

Low Power Preamplifier for UWB-FM Receiver

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Abstract—UWB-FM is an alternative system that utilized the available bandwidth for UWB communications system for short range personal area network (PAN) application. A low power receiver is required to demodulate the wideband FM signal. A receiver architecture utilizing FM to AM conversion is proposed to obtain good performance, low power and simple hardware. The key element in the receiver, namely the narrow band preamplifier has been designed in CMOS 0.18 μ m technology. The simulation shows that the circuit able to demodulate UWB-FM signal at $f_c=4.5$ GHz and consume 1.4 mA at 1.2V supply voltage.

Index Terms— UWB, FM, LNA, FM demodulator

I. INTRODUCTION

SHORT range communication system using unlicensed RF links are becoming extremely popular all over the world [1]. Ultra Wideband (UWB) communications, which use very broad unlicensed spectral, are perfectly suitable for short range applications like home or office automation, personal area network (PAN). Since Federal Communications Commission (FCC) agree to allocate unlicensed spectrum from 3.1-10.6 GHz for UWB application [2], this technology has gain many research interest.

Impulse radio, where a very short duration of pulse is transmitted, is a popular way of utilizing UWB frequency band [3]. This system provide a robust and high data rate but at the cost of system complexity and power consumption. There is an alternative system that uses a modulated continues time sinusoidal carrier. This approach called UWB frequency modulation (UWBFM) [4],[5].

In UWB FM system RF signal is not pulsed hence no synchronization is required, hence there is no local oscillator needed. This system has steep spectral roll off, allowing coexist with 5 to 6 GHz WLAN band and 2.4 GHz wireless system. Since the system allowing non coherence detection, a simple hardware implementation with low power consumption can be realized.

In this paper, an UWB-FM system will be shortly introduced in section II. Our objective is to build a simple and low power receiver for this system. The key element in the UWB-FM receiver is the wideband FM demodulator. A wideband FM demodulator for UWBFM receiver has been realized in [6]. Its key element, a wideband delay block, is difficult to realize accurately on-chip. The principle of this demodulator and a new FM demodulator design are described

in section III. The new FM demodulator is designed to overcome aforementioned limitation and to obtain lower power consumption. The CMOS circuit realization of the preamplifier is also described in section IV, and the paper is concluded in section V.

II. UWB-FM

Utilizing the allocated frequency band for UWB applications, UWB-FM system divided into lower and upper band. The lower band is centered at 4.5GHz, the upper band is between 6 GHz and 9 GHz as shown in Fig.1 Between both band there is ISM band for 5GHz communication system. By definition, the minimum bandwidth for UWB is around 500MHz. The lower band can allocated only 1 channel, while the upper band will be allocating up to 4 channels. This paper will focus on the receiver for the lower band UWB-FM.

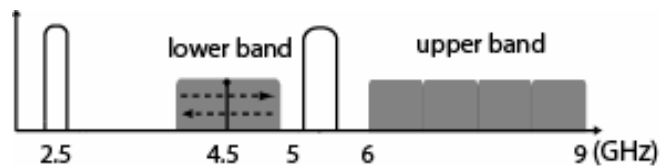


Fig. 1: Ultra Wideband FM frequency band

UWBFM uses low modulation index ($\beta=1$) frequency shift keying (FSK) of sub-carrier followed by high modulation index ($\beta=500-800$) FM to achieve the wide bandwidth [4]. Triangular wave is used for the sub-carrier signal to obtain flat wideband spectral. Fig 2 illustrates the cascade modulation scheme that is used in UWB-FM.

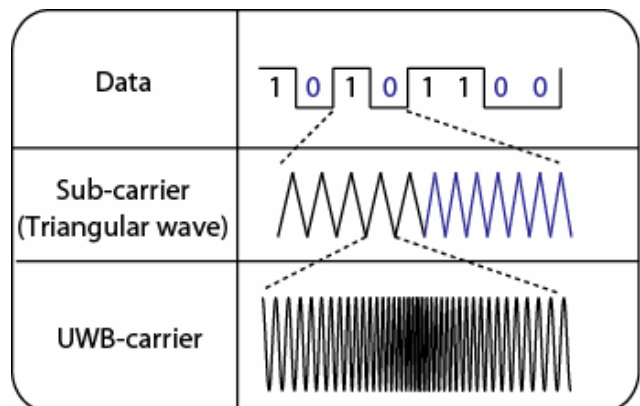


Fig. 2: Ultra Wideband FM wave

Since UWB-FM does not have a standard yet, a certain parameter has to be specified. UWB-FM system for lower band specifications are summarized in Table I.

TABLE I UWB-FM SPECIFICATIONS

Parameters	Value
RF center frequency	4500 MHz
Sub carrier frequency	1-2MHz
Sub carrier modulation	FSK, $\beta=1$
RF Bandwidth	0.8 GHz
Data rate	100kbps
β	500
Receiver sensitivity	-80dBm

A Receiver block diagram for UWB-FM system is illustrated in Fig. 3. The antenna receives the FM signal and the signal is filtered by the bandpass filter. The antenna design should be designed closed to the receiver, if possible on chip, such that optimized performance can be obtained [7]. Integrated antenna can be combined with the bandpass filter. The bandpass filter required to remove strong interference signal from other standard communication system or other ISM band system.

LNA are required to amplify the signal and improve the sensitivity of the receiver. The key element, wideband demodulator, is then employed to demodulate the FM signal. Automatic gain control (AGC) amplifier is then amplified the sub-carrier signal until certain level such that it can be quantized optimally using 1 bit quantizer. The FSK demodulation is done in digital domain using all digital FSK demodulator to minimize power consumption [8].

III. UWB FM DEMODULATOR

A physical FM demodulators based on direct frequency demodulation do not exist, because physical system are unable to read instantaneous frequency of a carrier [9]. FM signal is therefore can only be detected indirectly by converting the signal into phase modulation (PM) or amplitude modulation (AM) signal. Both types of demodulator will be discussed in the next section.

One way to demodulate FM signal is by indirectly converting the FM signal into AM signal by using a spectral shaping filter [9]. The filter typically has a linear function across the FM bandwidth. The demodulated signal has the

amplitude proportional to the frequency deviation ($\Delta f_c(t)$).

In UWB-FM system, the shape of the sub-carrier signal is known, a triangular wave. It is unnecessary to obtain the full-wave of the subcarrier signal. The subcarrier is modulated using FSK modulation scheme. Hence it is possible to demodulate the data just by knowing the frequency of the sub-carrier signal without obtaining the original triangular wave.

In this proposed FM demodulator shown in Fig. 4, the filter has a narrow band response. It is effectively a conversion from FM signal into Gaussian shape AM signal. The filter response controls the envelope of the demodulated signal. The envelope of the AM signal is preserved and the carrier is removed by the envelope detector circuit. The low pass filter added to further remove the harmonics from the envelope and to obtain the desired sub-carrier frequency.

Fig.5 illustrates the transfer function of the FM signal into AM signal. In UWB-FM wave, the carrier signal frequency is moving back and forth according to the sub-carrier signal. The FM to AM filter act like sensor that detect the present of the carrier signal in that filter pass frequency. If the carrier is present on the filter pass frequency, the magnitude of the signal is amplified creating a pulsating wave. In contrast with the impulse radio UWB system when the pulse is sent and occupy the whole UWB band. In UWB-FM the carrier is swept through the band and by using this demodulator, a pulse can be obtained. Some modulation schemes used in impulse radio, e.g. pulse position modulation (PPM), are possibly to be used in this case.

The filter center frequency plays important part on producing the frequency of the AM pulse signal. As illustrated in Fig.5, if the filter center frequency is located in the edge of the FM signal bandwidth, the pulse rate is equal to the sub-carrier frequency. In other case, when the filter center frequency is in the center of the FM bandwidth, the pulse rate is two times the sub-carrier frequency.

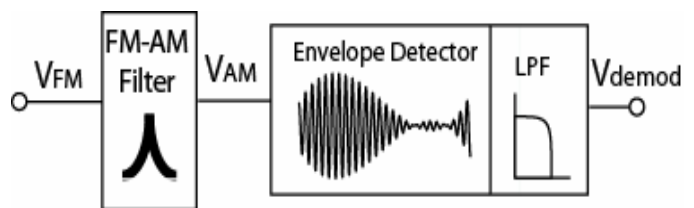


Fig.4: FM to AM demodulator block diagram

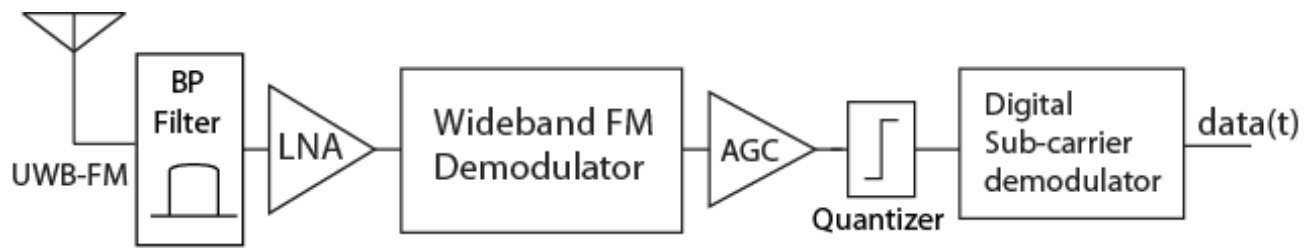


Fig.3: UWB-FM Receiver block

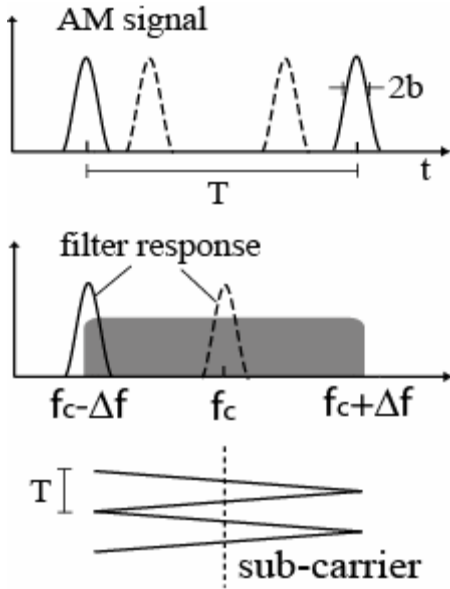


Fig.5: FM to AM demodulator transfer function

Simulation has been performed using ideal filter, amplifier and envelope detector. The UWB-FM signal with $f_c=4.5GHz$ at -40 dBm power is fed into the demodulator. The UWB-FM bandwidth is $800MHz$ and the sub-carrier frequency is $5MHz$. The carrier wave is shown in Fig.6(a). A combination of amplifier and narrowband filter (Bandwidth = $50MHz$) convert the FM into AM signal as shown in Fig.6(b). A mixer with a low pass filter is used as the envelope detector, producing the pulse wave as shown in Fig.6(c). The pulse wave is then amplified and can be directly processed using edge triggered flip-flop in digital domain.

The demodulated signal spectral has a Gaussian shape. The spectral also consist of many equally spaced spectral lines. A filter can remove the rest of the spectral line, while preserving the fundamental frequency of the demodulated signal. Careful planning is needed when UWB-FM system employs more than one sub-carrier frequency at the same time [5].

In this demodulator, the demodulated signal amplitude is not dependant on the signal bandwidth. Amplitude of demodulated signal depends on factor such as the bandpass filter shape. The signals that pass the filter compare to the rejected signals determine its amplitude. While the ultra wideband bandwidth seems to be not utilized in this case, it is possible to apply the filter response at other frequency inside the band. In this sense many of the pulse waves can be correlated to improve the overall signal to noise ratio (SNR).

The implementation of the narrow band filter at RF frequency is proven to be challenging. The required Q factor of the filter is around 80. Not only it requires high Q but also tunability is essential in the filter design as well. The center frequency of the filter must be able to be tuned in correspond to different bandwidth of the FM signal and to mitigate the process variation. In order to minimize the power consumption, the filter is integrated with the preamplifier/LNA in the implementation. A Q enhanced LNA topology is selected to cater this requirements [10]. Due to a

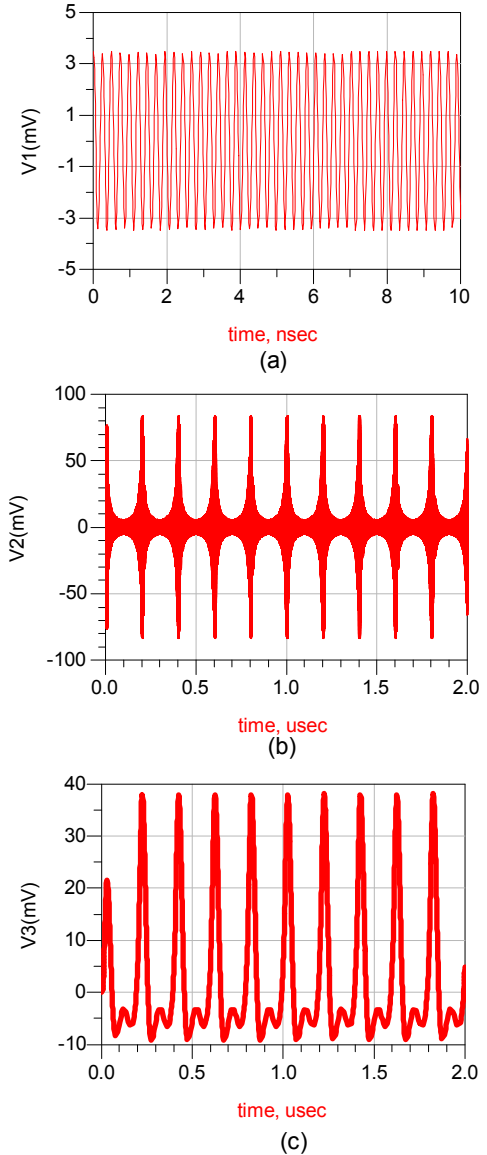


Fig.6: FM to AM demodulator simulation result

narrow band nature of the LNA, a high gain can be obtained by reducing its bandwidth without consuming additional power. The LNA design will be described in detail in the next section.

IV. LNA DESIGN

In this receiver architecture, the LNA design becomes the most important element because it is incorporating the demodulator block as well. Fig. 7 shows the LNA schematic. The LNA is designed in pseudo-differential mode. A differential circuit has some advantage in term of reducing the common mode noise or second order distortion. However, the circuit doubles its power consumption. In this case the differential mode is necessary to obtain a controlled positive feedback in the circuit.

The LNA is designed in common source configuration (M1

and M2) with cascode transistors (M3 and M4) to improve the isolation between input and output. M5 and M6 are cross couple transistor pair that provides negative resistance in the output node. This negative resistance provides positive feedback, and hence provides high gain for the LNA while reducing its bandwidth. Effectively, the negative resistance increases the Q factor of the LC tank in the output node. The I_{con} is a tunable current source that controls the amount of negative resistance that provided in the output. This negative resistance must be well controlled, in order to obtain high gain, while keep the LNA stable. Varactor (C_{var}) is added in the output LC tank in order to tune the tank center frequency. The LC tank acts as the FM demodulator for the receiver. Fig.8 shows the simulated S11 and noise figure of the LNA. Since the noise figure is rather high, we call it preamplifier instead of LNA. In UWB-FM the NF requirement is not so strict [6]. The FM signals transforms into AM signal and hence demodulated by the LNA circuit. Fig. 9 shows the gain of the preamplifier at different center frequency by tuning the varactor and I_{con} . Table II summarized the LNA performances.

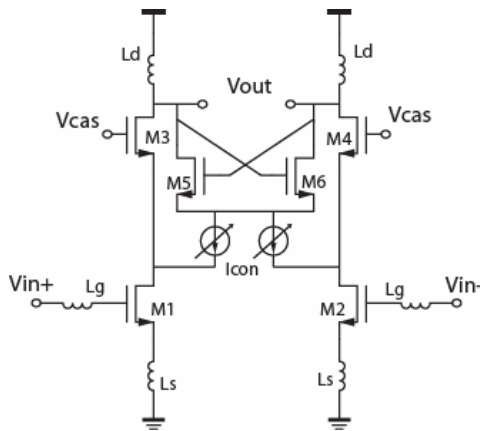


Fig.7: A Q enhanced LNA simplified schematics

TABLE II LNA PERFORMANCES.

Parameter	Value
V_{DD}	1.2 V
I_D	1.4 mA
S11	-17dB
Voltage Gain _x	40 dB
Bandwidth	25 MHz
Q	140
NF	7.5dB

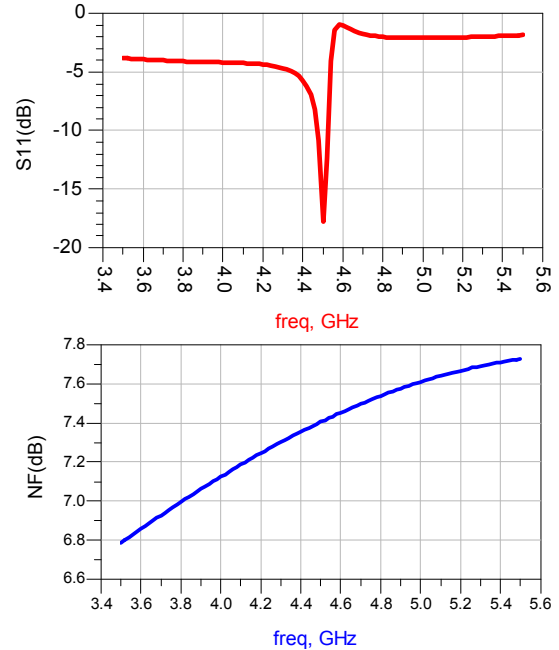


Fig.8: S11 of the amplifier (top) and Noise figure of the amplifier (bottom)

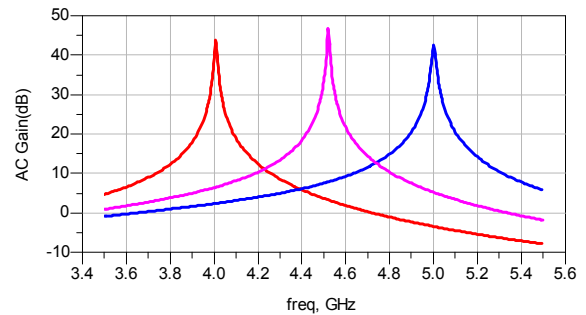


Fig.9: Amplifier gain at different C_{var} ad I_{con}

V. CONCLUSION

A low power LNA that also work as an FM demodulator has been designed. The simulation shows that the demodulator able to demodulate the UWB-FM signal. The LNA achieves 40dB of gain at 1.7 mW of power dissipation. The wideband demodulator is the main block that consumes most power. Hence, Low power receiver for UWB-FM can be built based on this architecture.

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