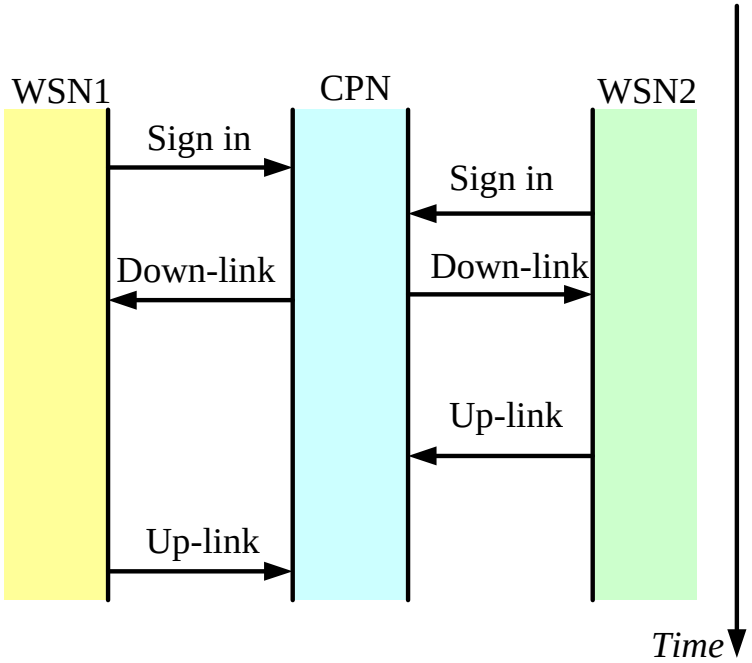
System Link Budget

Parameter	Value
Data rate (R_b)	5M b/s
Tx power (P_T)	0 dBm
Tx antenna gain (G_T)	-15dBi
Geometric center frequency	1397.5M Hz
Path loss at 1 meter (L_1)	35.5 dB
Path loss at 3 meter (L_2)	10 dB
Path loss at TX/RX angle	20 dB
Rx antenna gain (G_R)	2 dBi

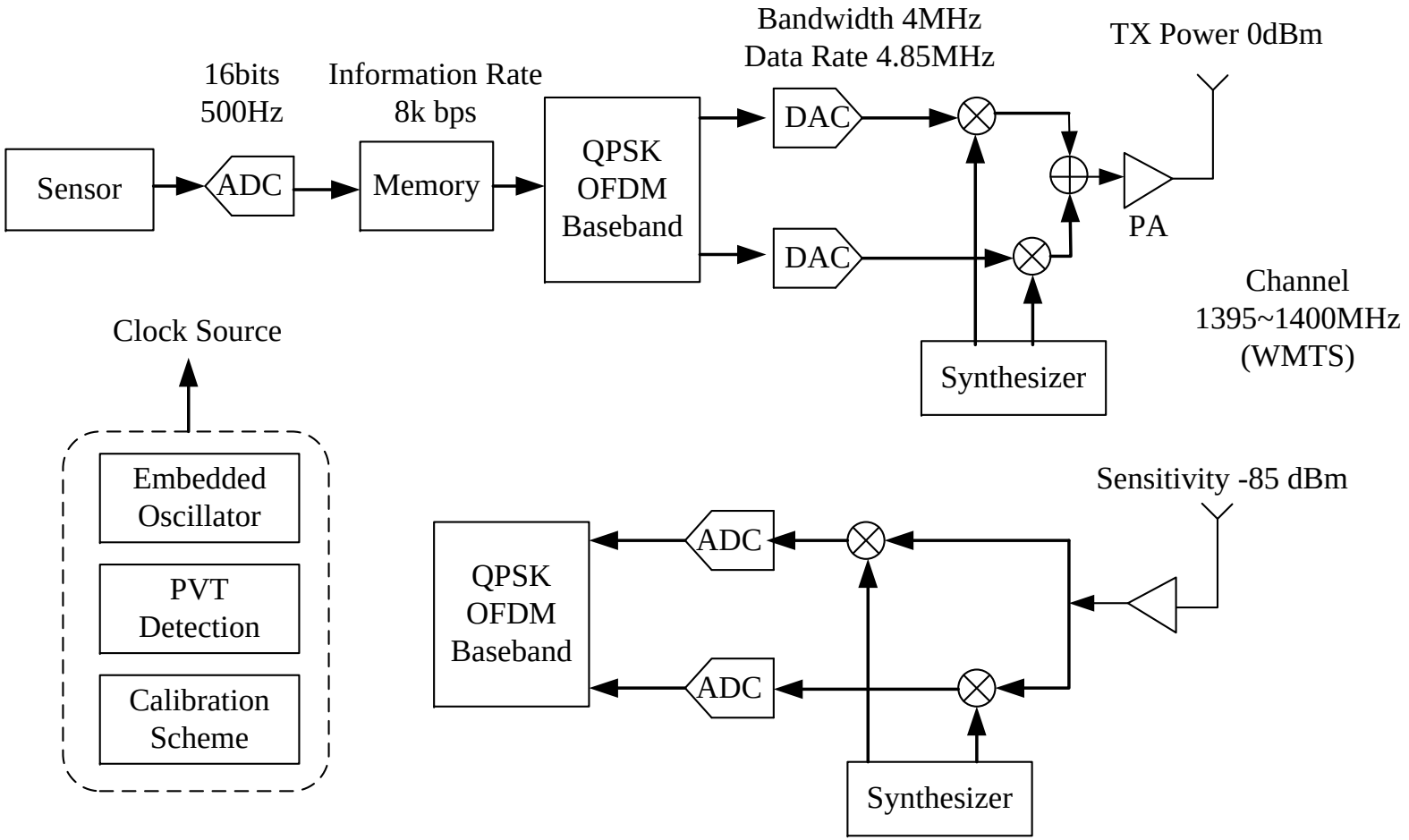
Parameter	Value
Rx power ($P_R = P_T + G_T + G_R - L_1 - L_2 - L_3$)	-78 dBm
Average thermal noise per bit ($N = -174 + 10*\log10(R_b)$)	-107 dBm
Rx noise figure referred to the antenna terminal (N_F)	7 dB
Average noise per bit ($P_N = N + N_F$)	-100 dBm
Required E_b/N_0 (S)	12
Implementation loss (I)	3
Link margin ($M = P_R - P_N - S - I$)	7
Proposed min. Rx sensitivity level	-85 dBm

System Operation Behavior

- 2-direction communication:
  - Down-link: (CPN to WSN)
    - Network synchronization
    - Transmit network information
    - Network behavior control
    - Estimate the channel
  - Up-link: (WSN to CPN)
    - Transmit body information

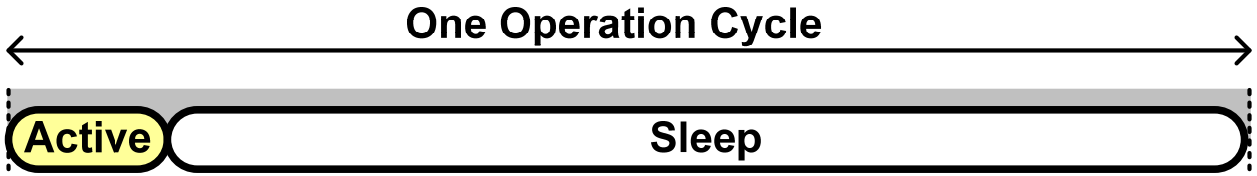


WSN Architecture



Power Estimation

- Information rate: 8k bps. Data rate: 4.85 M bps
  - Duty cycle: 0.165%

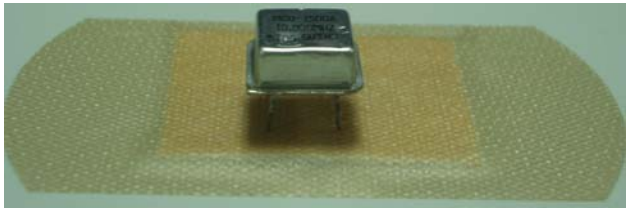


- Power estimation:
  - Baseband + Data converter : 1mW
  - Synthesizer : 4mW
  - PA: 10mW
  - Total active power: 15mW (Active) ; leakage power: 0.15mW (1%) *
  - Sensor + ADC + storage: 2mW (ECG sensor, 16bits 500Hz ADC)
- WSN average power: 2.17475mW
  - About 275 hours for 200mAh battery

*: Jui-Yuan Yu, Ching-Che Chung, Wan-Chun Liao, and Chen-Yi Lee, "A sub-mW Multi-Tone CDMA Baseband Transceiver Chipset for Wireless Body Area Network Applications," ISSCC Dig. Tech. Papers, pp. 364-365, Feb. 2007.

Why Crystal-less ?

- Crystal cost: *
  - Power:
    - In-crystal power: 1mW~200mW
    - Oscillator power: 1mW~50mW (active)
      10 μW~50 μW (standby)
  - Area:
    - 3.2mm x 2.5mm x 0.55mm (SMD)
    - 11.5mm x 4.7mm x 3.5mm (DIP)



- Use embedded oscillator to replace the crystal

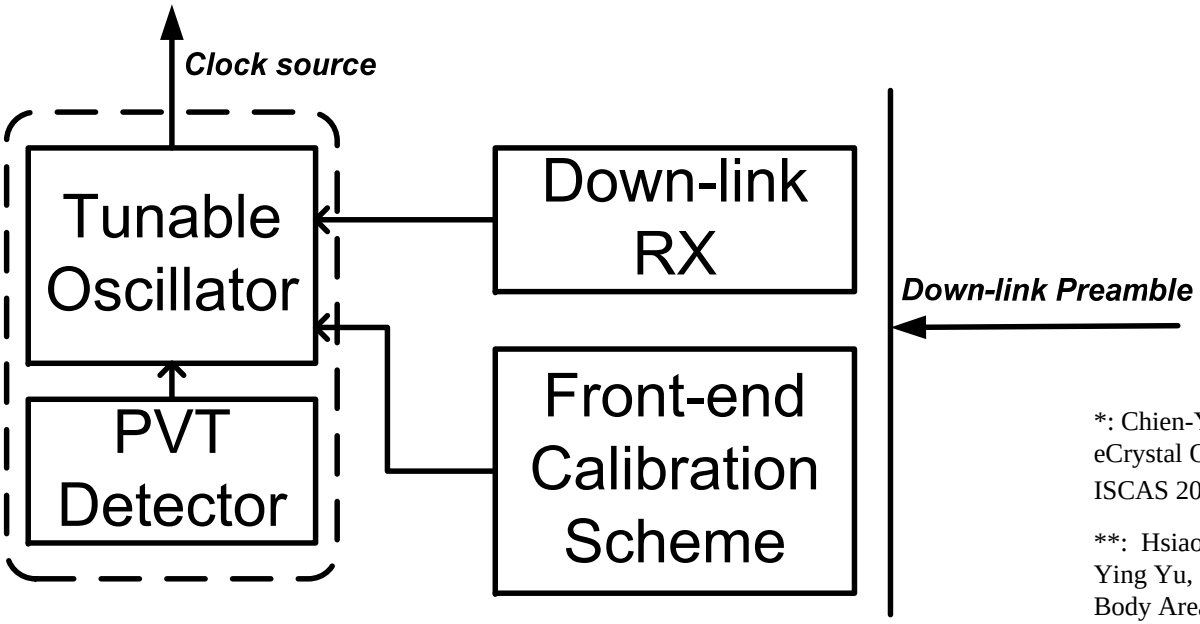
*** Citizen [Online]. Available: http://www.citizencrystal.com**

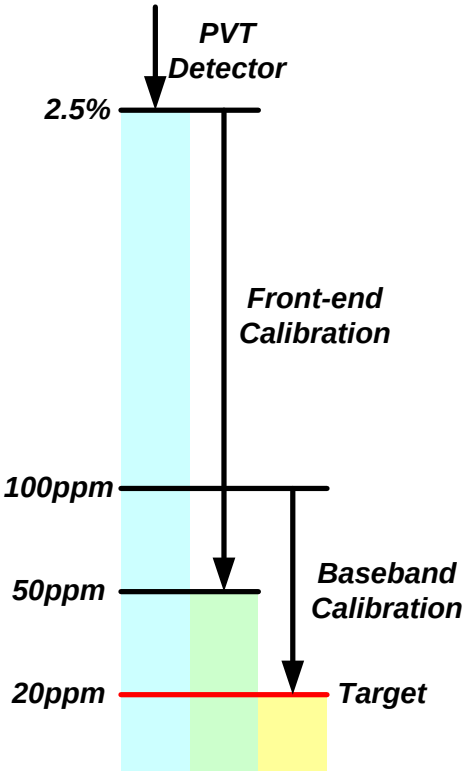
Crystal-less Approach

- CMOS oscillator:
  - μ-level power consumption, SOC integration
- Oscillator circuit has less accuracy and causes larger frequency mismatch.
  - Carrier frequency offset (CFO)
  - Sampling clock offset (SCO)
  - State-of-the-art transmission tolerance: 20~40 ppm
- Proposed crystal-less specification:
  - Initial error: 2.5%
  - Front-end calibration: 50~100 ppm
  - Baseband frequency mismatch tolerance: 100 ppm

Mismatch Calibration

- Embedded oscillator with PVT detector *
- Front-end calibration
- Baseband DSP **



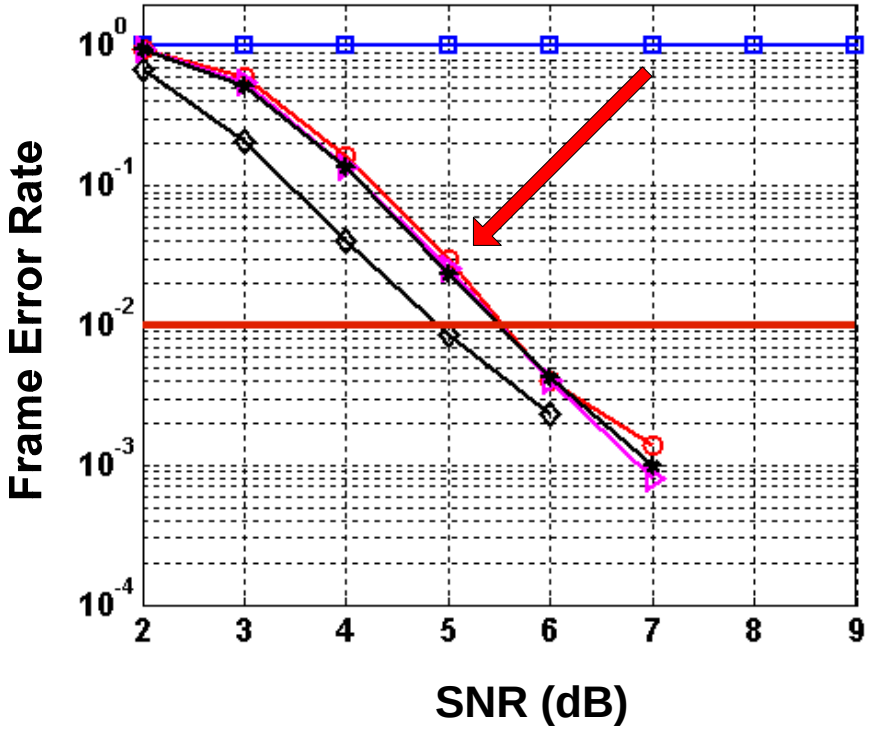


*: Chien-Ying Yu, Jui-Yuan Yu, and Chen-Yi Lee, "An eCrystal Oscillator with Self-Calibration Capability," IEEE ISCAS 2009, to be published.

**: Hsiao-Han Ma, Jui-Yuan Yu, Tsan-Wen Chen, Chein-Ying Yu, and Chen-Yi Lee, "An OFDMA Scheme Wireless Body Area Network with Frequency Pre-Calibration," in Proc. 2008 IEEE VLSI-DAT, pp. 192-195, Apr.2008

Performance Simulation

- Proposed OFDM system + baseband frequency mismatch calibration: extend the mismatch tolerance to 100ppm

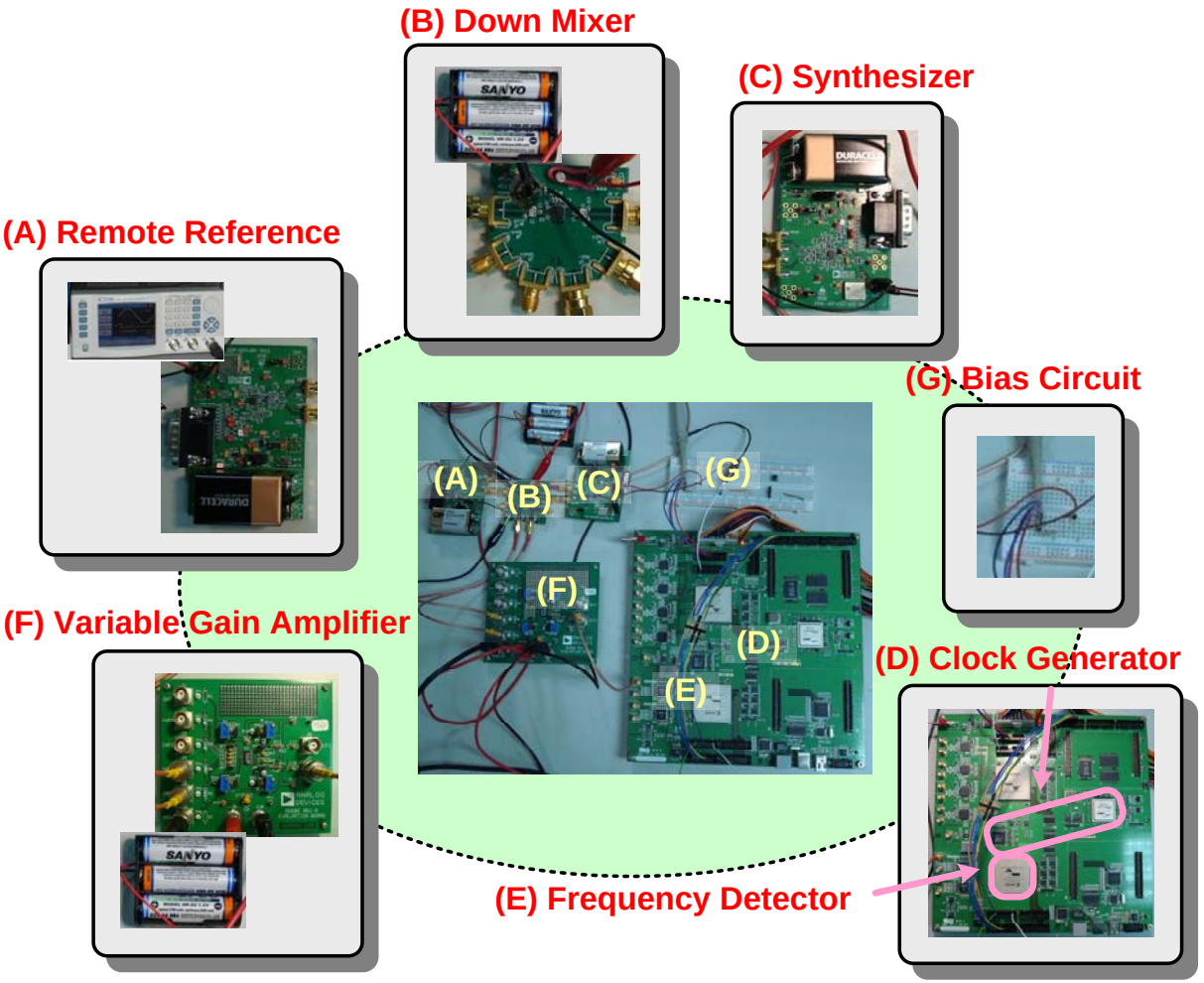


	pre-cal.	CFO (ppm)	SCO (ppm)
	NO	0	0
	NO	0	20
	NO	100	100
	YES	100	100
	YES	0	20
	Design target		

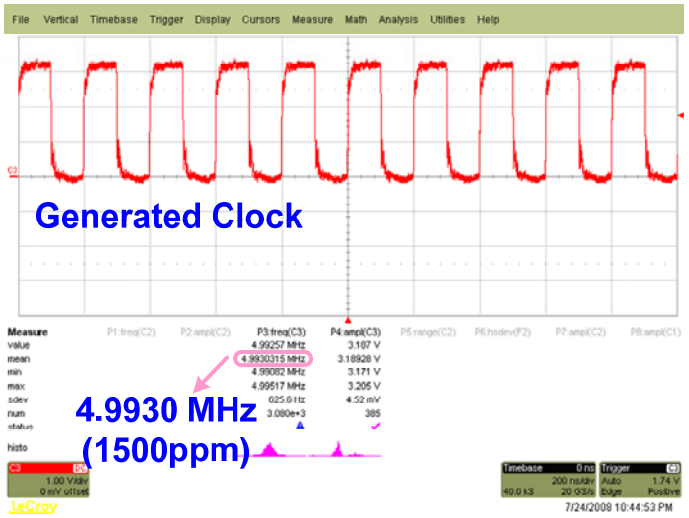
Ps1. Simple (2,1,6) convolution code is used in this simulation
Ps2. Simulation in AWGN channel + CFO + SCO

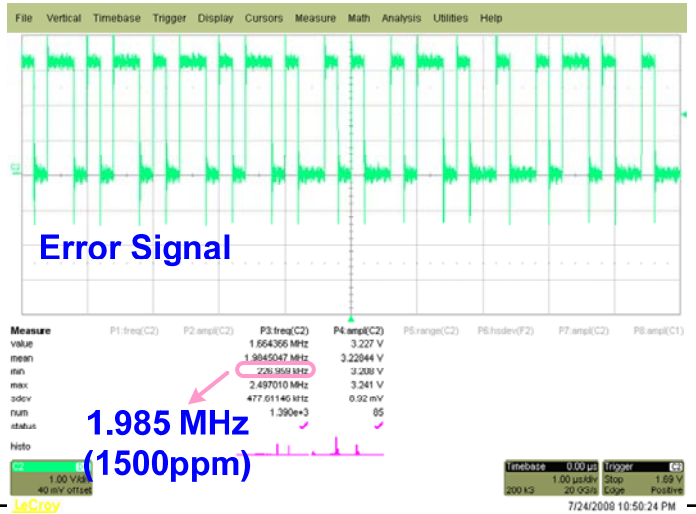
Prototype Construction

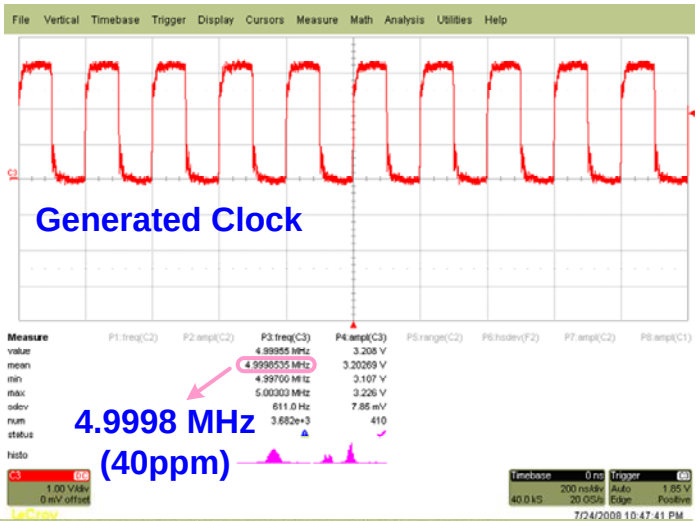
- Front-end calibration
- Reference tone at 1.4GHz
- System clock: 5MHz

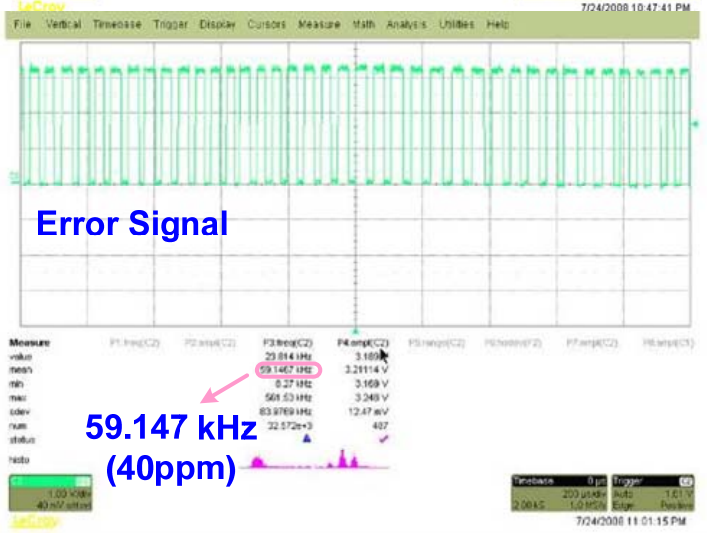


Testing Results









Conclusion

- OFDM-based WBAN system
  - WMTS band (1395MHz ~ 1400MHz)
  - OFDM QPSK modulation
  - 4.85MHz data rate
  - Continuous working more than 7 days
  - Reliable, low power
- Crystal-less approach
  - Use embedded oscillator instead of crystal
  - Power reduction and tiny area integration

Acknowledgment

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Reference

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