A Survey on FM-UWB Transceivers

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ABSTRACT
This paper surveys the research on frequency modulated ultra-wideband (FM-UWB) transceivers. FM-UWB system uses low modulation index digital FSK followed by high modulation index analog FM to generate a constant envelope UWB signal with a flat power spectral density and steep spectral roll-off. FM-UWB can be seen as an analog implementation of a spread spectrum system with spreading gain equal to the modulation index. FM-UWB system is suitable for low data rate and short-range applications. The advantages of FM-UWB system such as low power consumption, very low radiated power (−41.3 dBm/MHz), good coexistence with other existing wireless technologies, and robustness to interference and multipath making it suitable for Wireless Body Area Network (WBAN) in medical applications.

General Terms
Ultra-wideband (UWB), UWB transceivers.

Keywords
Ultra-wideband (UWB), FM-UWB, Wireless Body Area Network (WBAN).

1. INTRODUCTION
Ultra-wideband (UWB) is a promising technology for short-range and low data rate wireless communications, especially for wireless personal area network (WPAN) and wireless body area network (WBAN) systems. This tremendous growth began after the release for unlicensed uses of the UWB applications within the 3.1-10.6 GHz frequency band by Federal Communications Commission (FCC) in 2002 [1].

Two UWB techniques are considered for short range and low cost UWB systems; impulse radio UWB (IR-UWB) and frequency modulated UWB (FM-UWB). In the IR-UWB system, a sequence of extremely short pulses is transmitted through an antenna [2]. Thus, IR-UWB is a carrier-less transmission technique. However, because of using low duty pulses, synchronization between the transmitter and the receiver becomes very challenging, which increases hardware complexity and power consumption.

On the other hand, the FM-UWB system generates a constant-envelope UWB signal with wideband FM modulation, featuring a very steep spectral roll off [3], [4]. Since the FM-UWB receiver can perform FM demodulation without a local oscillator, carrier synchronization is not needed as in the case of the IR-UWB. This makes the overall system design simple and robust. The FM-UWB system is suitable for short-range (<10 meters), low and medium data rate applications (up to 250 kbps).

The advantages of FM-UWB system such as low power consumption, very low radiated power (−41.3 dBm/MHz), good coexistence with other existing wireless technologies, and robustness to interference and multipath making it suitable for Wireless Body Area Network (WBAN) in medical applications[5]. Furthermore, the low radiated power of the FM-UWB is safe for human tissue exposure, which enables FM-UWB to be used as both a sensing and a communication standard for biomedical applications, which gives compact implementation in terms of integrated system [6-9].

2. FM-UWB TRANSMITTER
FM-UWB is an analog implementation of a spread spectrum system with spreading gain equal to the modulation index. Figure 1 shows the block diagram of the FM-UWB transmitter. It uses low modulation index digital FSK to encode binary data onto a sub-carrier followed by high modulation index analog FM of the RF carrier to create a constant-envelope UWB signal [3].

The power spectral density of a wideband FM signal reflects the probability density function of the sub-carrier signal m(t) [10]. Triangular subcarrier waveforms have a uniform probability density function and therefore, produce a flat RF spectrum.

The transmitter comprises a subcarrier oscillator in the range of MHz to generate a triangular signal that is FSK modulated by the transmitted data. The subcarrier signal m(t) modulates the RF VCO, generating a constant-envelope UWB signal with a flat power spectral density and steep spectral roll-off.

Figure 2 shows the data, the subcarrier and the UWB signals in the time domain for a data transition at t = 0. Sub-carrier frequency is 1 MHz; the center frequency of the UWB signal was scaled down for the sake of clarity.

A multi-user system may use conventional time-division multiple access (TDMA) or RF frequency division multiple access (FDMA) techniques and also subcarrier FDMA, i.e., different users can be distinguished by different subcarrier frequencies.

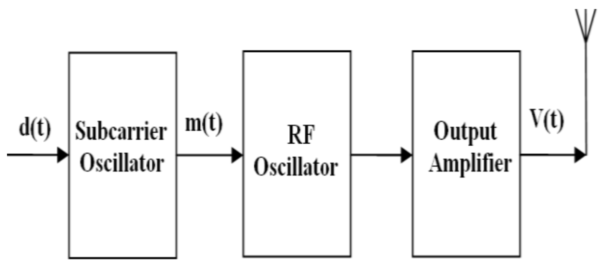

Fig 1: FM-UWB transmitter block diagram

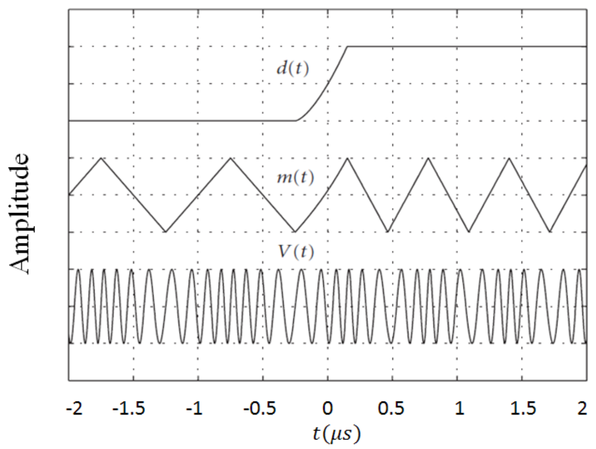

Fig 2: Data d(t), sub-carrier m(t), and UWB signal V(t)

2.1 Subcarrier Generation

Direct Digital Frequency Synthesizer (DDFS) is used in the subcarrier generation [11]. In order to provide a digital FSK modulation with high accuracy, a ΔΣ fractional-N PLL is used, instead of using a direct digital frequency synthesizer (DDFS), to generate the subcarrier [12], [13].

For high data rate FM-UWB, >250kbps, the frequency of the subcarrier should be increased. The use of DDFS for high frequency subcarrier generation requires another PLL to generate the high clock frequency. This increases the power consumption of the DDFS. Instead, a finite-modulo fractional-N PLL is used to provide high frequency subcarrier generation [14], [15]. In [16], [17], a successive approximation register frequency-locked loop (SAR-FLL) is used to calibrate the subcarrier frequency which is generated by a relaxation oscillator.

2.2 RF Carrier Generation

The most challenging part of the transmitter design is the RF VCO. Many ring VCOs operating at UWB frequencies have been presented in the literature [18-20]. Ring VCO has a wide tuning range and it consumes less silicon area but it suffers from high power consumption and poor phase noise performance. Furthermore, ring VCO is susceptible to supply, temperature, and process variations [21], [22], which make it unsuitable for FM-UWB applications. Hence, LC VCO is a better choice for FM-UWB applications. Furthermore, several LC VCOs operating at the UWB frequencies have been reported [23-31] and are widely used in FM-UWB transmitters for RF carrier generation [12-15], [32-34]. Table 1 provides a comparison among the most recent published VCOs operating at the UWB frequencies. It is clear from the table that the ring VCO consumes more power than the LC VCO and has poorer phase noise than that of the LC VCO. Also current-controlled ring oscillator (ICO) can be used as the RF source, where the triangular voltage is converted to a current by transconductor, gm [16], [17].

Due to that RF oscillator is open loop modulated and to avoid out of band operation, RF frequency is periodically calibrated. Different techniques have been used to calibrate the RF frequency. A digitally configurable duty-cycled frequency-locked loop has been used in [12].

The RF frequency is quasi-continuously tuned by a Δ−Σ DAC based frequency-locked loop in [13], [15]. In [14], a semi-digital quasi-continuous frequency-locked loop (FLL) has been used, which enables digital tuning of the UWB frequency band. A successive approximation register frequency-locked loop (SAR-FLL) has been used to calibrate the RF oscillator frequency in [16], [17]. A single-loop integer-N PLL frequency synthesizer has been used to calibrate the VCO in [32] where multiple lock signals have been used to identify coarse frequency lock and fine phase lock. And to achieve low power requirements, the PLL is only powered up for VCO calibration.

2.3 The Output Amplifier (OA)

The output amplifier (OA) drives the antenna and also isolates it from the RF VCO. The OA consumes most of the total transmitter power to maximize the link span between transmitter and receiver. FM-UWB generates a constant envelope RF signal that enables the OA to operate at its maximum power output where its efficiency is highest [17], [32].

Table 1. VCOs performance comparison

Ref.	**Type**	**Tech.**	**VDD (V)**	**Power (mW)**	**Tuning Range (GHz)**	**Phase Noise (dBc/Hz@1MHz)**	**FOM**
[18]	Ring	180nm CMOS	1.5	9.5	2.7-4.1	-70	-
[19]	Ring	130nm CMOS	1.2	7.48	2.41-7.63	-84.87	-153.3
[20]	Ring	180nm CMOS	1.8	48	7.95-8.45	-88.24	-
[23]	LC	90nm CMOS	1.6	14	4.5-7.1	-108.5	-172
[24]	LC	130nm CMOS	1.8	7.8	3.31-4.83	-120.7	-185.5
[25]	LC	90nm CMOS	1.2	7.67	8.11-15.38	-103.9	-
[26]	LC	In GaP/GaAs	16	228.3	5.6-16.8	-112	-200
[27]	LC	130nm CMOS	1.5	1.32	3.841-5.381	-120.63	-192.13
[28]	LC	180nm CMOS	1.8	6.4	4.9-5.46	-100.3@100K	-187
[29]	LC	180nm CMOS	0.8	3.92	4.567-5.832	-116.708	-183.3
[30]	LC	180nm CMOS	1.8	5.9	3.47-5.46	-119	-187.4
[31]	LC	130nm CMOS	1.2	5	3.8-5.6	-119.21	-184.9

3. FM-UWB RECEIVER

Figure 3 shows the block diagram of the FM-UWB receiver. The receiver in its basic form consists of a wideband FM demodulator, one or several low frequency subcarrier filtering and amplification stages, and subcarrier demodulators [3]. The receiver demodulates the FM-UWB signal without frequency translation. No local oscillator and no carrier synchronization are needed where the receiver synchronization is only limited by the bit synchronization time. This reduces the power and the cost of the receiver.

As the low-noise amplifier (LNA) is the first block of the FM-UWB receiver, it should provide enough gain to improve the input signal to noise ratio (SNR) within the power-budget. Several LNA topologies for UWB applications have been presented [35-43].

3.1 Wideband FM Demodulator

The key receiver building block is the wideband FM demodulator. A wideband FM demodulator is implemented as a delay-line demodulator that is shown in Figure 4 [15], [34], [44-46]. It transforms the FM to a phase-modulated (PM) signal via a delay line, and then multiplies it with the original FM signal through a multiplier [47] to produce an amplitude-modulated (AM) output suitable for envelope detection. A fully differential delay line RF demodulator has been presented in [48], [49].

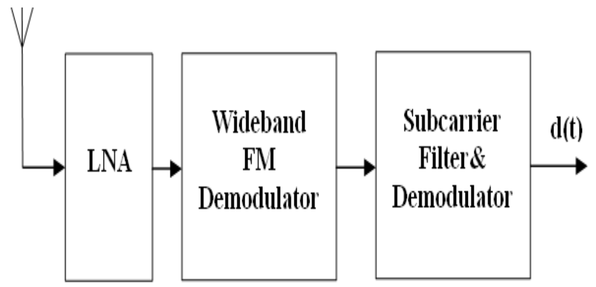

Fig 3: FM-UWB receiver block diagram

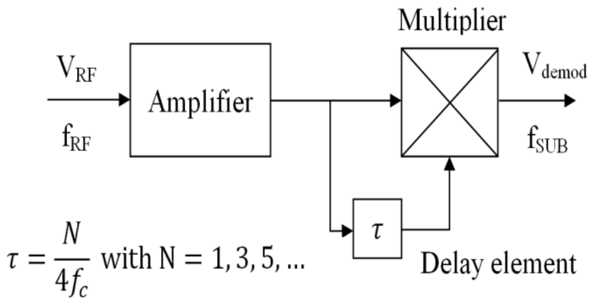

Fig 4: Wideband FM delay line demodulator

The circuits that are used to implement the delay line such as parallel resonant circuit [34], all-pass filter (APF), or the band-pass filter (BPF) [45] employ many inductors, which increase the chip area significantly.

A phase-interpolator based delay line has been proposed in [15]. It is an inductor-less delay circuit. A different demodulation technique has been used in [50], [51] where the FM-AM transformation is realized directly via a bandpass filter. One disadvantage of this technique is that a receiver calibration is required to optimize the SNR for a selected sub-band. Despite all the aforementioned implementations, FM-UWB transceivers still meet many design challenges and represent a promising topic for researchers.

4. CONCLUSIONS

FM-UWB system generates a constant-envelope UWB signal with wideband FM modulation, featuring a very steep spectral roll off. Since the FM-UWB receiver can perform FM demodulation without a local oscillator, carrier synchronization is not needed. This makes the overall system design simple and robust. FM-UWB system is suitable for low data rate, short-range applications. It is a low complex, low cost, and low power system.

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