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Generation of Narrowband Signals for Wireless Body Area Networks

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Abstract - *Wireless body area networks (WBAN's) have gained much attention recently because of miniaturization of electronic device and due to a multitude of applications. Narrowband communication is emerging transmission technology for WBAN's because of reduced hardware complexity. In this paper summarizes the design issues for physical layer proposals with narrowband signals. Here minimum shift keying (MSK) modulation technique is used as one of the design issues of the WBAN's and presents the MATLAB and SIMULINK implementation of generation of narrowband signals using MSK modulation scheme.*

Key Words: modulations, continuous phase frequency shift key (CPFSK), minimum shift key (MSK), wireless body area networks (WBAN's).

1. INTRODUCTION

The recent trends in communication and technical developments of the last few decades are grasping attention towards several prominent applications for wireless body area networks (WBANs) such as health monitoring or ubiquitous computing. The use of wireless networks and the constant miniaturization of electrical invasive/non-invasive devices have empow- ered the development of Wireless Body Area Networks (WBANs). In a WBAN, several small nodes are placed close or directly on the human body. Since such nodes shall get their power from rechargeable batteries or by energy harvesting they have to be very energy efficient. Moreover, due to cost reasons and due to the relative high number of nodes in a WBAN the nodes shall be of low complexity. One transmission technology for WBANs promising less complex hardware is narrowband communication.

WBAN system can be categorized into two parts by its applications: medical BAN and non-medical BAN. Nonmedical BAN can be regarded as wearable consumer electronics and entertainment devices for the on-body communications. Medical BAN consists of implant devices and wearable medical systems to measure the health status of human body with In-body or on-body communications. Since there are different requirements for the systems by various applications, the several technologies for physical layer designs are suggested as amplitude shift keying (ASK), variations of frequency-shift keying (FSK), offset quadrature. The ultra wideband (UWB) technologies are also proposed with impulse radio (IR), chirp, and frequency modulation (FM) method. The narrowband proposals are explained interms of frequency bands, modulation options, and some key features such as modulation, packet structure, and so on.

2. NARROWBAND TECHNOLOGY

The basic design approach for the in-body or on-body communications demands the simplicity and efficiency in physical layer implementation. Since the technical requirements show diverse applications and large span of data rate, however, there will be a difficulty in selecting the prominent technology for the WBAN systems. The merit of narrow band communication is to realize stable long-range communication. In addition to, the carrier purity of transmission spectrum is very good; therefore it is available to manage an operation of many radio devices within same frequency bandwidth at same time. [1]

2.1 Modulation technic overview

In the analog communication, digital modulation of data transmission relies on the use of sinusoidal carrier wave to modulate the incoming data bit stream. In digital pass band transmission the incoming data stream is modulated onto a carrier with fixed frequency limits imposed by band pass channel of interest. In this event the modulation process making the transmission possible involves switching, or commonly known as keying, the amplitude, frequency or the phase of the sinusoidal carrier in some fashion in accordance with the incoming data stream. Thus there are three basic signaling schemes [2]

1. Amplitude shift keying : Amplitude is varied in accordance with the input data
2. Frequency shift keying : Frequency is varied in accordance with the input data
3. Phase shift keying : Phase is varied in accordance with the input data.

3. MINIMUM SHIFT KEYING (MSK)

In digital communication modulation technique binary data consisting of sharp transitions between "one" and "zero" states and vice versa actually creates signals that have sidebands extending out a long way from the carrier, and this leads problems for many radio communications systems, as any sidebands outside the allowed bandwidth cause interference to adjacent channels and any radio communications links that may be using them.

MSK, minimum shift keying has the feature that there are no phase discontinuities and this significantly reduces the bandwidth needed over other forms of phase and frequency shift keying.

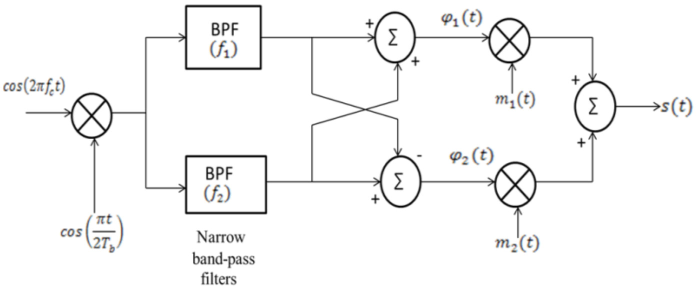

Fig -1: Block diagram of MSK transmitter

Fig 1 shows the block diagram of a typical MSK transmitter. The advantage of this method of generating MSK signals is that the signal coherence and deviation ratio are largely unaffected by variations in the input data rate. Two input sinusoidal waves, one of frequency $f_c = \frac{n_c}{4T_b}$ for some fixed integer n_c, and the other frequency $\frac{1}{4T_b}$, are first applied to a product modulator. This produces two phase-coherent sine waves at frequencies f_1 and f_2, which are related to f_c and the bit rate $\frac{1}{T_b}$ by equations (3) and (5) for $h = 1/2$. These two sinusoidal waves are separated from each other by two narrow-band filters, one cantered at f_1 and the other at f_2. The resulting filter outputs are next summed to produce the pair of quadrature carriers or Orthonormal basis functions $\varphi_1(t)$ and $\varphi_2(t)$. Finally $\varphi_1(t)$ and $\varphi_2(t)$ are multiplied with two binary waves $m_1(t)$ and $m_2(t)$, both of which have a bit rate equal to ${}^1/_{2T_b}$. These two binary waves are extracted from the incoming binary wave $b(t)$.

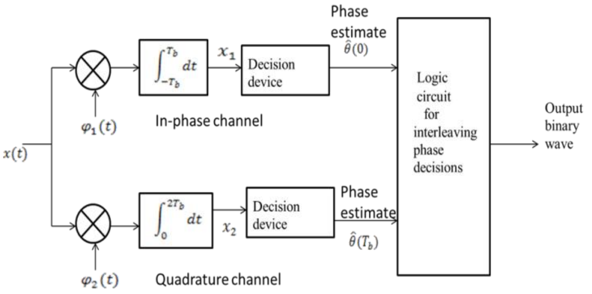

Fig -2: Block diagram of MSK receiver

Fig 2 shows the block diagram of a typical MSK receiver. The received signal $x(t)$ is correlated with locally generated replicas of the coherent reference signals, $\varphi_1(t)$ and $\varphi_2(t)$. Note that in both the cases the integration interval is $2T_b$ seconds, and the integration in the quadrature channel is delayed by T_b seconds with respect to that in the in-phase channel. The resulting in-phase and quadrature channel correlator outputs, x_1 and x_2, are next compared with a threshold of zero volts. Finally these phase decisions are interleaved so as to reconstruct the original input binary wave $b(t)$ with minimum average probability of symbol error.

In coherent detection of BFSK signal the phase information contained in the received signal is not fully exploited. It is used only to provide synchronization of the receiver to the transmitter. By the proper use of the phase it is possible to improve the noise performance of the receiver significantly. This is achieved through the use of minimum shift keying) MSK modulation scheme.[2]

MSK Signals should satisfy two conditions

1. The modulating pulse must be symmetrical about $t + \frac{T_b}{2}$ and 0 otherwise
2. The modulated carrier has to have a constant envelope.

We now look at satisfying the above conditions. Minimum shift keying is the form of CPFSK.

Consider a continuous phase frequency shift keying signal, which is defined for the interval $0 \le t \le T_b$, given by the equation

$$s(t) = \begin{cases} \sqrt{\frac{2E_b}{T_b}} \cos[2\pi f_1 t + \theta(0)] & for\ symbol\ 1 \\ \sqrt{\frac{2E_b}{T_b}} \cos[2\pi f_2 t + \theta(0)] & for\ symbol\ 0 \end{cases} \quad (1)$$

Where E_b is the transmitted signal energy per bit and T_b is the bit duration. The phase θ(0), denoting the value of phase at time 0 , sums up the past history of the modulation process up to time 0.The frequencies f_1 and f_2 are sent in response to binary symbols 1 and 0 appearing at the modulation input respectively. Another method of representing the CPFSK signal is to express in the conventional form of angle modulated signal.

$$s(t) = \sqrt{\frac{2E_b}{T_b}} \cos[2\pi f_c t + \theta(t)] \quad (2)$$

Where θ(t) is the phase of the signal s(t). When the phase θ(t) is a continuous function of time, we find that the modulated wave s(t) itself is also continuous at all times, including the inner bit switching times. The nominal carrier frequency f_c is chosen as the arithmetic mean of two frequencies f_1 and f_2 as shown by,

$$f_c = \frac{1}{2}(f_1 + f_2) \quad (3)$$

The phase θ(t) of a CPFSK signal increases or decreases linearly with time during each bit period of $T_b$seconds, as shown by

$$\theta(t) = \theta(0) \pm \frac{\pi h}{T_b} t \quad 0 \le t \le T_b \qquad (4)$$

Where the + sign corresponds to sending symbol 1, and the minus sign corresponds to sending symbol 0.the parameter h is defined by

$$h = T_b(f_1 + f_2) \qquad (5)$$

We refer to h as a deviation ratio, measured with respect to the bit rate $\frac{1}{T_b}$ from equation 5, we find that at time t=T_b

$$\theta(T_b) - \theta(0) = \begin{cases} \pi h & \text{for symbol 1} \\ -\pi h & \text{for symbol 0} \end{cases} \qquad (6)$$

That is to say, the sending of symbol 1 increases the phase of the CPFSK signal s(t) by πh radians, where as the sending of symbol 0 reduces it by an equal amount. it is justified from Fig.4 that the phase of the CPFSK is an odd or even multiple of πh radians at odd or even multiples of the bit duration T_b, respectively. This graph is called a phase trellis, since a trellis is a tree like structure with remerging branches. Each path from left to right through the trellis of fig4 corresponds to a specific binary sequence input. We may express the CPFSK signal s (t) in terms of its in-phase and quadrature components as follows:

$$s(t) = \sqrt{\frac{2E_b}{T_b}} \cos[\theta(t)] \cos(2\pi f_c t) - \sqrt{\frac{2E_b}{T_b}} \sin[\theta(t)] \sin(2\pi f_c t) \qquad (7)$$

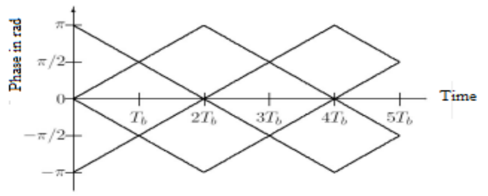

Fig -3: Phase trellis [2]

Consider first the in-phase component $\sqrt{\frac{2E_b}{T_b}} \cos[\theta(t)]$ with a deviation ratio h=1/2, we have from equation 4 that

$$\theta(t) = \theta(0) \pm \frac{\pi}{2T_b} t \qquad 0 \le t \le T_b \qquad (8)$$

Where the plus sign corresponds to symbol 1 and the minus sign corresponds to symbol 0. Thus for this interval, the in-phase component, $s_1(t)$, consists of a half-cosine pulse defined as follows

$$s_I(t) = \sqrt{\frac{2E_b}{T_b}} \cos[\theta(t)]$$

$$= \sqrt{\frac{2E_b}{T_b}} \cos[\theta(t)] \cos\left(\frac{\pi}{2T_b} t\right)$$

$$= \pm \sqrt{\frac{2E_b}{T_b}} \cos\left(\frac{\pi}{2T_b} t\right) \quad -T_b \le t \le T_b \qquad (9)$$

Where the plus sign corresponds to $\theta(0)$=0 and the minus sign corresponds to $\theta(0) = \pi$. In similar way, we may show that, in the interval $0 \le t \le 2T_b$, the quadrature component, $s_Q(t)$, consists of a half-sine pulse, whose polarity depends only on $\theta(T_b)$, as shown by

$$s_Q(t) = \sqrt{\frac{2E_b}{T_b}} \sin[\theta(t)]$$

$$= \sqrt{\frac{2E_b}{T_b}} \sin[\theta(t)] \sin\left(\frac{\pi}{2T_b} t\right)$$

$$= \pm \sqrt{\frac{2E_b}{T_b}} \sin\left(\frac{\pi}{2T_b} t\right) \quad 0 \le t \le 2T_b \qquad (10)$$

Where the plus sign corresponds to $\theta(T_b) = \frac{\pi}{2}$ and the minus sign corresponds to $(T_b) = -\frac{\pi}{2}$. With h=1/2, we find from equation 5 that the frequency deviation equals half the bit rate. This is the minimum frequency spacing that allows the two FSK signals representing symbol 1 and symbol 0, as in equation 1to be coherently orthogonal in the sense that they do not interfere with one another in the process of detection .it is for this reason, a CPFSK signal with a deviation ration of half bit is referred to as minimum shift keying (MSK). We see that the phase states $\theta(0)$ and $\theta(T_b)$ can each assume one of the two possible values, any one of four possibilities can arise,

The phase $\theta(0)$=0 and $\theta(T_b) = \frac{\pi}{2}$, corresponding to the transmission of symbol 1.

The phase $\theta(0) = \pi$ and $\theta(T_b) = \frac{\pi}{2}$, corresponding to the transmission of symbol 0.

The phase $\theta(0) = \pi$ and $\theta(T_b) = -\frac{\pi}{2}$, corresponding to the transmission of symbol 1.

The phase $\theta(0)$=0 and $\theta(T_b) = -\frac{\pi}{2}$, corresponding to the transmission of symbol 0.

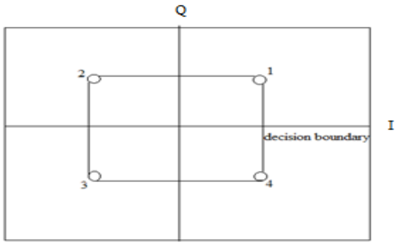

Fig -4: Signal space diagram [3]

Message point m1 : symbol 0; [θ(0) = 0, θ(Tb) = -π/2; Coordinates (√ Eb , √ Eb)

Message point m2 : symbol 1; [θ(0) = π, θ(Tb) = -π/2; Coordinates (√ Eb , -√ Eb)

Message point m3 : symbol 0; [θ(0) = π, θ(Tb) = π/2; Coordinates (-√ Eb , -√ Eb)

Message point m4 : symbol 1; [θ(0) = 0, θ(Tb) = π/2; Coordinates (√ Eb , -√ Eb)

This, in turn, means that the MSK signal itself may assume any one of four possible forms, depending upon the values of $\theta(0)$ and $\theta(T_b)$.From the expansion of equation (7), we deduce that in case of an MSK signal the appropriate form for the orthonormal basis functions $\varphi_1(t)$ and $\varphi_2(t)$ is as follows:

$$\varphi_1(t) = \sqrt{\frac{2}{T_b}}\cos\left(\frac{\pi}{2T_b}t\right)\cos[2\pi f_c(t)] \quad -T_b \le t \le T_b \quad (11)$$

$$\varphi_2(t) = \sqrt{\frac{2}{T_b}}\sin\left(\frac{\pi}{2T_b}t\right)\sin[2\pi f_c(t)] \quad 0 \le t \le 2T_b \quad (12)$$

Note that both $\varphi_1(t)\ and\ \varphi_2(t)$ are defined for a period equal to twice the bit duration. This is necessary, so as to ensure that they satisfy the condition of orthogonality, correspondingly, we may express the MSK signal in the form

$$s(t) = s_1\varphi_1(t) + s_2\varphi_2(t) \quad (13)$$

Where the coefficients $s_1\ and\ s_2$ are related to the phase states $\theta(0)$ and $\theta(T_b)$ respectively. To evaluate s_1 we integrate the product $s(t)\varphi_1(t)$ between the limits $-T_b\ and\ T_b$. We thus obtain,

$$s_1 = \int_{-T_b}^{T_b} s(t)\varphi_1(t)dt$$

$$= \sqrt{E_b}\cos[\theta(0)] \quad -T_b \le t \le T_b \quad (14)$$

Similarly, to evaluate s_2 we integrate the product $s(t)\varphi_2(t)$ between the limits 0 and 2T_b, we therefore obtain

$$s_2 = \int_0^{2T_b} s(t)\varphi_2(t)dt$$

$$= -\sqrt{E_b}\sin[\theta(T_b)] \quad 0 \le t \le 2T_b \quad (15)$$

Note that in equations (13) and (14)

1.Both integrals are evaluated for a time interval equal to twice the bit duration, for which $\varphi_1(t)$ and $\varphi_2(t)$ are orthogonal.

2.Both the lower and upper limits of the product integration used to evaluate the coefficients s_1 are shifted by T_b seconds with respect to those used to evaluate the coefficient s_2.

3.The time interval $0 \le t \le T_b$, for which the phase states $\theta(0)$ and $\theta(T_b)$ are defined, is common to both integrals.

Table -1: Signal space characterization of MSK [3]

Transmitted binary symbol, $0 \le t \le T_b$	Phase states(radians) $\theta(0)$ $\theta(T_b)$	Coordinates of massage points
		s_1 s_2
1	0 $+\pi/2$	$+\sqrt{E_b}$ $-\sqrt{E_b}$
0	π $+\pi/2$	$-\sqrt{E_b}$ $-\sqrt{E_b}$
1	π $-\pi/2$	$-\sqrt{E_b}$ $+\sqrt{E_b}$
0	0 $-\pi/2$	$+\sqrt{E_b}$ $+\sqrt{E_b}$

In the case of an AWGN channel, the received signal is given by

$$x(t) = s(t) + w(t) \quad (15)$$

Where $s(t)$ is transmitted MSK signal, and $w(t)$ is the sample function of white Gaussian noise process of zero mean and power spectral density $N_o/2$, in order to decide whether symbol 1 symbol 0 was transmitted in the interval $0 \le t \le T_b$,say we have to establish a procedure for the use of $x(t)$ to detect the phase states $\theta(0)$ and $\theta(T_b)$. For the optimum detection of $\theta(0)$, we first determine the projection of the received signal $x(t)$ on to the reference signal $\varphi_1(t)$, obtaining

$$x_1 = \int_{-T_b}^{T_b} x(t)\varphi_1(t)dt$$

$$= s_1 + w_1 \quad T_b \le t \le -T_b \quad (16)$$

Where s_1 is as defined by equation 13 and w_1 is the sample function of white Gaussian noise process of zero mean and power spectral density $N_o/2$, from the signal space diagram of fig we observe that if $x_1 > 0$, the receiver chooses the estimate $\hat{\theta}(0)$=0. On the other hand, if $x_1 < 0$, it chooses the estimate $\hat{\theta}(0)$=π. Similarly for the projection of the received signal $x(t)$ on to the reference signal $\varphi_2(t)$, obtaining

$$x_2 = \int_0^{2T_b} x(t)\varphi_2(t)dt$$
$$= s_2 + w_2 \qquad 0 \le t \le 2T_b \qquad (17)$$

Where s_2 is as defined by equation 14 and w_2 is the sample function of white Gaussian noise process of zero mean and power spectral density $N_o/2$, from the signal space diagram of fig we observe that if $x_2 > 0$, the receiver chooses the estimate $\ddot{\theta}(T_b)$=$-\pi/2$. On the other hand, if $x_2 < 0$, it chooses the estimate $\ddot{\theta}(T_b)$=$\pi/2$. The average probability of symbol error for the MSK is given by

$$P_e = erfc\left(\sqrt{\frac{E_b}{N_o}}\right) \qquad (18)$$

We may ignore the second term on the right hand side of equation 18 in the region where $\frac{E_b}{N_o} \gg 1$ hence the formula for average probability of symbol error as

$$P_e = erfc\left(\sqrt{\frac{E_b}{N_o}}\right) \qquad (19)$$

4. GENERATION OF NARROW-BAND PULSE BY MSK SIGNAL USING MATLAB and SIMULINK

4.1 Generation of MSK signal

Data generator generates the random binary numbers using Bernoulli distribution. Generated random binary numbers are converted in to bipolar signals using unipolar to bipolar converter converted bipolar signal is than send to the MSK modulator where the output is baseband representation of modulated signal and passed through the AWGN channel where AWGN channel adds the white Gaussian noise signal to the input signal. When the input signal is real, this block adds real Gaussian noise and produces a real output signal. When the input signal is complex, this block adds complex Gaussian noise and produces a complex output signal. Hence complex output can separated in to the real and imaginary by using the complex to real-imag block. Hence producing the in phase and quadrature components.

4.2 Generation of Narrow-Band signal

For the demodulation process, the MSK wave which we obtained is send through the MSK demodulator block where the input is the baseband representation of the modulated signal. And again real and imaginary parts should be separated using the complex to real imag block. Finally the output of the MSK demodulator is converted back to unipolar signal to get the original signal.

In the generation of the narrowband signal we need to get the original signal for that in phase component of the MSK signal and sine wave (generates continuous and discrete sine wave) are multiplied in product modulator1. And imaginary component of the MSK signal and cosine wave are multiplied in product modulator 2. Now the output of product modulator1 and product modulator2 are added and passed through the AWGN channel which adds the additive white Gaussian noise to the signal, produces the original signal. Original is then separated in to in phase and quadrature components. In phase component and discrete time VCO signal is multiplied in product modulator 3.

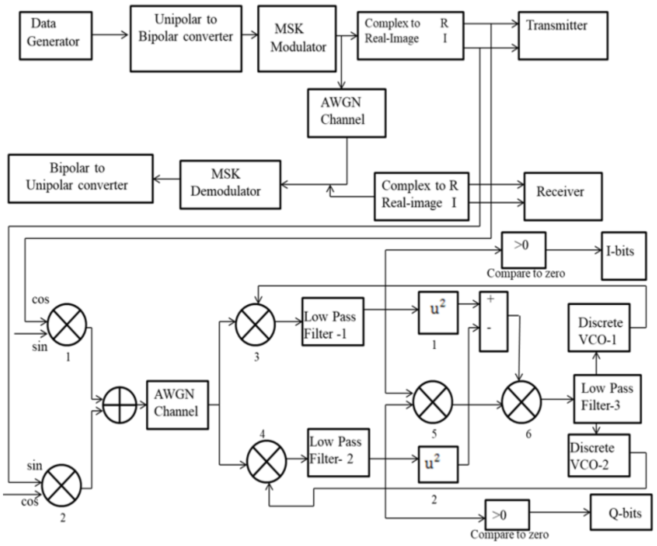

Fig -5: Block diagram of generation of MSK signal and Narrowband signal

Discrete-time VCO generates a signal whose frequency shift from the quiescent frequency parameter is proportional to the input signal the input signal is interpreted as a voltage. Discrete-time VCO is a feedback to the signal. The output of the product modulator3 is then passed through the low pass filter1 which attenuates the high frequency components. When passing the signal through the filter signal becomes week hence to strengthen the signal pass the signal to the squaring pulse block1, where the amplitude of the signal gets doubled. Quadrature components and signal from the discrete-time VCO is multiplied in product modulator4 and passed through the low pass filter2 and again amplitude of the signal is doubled in squaring pulse block2. The output from the low pass filter1 and low pass filter2 is multiplied in product modulator5. The output of squaring pulse 2 is subtracted by the squaring pulse 1. The obtained output is then multiplied with product modulator5 in product modulator6.

The output from the product modulator6 is then passed through the low pass filter 3 to remove the unwanted components if any and the signal is send to the discrete-time

VCO1 and discrete-time VCO2. The output of the low pass filter1 is than compared with zero and produces the narrowband signal of in phase components. And the output of the low pass filter2 is compared with zero and produces the narrowband signal of quadrature component.

5. RESULTS

Fig 6 shows the output waveform of MSK transmitter, contains inphase and quadrature phase component for given input binary data. Fig 7 shows the output of MSK receiver consist of Iphase and Qphase component. Fig 8 and Fig9 shows the generation of narrow band signal for Iphase and Qphase component.Fig.10 shows the received binary data at receiver observed in MATlab simulink simulation.

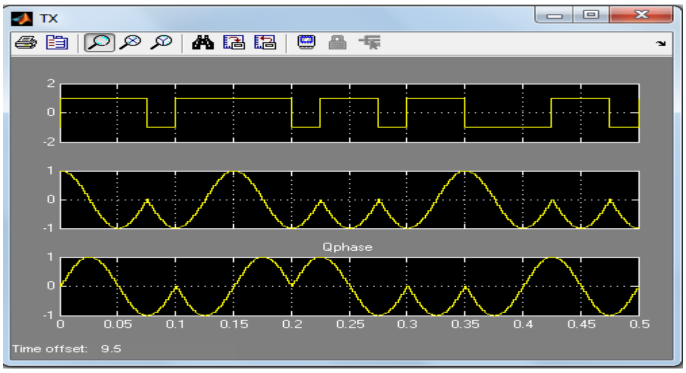

Fig -6: MSK transmitter waveforms

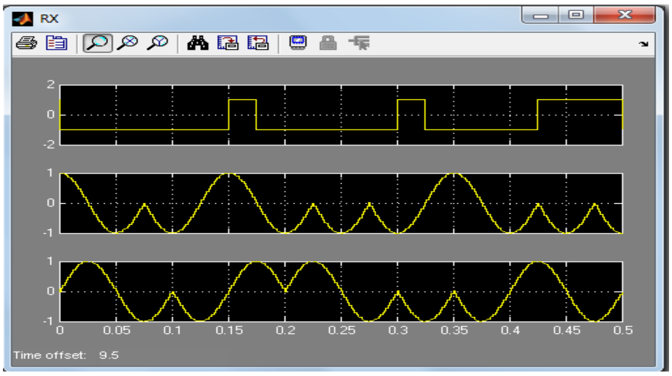

Fig -7: MSK receiver waveforms

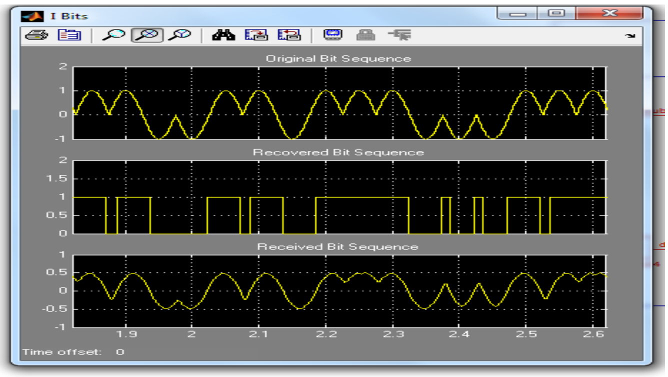

Fig -8: Narrow band signal of I phase component

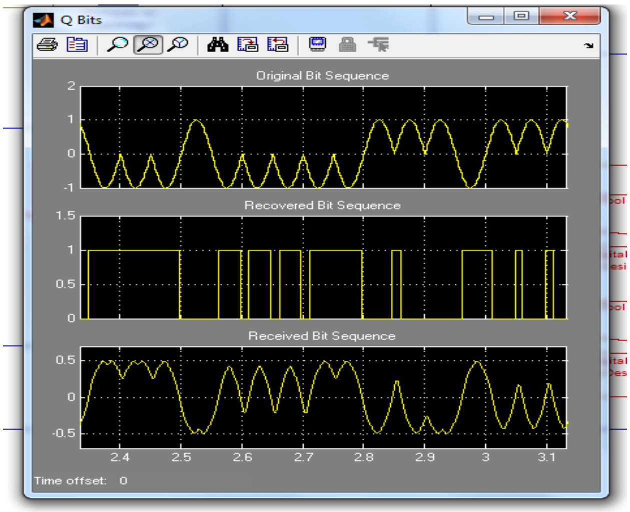

Fig -9: Narrow band signal of Q phase component

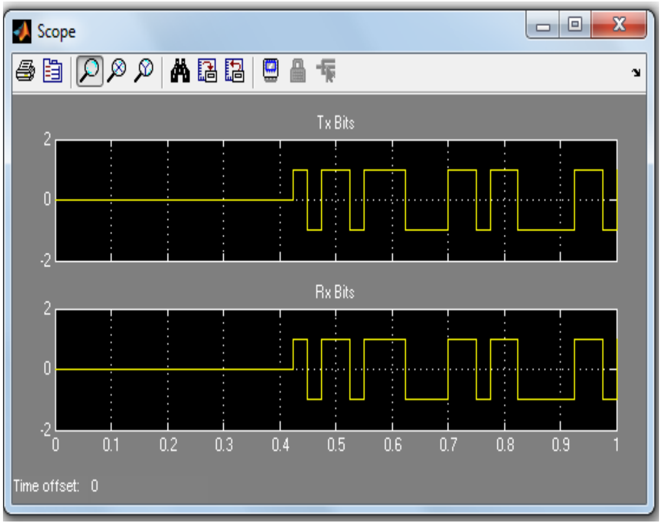

Fig -10: Transmitted and received bits

6. CONCLUSIONS

WBAN systems cover variety for in-body versus on-body communications and medical versus non-medical applications.

This paper presents the summary of narrowband proposals. One of the problems with other form of modulations is that sidebands extend out from the carrier, this creates interference in the channels, and to overcome this MSK is used. Narrow band communication is to realize stable long-range communication. In addition to, the carrier purity of transmission spectrum is very good; therefore it is available to manage an operation of many radio devices within same frequency bandwidth at same time. In other words, it leads the high efficiency of radio wave use within same frequency band.

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