A BPSK demodulator for a crystal-free mote-on-chip

July 20, 2022

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- SCµM exclusively uses on-chip oscillators, including a 2.4-GHz LC oscillator to synthesize the communication frequency.
- LC oscillator drifts at 2100 ppm over a temperature range of 45C.
- Continuous Calibration (CoCa) : SCµM tracks and compensates for the drift of its oscillators.
- BPSK modulation requires efficient phase/frequency synchronization algorithms

⇒ How to demodulate the BPSK-modulated IEEE 802.15.4 frames?

Contents

- The PHY Protocol Data Unit (PPDU) is formatted as:

SHR	PHR	PHY payload

- The SHR field is formatted as:

Preamble	SFD

- The SFD is a field indicating the end of the SHR and the start of the packet data:

Bits: 0	1	2	3	4	5	6	7
1	1	1	0	0	1	0	1

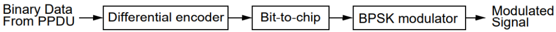
- The PHR is formatted as:

Bits: 0–6	7
Frame Length	Reserved

- Enhanced Beacon frame format:

Octets: 2	0/1	variable	variable	variable		variable	2/4
Frame Control	Sequence Number	Addressing fields	Auxiliary Security Header	IEs		Beacon Payload	FCS
				Header IEs	Payload IEs		
MHR					MAC Payload		MFR

- BPSK reference modulator block diagram:



- Differential encoding:

$$E_n = R_n \oplus E_{n-1}$$

where

R_n	is the raw data bit being encoded
E_n	is the corresponding differentially encoded bit
E_{n-1}	is the previous differentially encoded bit

- Bit-to-chip mapping:

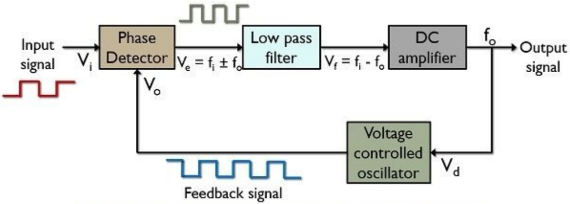
Input bits	**Chip values (c_0 c_1 ... c_{14})**
0	1 1 1 1 0 1 0 1 1 0 0 1 0 0 0
1	0 0 0 0 1 0 1 0 0 1 1 0 1 1 1

Contents

- Step 1: Optical Calibration
  - ⇒ The resulting calibration of the 2-MHz RC oscillator is within the 1000 ppm target
  - ⇒ The calibration of the 2.4-GHz LC oscillator is, however, not within the 40-ppm target
- Step 2: Frequency Sweep
  - With CoCA, SCµM sweeps LC frequency setting from (23.31.31) to (24.31.31), listening for Beacon frames
  - SCµM records the best setting on which it received Beacon frames as its RX frequency setting.

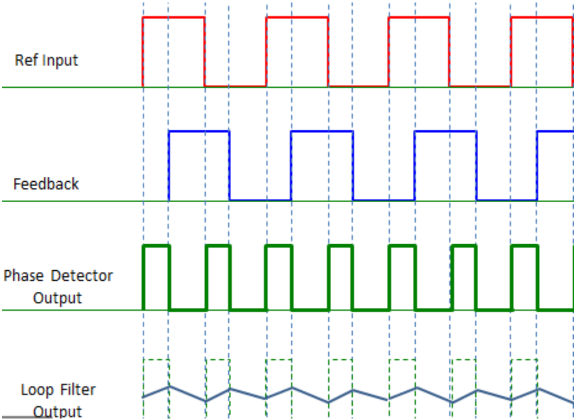
⇒ How to correctly receive beacons sent with BPSK modulation?

XOR based PLL

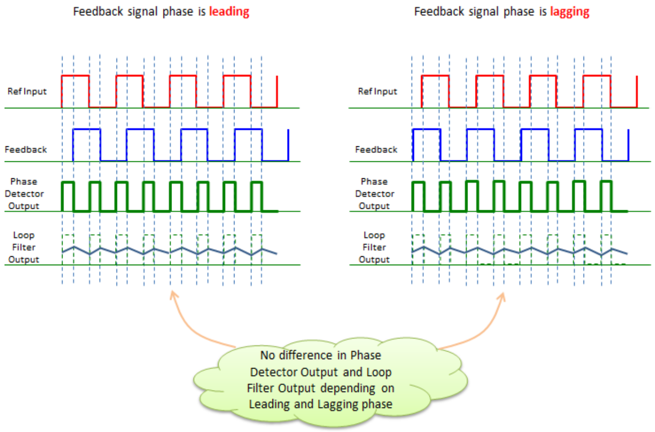


Block Diagram of Phase-Locked Loop

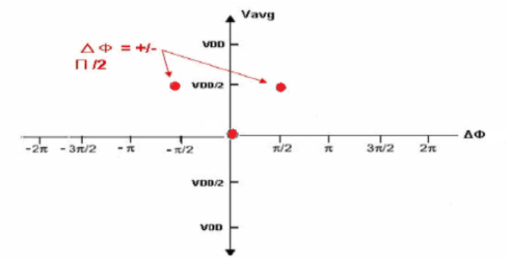
XOR based PLL



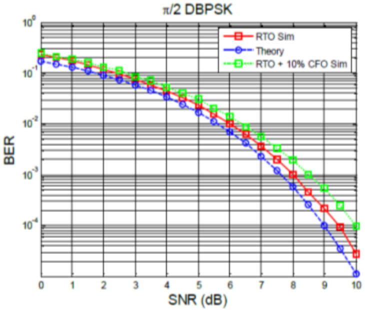
XOR based PLL



XOR based PLL



* Frame synchronization
* Frequency synchronization
* Time synchronization
* Phase synchronization



T. Arbi, B. Geller, "Multi-standard Receiver for Medical IoT Sensor Networks," *Chap. 5 Challenges of the Internet of Things, 2018,* Wiley, ISBN : 9781786303615, Sept. 2018.

Thank!