Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [A Crystal-less OFDM-based WBAN System]
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Source: [Tsan-Wen Chen, Jui-Yuan Yu, Chien-Ying Yu, and Chen-Yi Lee]
Company [National Chiao Tung University (NCTU), Taiwan]
Address [1001 University Road, Hsinchu, Taiwan 300, ROC]
Voice:[+8863-5712121-59395]
FAX: [+8863-5710638]
E-Mail:[{goodidea,blues,cyyu,cylee}@si2lab.org]

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

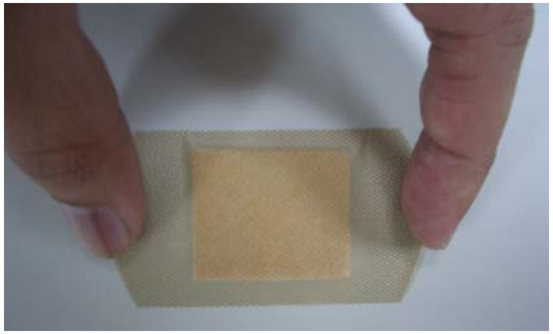
Tsan-Wen Chen
National Chiao Tung University
March, 2009

Outline

- Requirements
- Proposed crystal-less OFDM-based system
  - OFDM-based system
    - Specification and behavior
    - Preliminary results
  - Crystal-less approach
    - Specification
    - Simulation and prototype
- Conclusion

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

- ECG monitoring, wearable medical application
- Frequency band: 1395M Hz ~ 1400M Hz (WMTS)
- Modulation: QPSK + OFDM
- Signal bandwidth: 4M Hz
- Max data rate: 5M bps (no FEC coding)
- Spectrum efficiency: 1.25 (bps)/Hz
- Body information rate: 8k bps (16 bits 500 samples/sec.)
- Distance: 3 m
- Sensor node numbers: 12(sensor nodes) * 10(users)
- Multiple access: TDM
- Working duration: 7 days continuous monitoring

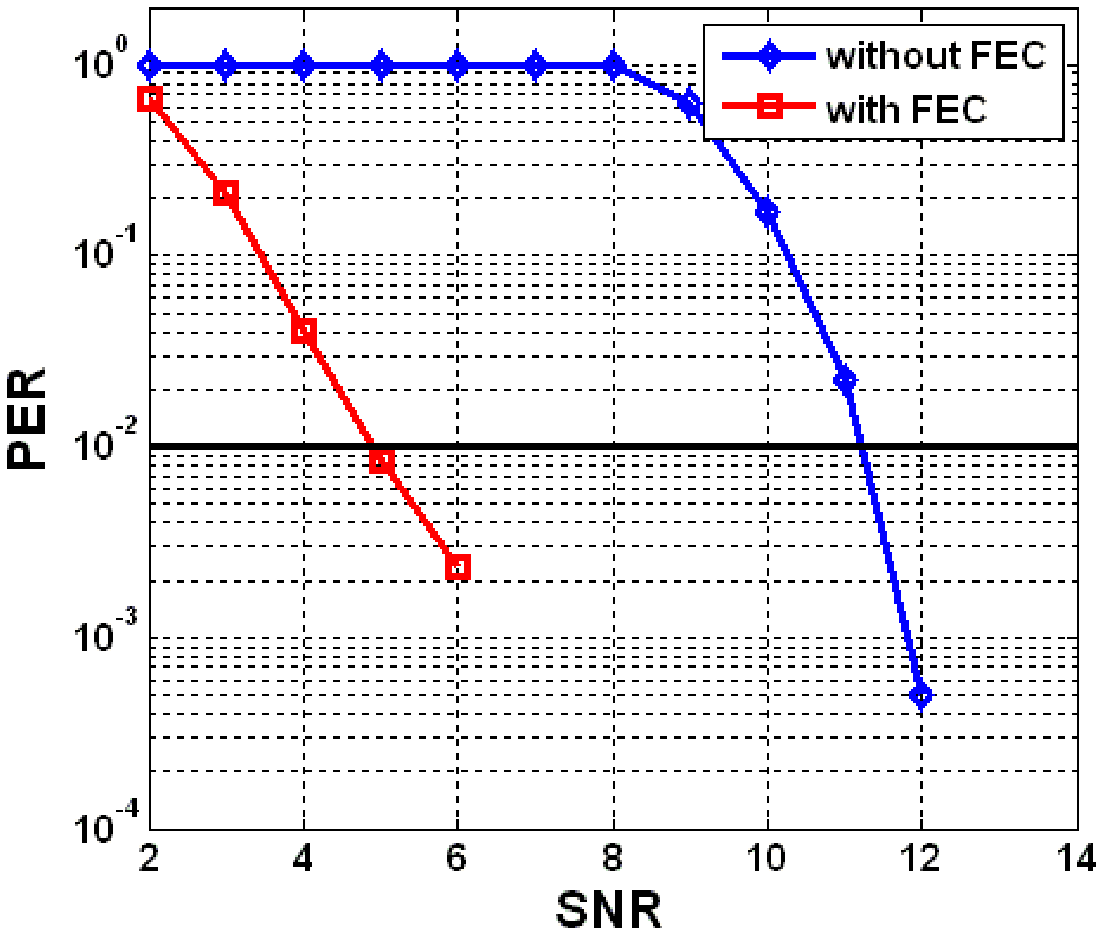
Why OFDM?

- Narrow band, high data rate
- Medical application
  - Medical band are often narrow
  - High spectrum efficiency
- Robust to multi-path effect

- Power consumption comparison?
  - High information rate
  - Low information rate

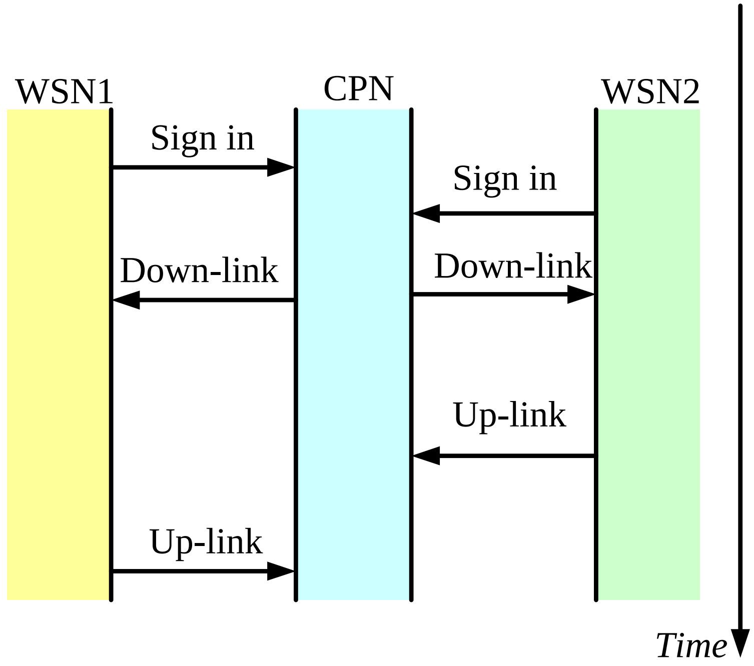
Performance Simulation

- OFDM QPSK, AWGN channel
- (2,1,6) convolution code
- PER=1%, Required SNR: 11.5dB

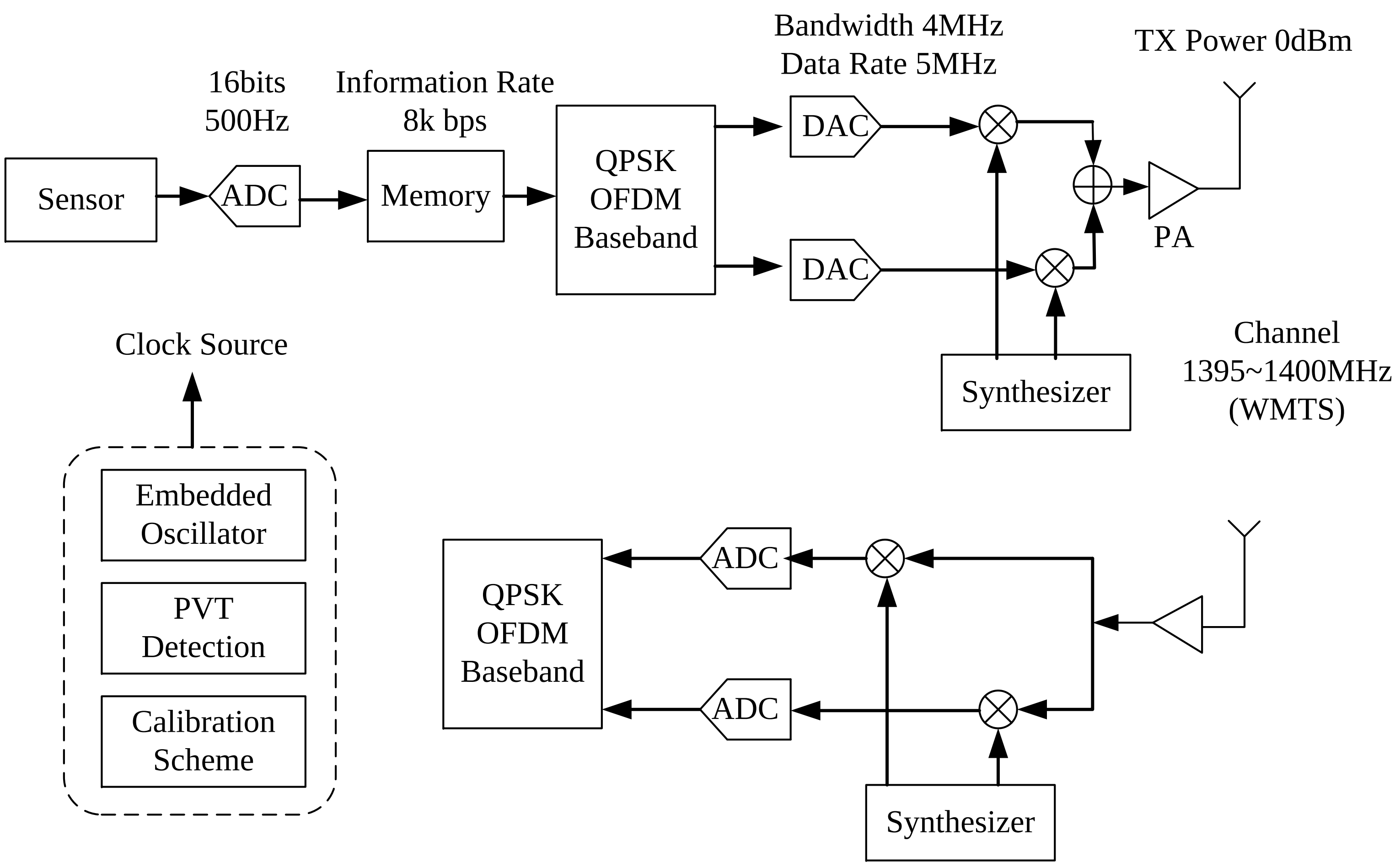


System Operation Behavior

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

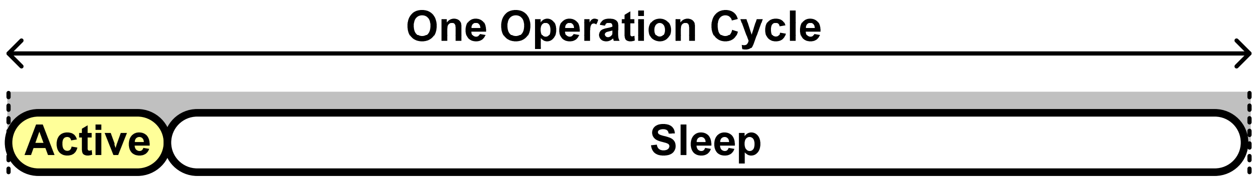


Sensor Node Architecture Example



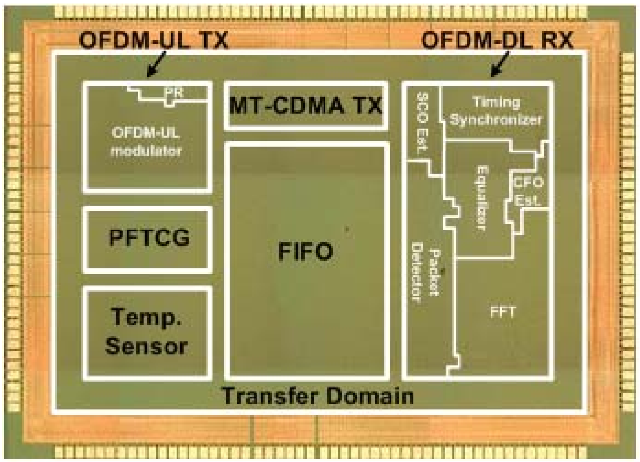
Power Estimation

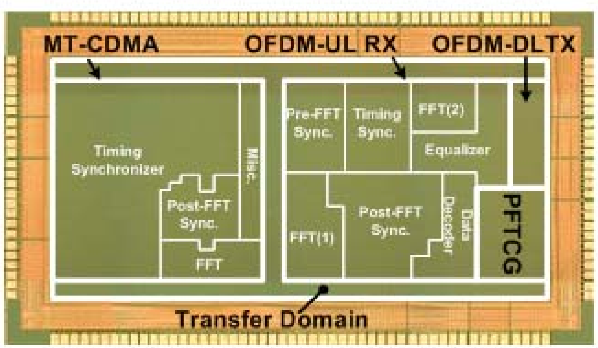
- Information rate: 8k bps.   Data rate: 5 M bps
  - Active duty cycle: **0.16%**



- 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)
- Sensor node average power: 2.174mW
  - More than 275 hours for 200mAh 3V battery

Preliminary Results





- Baseband chip

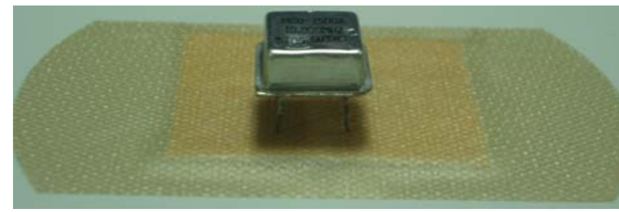
Technology	Standard 90nm SPHVT/SPRVT CMOS
Max Data Rate	4.85Mbps(OFDM) 143kbps(MT-CDMA)
Die Size	WSN:2191μm x 3030μm CPN:1980μm x 2980μm

WSN		CPN	
Total Modulator	5.52μW	DL-TX	3.94μW
		UL-RX	520μW
		MT-RX	490μW
FIFO+TS	289.5μW	N/A	N/A
PFTCG	145.8μW	PFTCG	145.8μW

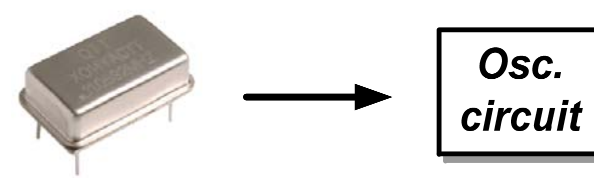
Crystal-less Approach for Sensor Node

Why Crystal-less ?

- Always-on function blocks
- 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



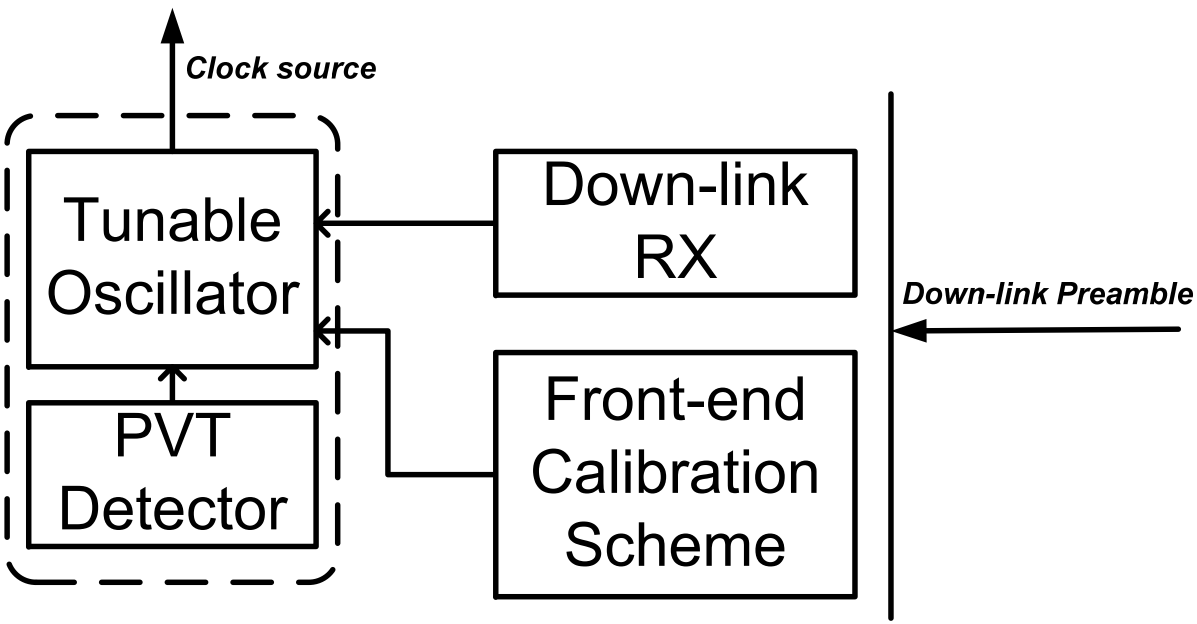
*** Citizen [Online]. Available: http://www.citizencrystal.com**

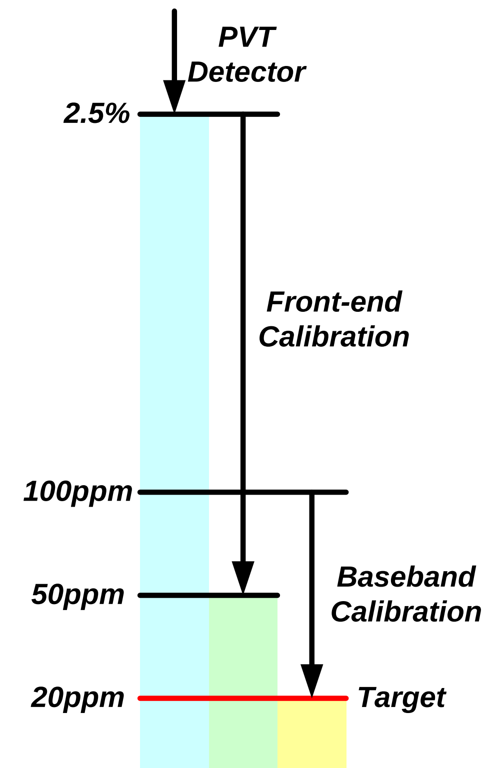
Crystal-less Approach for Sensor Node

- CMOS oscillator:
  - μ -level power consumption, single chip 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 approach:
  - Calibration before up-link transmission
- Proposed crystal-less specification:
  - Min. error: < 20ppm (for OFDM)

Mismatch Calibration

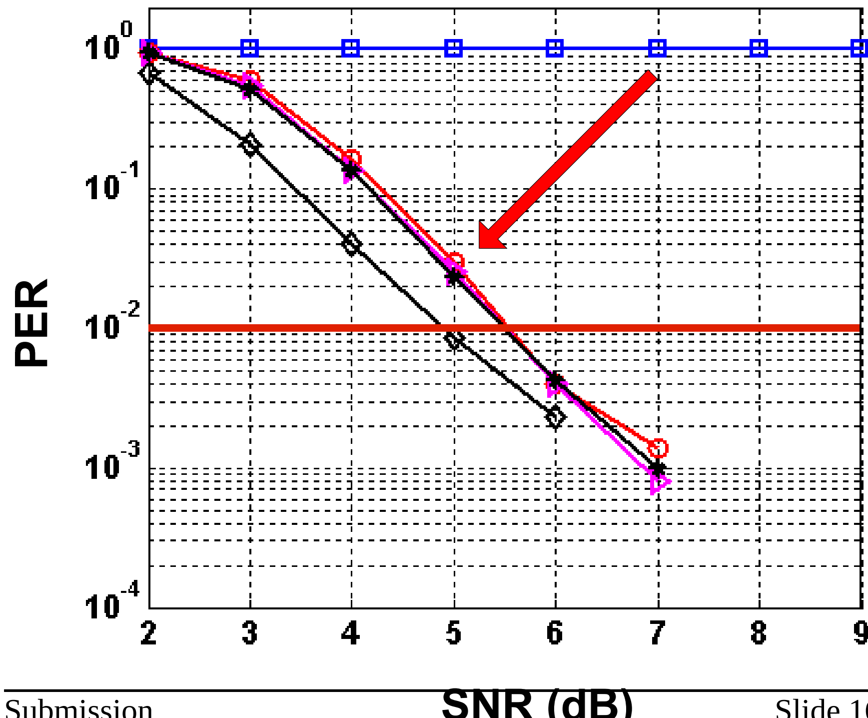
- Embedded oscillator with PVT detector*
- Front-end calibration
- Baseband DSP





Simulation

- OFDM system + baseband estimation + mismatch calibration
- Use 25 OFDM down-link preambles

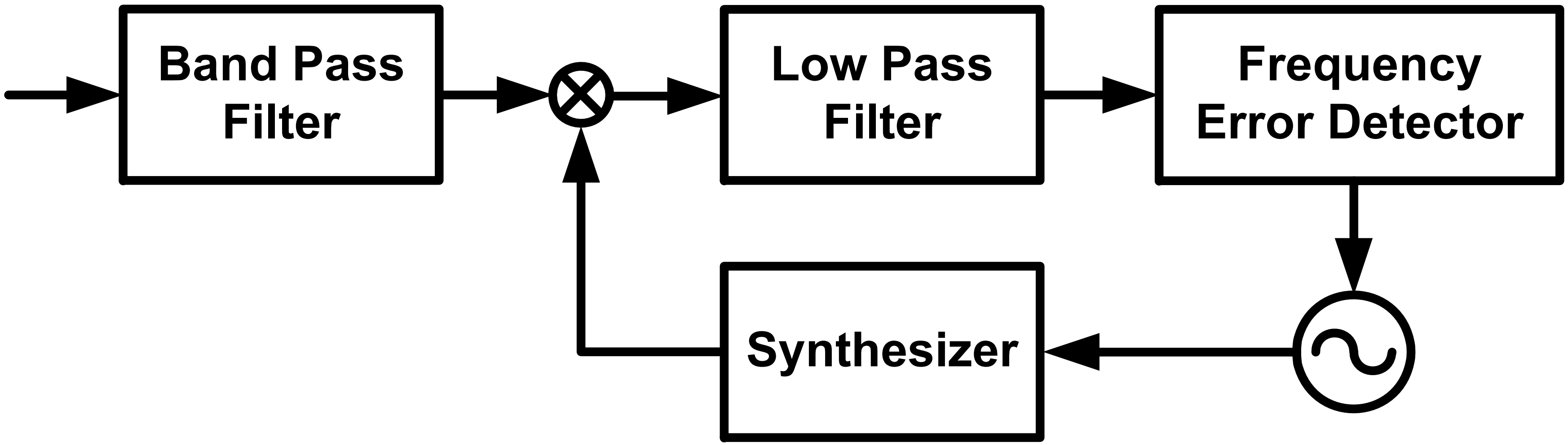


	pre-cal.	CFO (ppm)	SCO (ppm)
	NO	0	0
	NO	0	20
	NO	100	100
	YES	100	100
	YES	0	20
	Design target		

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

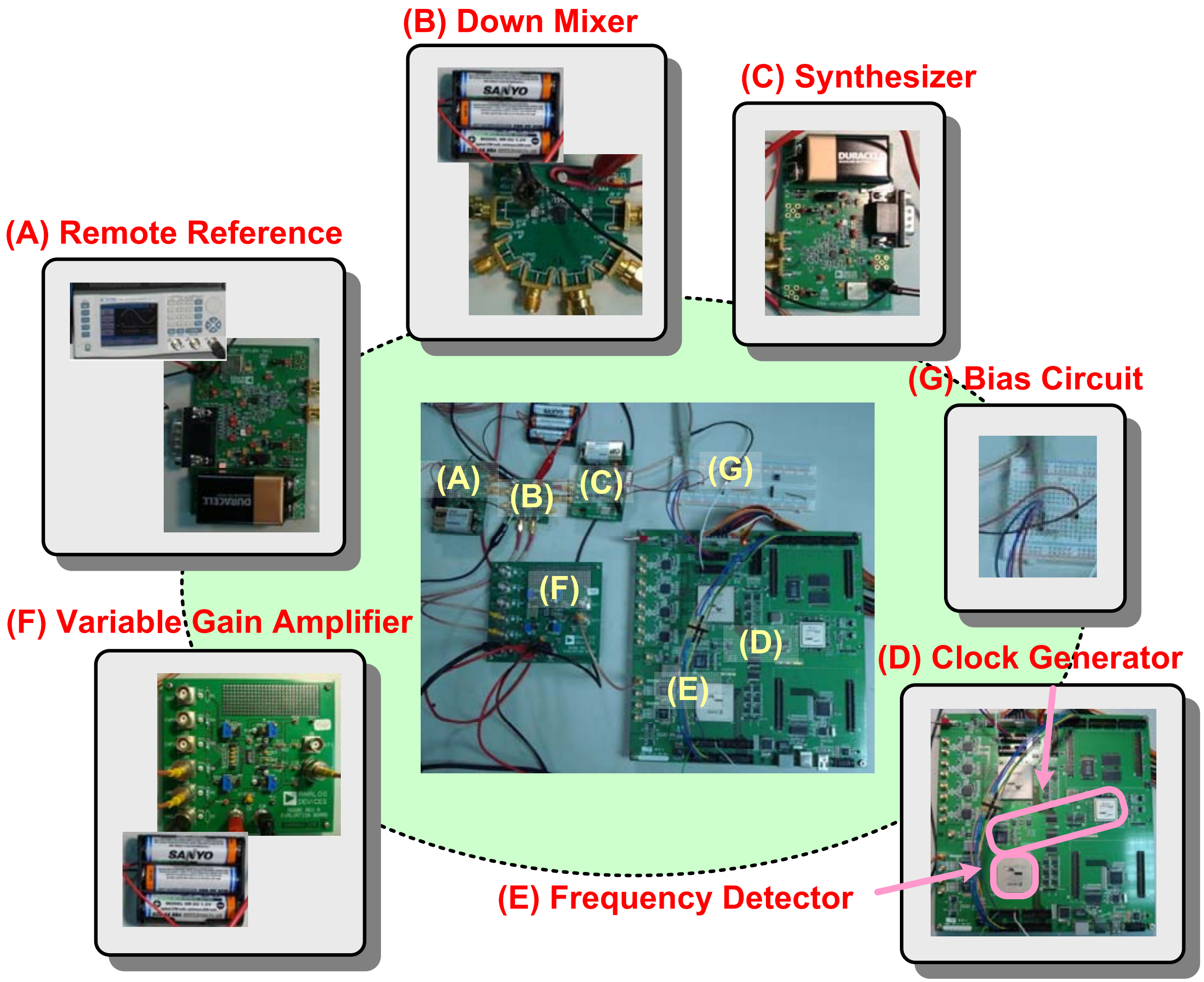
Front-end Calibration Example

- CPN transmit a reference tone

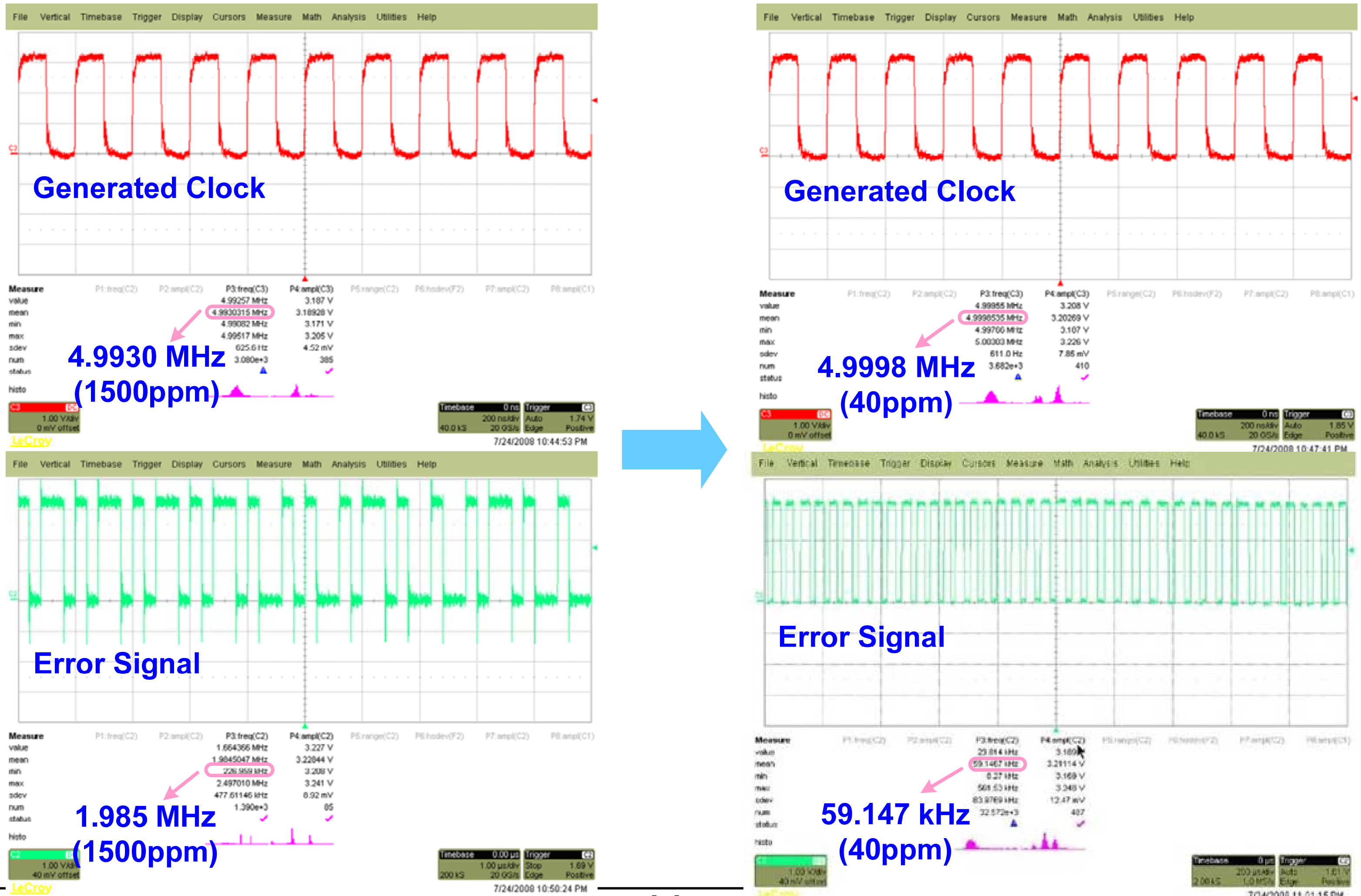


Prototype Construction

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



Testing Results

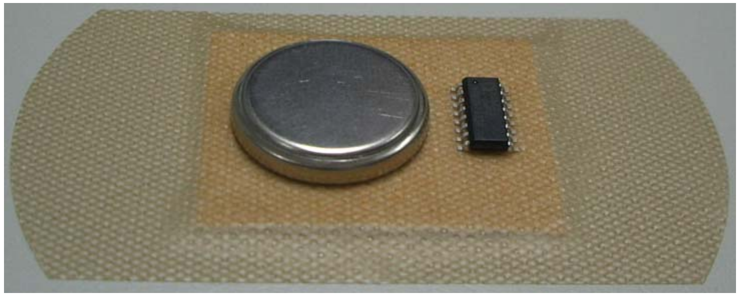


Summary

- Using embedded oscillator to replace the crystal is possible
- Can support required reference clock accuracy for different transmission scheme
- Require more down-link preamble flexibility and MAC control to calibrate the mismatch before up-link transmission

Conclusion

- OFDM-based WBAN system
  - Narrow band solution => WMTS band for example (1395MHz ~ 1400MHz)
  - High data rate
  - OFDM QPSK modulation
  - Reliable transmission



- Crystal-less approach
  - Use embedded oscillator instead of crystal
  - Power reduction and tiny area integration
  - Required suitable PHY and MAC support

Acknowledgment

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Reference

- Citizen [Online]. Available: http://www.citizencrystal.com
- 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
- Jui-Yuan Yu, Chien-Ying Yu, Shang-Bin Huang, Tsan-Wen Chen, Juinn-Ting Chen, Kuan-Ling Kuo, and Chen-Yi Lee, “A 0.5V 4.85Mbps Dual-Mode Baseband Transceiver with Extend Frequency Calibration for Biotelemetry Applications,” IEEE ASSCC 2008, pp. 293-296, Nov. 2008
- 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.
- Federal Communications Commission, “Amendment of Parts 2 and 95 of the Commission’s Rules to Create a Wireless Medical Telemetry Service,” FCC Washington, D.C., Rep. FCC00-211, 2000.
- Chien-Ying Yu, Jui-Yuan Yu, and Chen-Yi Lee, “An eCrystal Oscillator with Self-Calibration Capability,” IEEE ISCAS 2009, to be published.