AQ-DBPSK Modulation Performance Analysis for Wireless Sensor Communications

VASANTHI.M.S[1], DHARMESH KUMAR[2], RAMA RAO.T[3]
Department of Telecommunication Engineering
SRM University,
SRM Nagar, Kattankulathur, Tamilnadu- 603 203
INDIA
[1]vasanthi.m@ktr.srmuniv.ac.in, [2]kanishkdce002@gmail.com, [3]ramaraot@outlook.com

Abstract: - Wireless sensor nodes have a limited amount of energy resource that determines their lifetime. So, Energy efficient modulation techniques are of paramount importance for wireless sensor communication (WSC). Also the type and behavior of the pulse shaping filters used, influences the performance of the modulation scheme. The Alternating Quadratures Differential Binary Phase Shift Keying (AQ-DBPSK) modulation scheme which is a variation of the Differential Binary Phase Shift Keying (DBPSK) scheme is simulated and a comparative study of communication performance metrics like Magnitude Error, Phase Error, Bandwidth Efficiency and Bit Error Rate (BER) for Binary Phase Shift Keying (BPSK), DBPSK and AQ-DBPSK using Raised Cosine and Root Raised Cosine filters are presented and analyzed. The results obtained show that tradeoffs can be made between spectral efficiency and energy efficiency by selecting the proper modulation scheme and using the appropriate value of excess bandwidth for the pulse shaping filter.

Key-Words: - Energy efficient, Wireless sensor Communications, Fading Channels, Pulse Shaping, Bandwidth Efficiency, Modulation, Bit Error Rate

1 Introduction

Wireless Sensor Communications (WSC) is considered to have high potential for realizing the vision of ambient intelligence. Typically, a Wireless Sensor Communication network is composed of hundreds of autonomous and compact devices called sensor nodes [1] which are unobtrusively embedded to the environment for performing sensing, processing and actuating tasks. There are many applications for this low data rate, short-range wireless sensors ranging from industrial, military, commercial, home automation, personal health care and gaming. These sensor nodes have a limited amount of energy resource that determines their lifetime. Since it is unfeasible to recharge hundreds of nodes, each node should be energy efficient. A sensor node basically consists of a power unit, sensing unit, processing unit and communication unit.

The sensors are typically required to operate for years from a small energy source and therefore the energy consumption of the sensor networks must be minimized [2]. Many novel effective technological circuitry design and algorithmic solutions have been proposed [3] for improving the energy efficiency of these transceivers but still there are opportunities for further improving their efficiency. The modulation technique and pulse shaping filter used can contribute towards improving the energy efficiency. In this paper, the capabilities of Alternating Quadratures Differential Binary Phase Shift Keying (AQ-DBPSK) modulation scheme initially proposed and described in [4, 5] is investigated with respect to indoor Wireless Sensor Network (WSN) applications. A comparative study of some performance metrics for the WSC, such as Magnitude Error, Phase Error, Bandwidth Efficiency and Bit Error Rate(BER) for Binary Phase Shift Keying(BPSK), DBPSK and AQ-DBPSK using raised cosine and root raised cosine filters are presented and analyzed utilizing Agilent's Advanced Design System and Matlab simulations.

In section 2 the operating conditions of WSC in indoor environments are studied and the requirements for modulation techniques are derived from it. Based on the conventional Differential Binary Phase Shift Keying (DBPSK), a modulation technique named alternating quadrature DBPSK as proposed in [4] is investigated in sections 3 and 4. Section 5 compares and analyses the performance of AQ-DBPSK with BPSK and DBPSK techniques.

2 Analysis of Existing Modulation Schemes

The communication conditions in WSNs differ significantly for indoor environments particularly at very short-distances. The received signal strength (RSS) attenuation rate is higher in indoor environments which could be due to waveguide effects and architectural dimensions [7]. Indoor propagation conditions also differ due to different building materials and construction practices [8, 9]. Recent experimental results [10] indicate that building materials and furnishings in indoor environments affect propagation for WSC. In order to cope with the above communication conditions the modulation/demodulation techniques should provide high energy efficiency and efficient utilization of transmitter power. These requirements are the deciding factors to select the most adequate modulation schemes for WSCs. The highest energy efficiency in Additive White Gaussian Noise (AWGN) channels can be achieved with the coherently demodulated orthogonal, bi-orthogonal and simplex signals [11]. In comparing the probability of error of binary signal, we observe that antipodal signals provide a 3 dB improvement in performance over orthogonal signals [12]. Frequency Shift Keying (FSK), BPSK, Quadrature Phase Shift Keying (QPSK) are examples of coherently demodulated signals which have highest energy efficiency in AWGN channels [13, 14]. But BPSK and QPSK are two times more energy efficient than FSK. Though QPSK provides higher data rate with the same BER performance compared to BPSK, the BPSK modulators and demodulators are simpler than QPSK. So BPSK looks to be an attractive choice but phase ambiguity and complex synchronization are the major drawbacks. DBPSK modulation excludes the phase ambiguity and need for phase acquisition and tracking. These benefits come at the cost of only slightly reduced energy efficiency [15]. But the down side is that DBPSK provides 180^0 phase transitions between adjacent symbols which lead to side lobe regeneration which is the main cause for inefficient utilization of transmitter power. Therefore in the following section a variation to DBPSK proposed in [4] called AQ-DBPSK is considered.

3 AQ-DBPSK Modulation

3.1 Basic principles

AQ-DBPSK has been developed with the basic concepts of DBPSK [4]. AQ-DBPSK maintains all the advantages of DBPSK while eliminating its drawbacks. The basic principles of AQ-DBPSK are based on the quadrature phase difference phenomenon. The input bits are first divided into odd and even symbols. All odd symbols are sent in quadrature with the even symbols, so the data which is to be sent is achieved with a phase difference of 0^o and 180^o between the same parity symbols. Thus, this operation achieves $\pm 90^o$ phase transition between all adjacent symbols. This reduces the peak factor of the system and allows the transmission of signal in full-saturation mode without any additional regeneration of side lobes in power spectrum. Since side lobe regeneration provides inefficient utilization of power by transmitter, more efficient power utilization is achieved.

3.2 AQ-DBPSK Modulator

The block diagram of the AQ-DBPSK modulator [4] is shown in Fig.1. The input data bits of length Tb that contains the transmission data is fed to the Differential Encoder (DE). The differential encoder contains a modulo2 summing and digital memory with 2Tb delay. The differentially encoded output describing the encoding bits by following equations:

$$b_1 = a_1, b_2 = a_2, b_k = a_k \oplus b_{k-2} \quad for \;\; k \geq 3 \qquad (1)$$

where k is the symbol number, a_k is the input to the DE and b_k is the differentially encoded output. The Generator of Alternating Ones and Zeros (GAOZ) block generates alternating sequence of ones and zeroes which is then ex-ored with the differential encoded data.

The Frame Converter (FC) then maps the data with two bit digital symbols according to the rule, '1' to '-1' (01 in sign magnitude notation) and '0' to '+1' (11 in sign magnitude notation). The I and Q component data is then filtered using Low Pass Filters (LPF) to ensure suppression of side-lobes in the signal spectrum and also to provide ±90° phase transition between adjacent symbols.

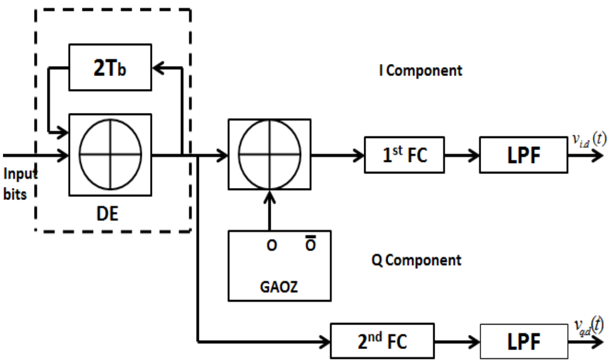

Fig.1 Block diagram of AQ-DBPSK modulator. [4]

The modulator is simulated using Agilent ADS software and the schematic is shown in Fig.2. Its operation is illustrated by timing diagrams in Fig.3. The input bit rate is 1MHz and raised cosine filter is used for pulse shaping.

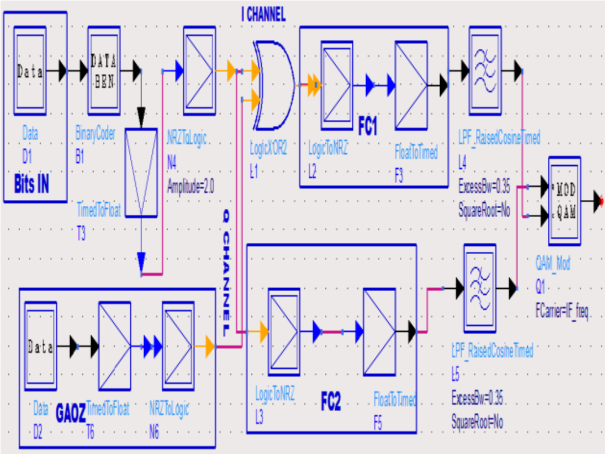

Fig.2 AQ-DBPSK Modulator Schematic

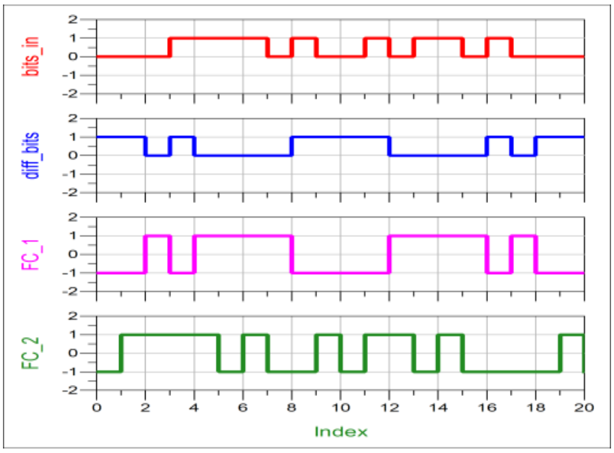

Fig.3 Timing diagrams for AQ-DBPSK Modulator

Signal constellation diagram for AQ-DBPSK is shown in Fig.4. The signal points present in 1st quadrant and 3rd quadrants are even symbols whereas the points in 2nd and 4th quadrants represent odd symbols. So the phase shifts of adjacent symbols is $+90^\circ$ or -90° and phase shifts between symbols of same parity is 0° or 180°. Thus, the ±90° phase transition contributes to reduced spectrum side lobes and the ±180° phase transition between same parity symbols allows the AQDBPSK modulation to provide more robustness to symbol error.

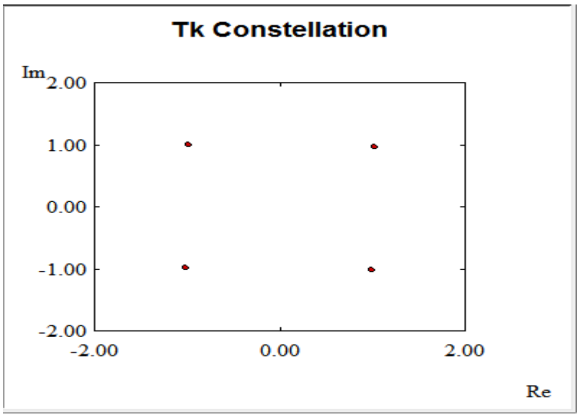

Fig.4 Signal constellation of the AQ-DBPSK Modulator

4 AQ-DBPSK Demodulation

The structure of the non-coherent AQ-DBPSK demodulator is similar to the non-coherent DBPSK demodulator. Since AQ-DBPSK conveys data by phase differences between same parity symbols, the symbol delay is longer. The block diagram of the non-coherent demodulator is shown in Fig.5.

A binary "0" in AQ-DBPSK is transmitted by

$$g_1(t) = \begin{cases} A_C Cos(\omega_c t + \varphi) & 0 < t \le T_b \\ A_C Cos(\omega_c t + \varphi) & 2T_b < t \le 3T_b \end{cases} \qquad (2)$$

A binary "1" is transmitted by

$$g_2(t) = \begin{cases} A_C Cos(\omega_c t + \varphi) & 0 < t \le T_b \\ A_C Cos(\omega_c t + \varphi \pm \pi) & 2T_b < t \le 3T_b \end{cases} \qquad (3)$$

Where A_C, ω_C, φ represent the carrier signal amplitude, frequency and phase respectively. The input voltage $V_{in}(t)$ represents the sum of desired signal and noise. The in-phase and quadrature channels are identical. The low pass filters in each channel reject out of band interference and also provide decimation. The integrators sum the signal samples during the bit time T_b.

The output of the correlator at $t = kT_b$ is :

$$i(k) = \frac{A_c T_b}{2} + n_i(k) \qquad (4)$$

$$i(k-2) = \frac{A_C T_b}{2} + n_i(k-2) \qquad (5)$$

$$q(k) = n_q(k) \qquad q(k-2) = n_q(k-2) \qquad (6)$$

where $i(k)$ is the in-phase channel integrator output, $q(k)$ is quadrature phase channel integrator output. $n_i(k)$, $n_i(k-2)$, $n_q(k)$, $n_q(k-2)$ are the in-phase and quadrature components of band pass noise signal which are uncorrelated zero mean Gaussian random variable with variance σ_n^2. The integrator outputs enter the Differential Decoder (DD) which contain $2T_b$ delay elements and a multiplier. The differential decoding in the in-phase channel is as follows :

$$\beta_1^i = i_1 \ , \ \beta_2^i = i_2 \ , \ \beta_k^i = i_k \times i_{k-2} \qquad for\ k \geq 3 \quad (7)$$

where β_k^i are bits at output of DD. Similarly for the quadrature channel:

$$\beta_1^q = q_1 \ , \ \beta_2^q = q_2 \ , \ \beta_k^q = q_k \times q_{k-2} \quad for\ k \geq 3 \ (8)$$

where β_k^q are bits at output of DD.

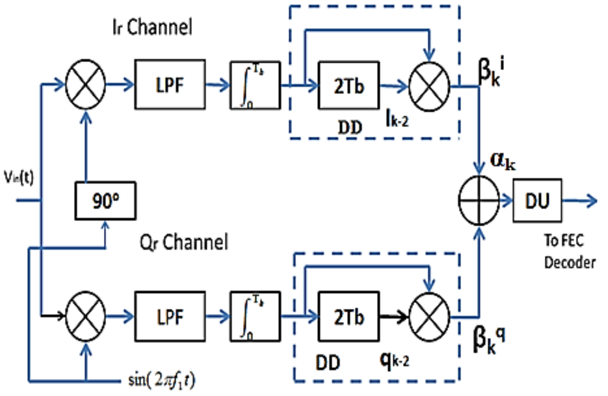

Fig.5. Block Diagram of AQ-DBPSK demodulator

The statistic α_k is formed by summing the output signals of the DD:

$$\alpha_k = \beta_k^i + \beta_k^q \qquad (9)$$

The Decision Unit (DU) forms a binary output signal using the sign and value of α_k. If $\alpha_k > 0$, the DU decides that $g_1(t)$ was transmitted. On the other hand, if $\alpha_k < 0$, then $g_2(t)$ was transmitted.

The probability of error, P_b for AQ-DBPSK [4] in AWGN channel is given in equation (10) where E_b is energy per bit and N_0 is one sided noise power spectral density.

$$P_b = 0.5 \exp(-E_b / N_o) \qquad (10)$$

The BER curve for simulated AQ-DBPSK modulation is shown in Fig.6 and is compared with DBPSK and BPSK. The E_b / N_o required for achieving a BER of 10^{-3} is 6.2dB. This is 0.4dB less as compared to BPSK which requires 6.6dB and 1.8dB less as compared to DBPSK which requires nearly 8 dB.

4.1 BER Comparison

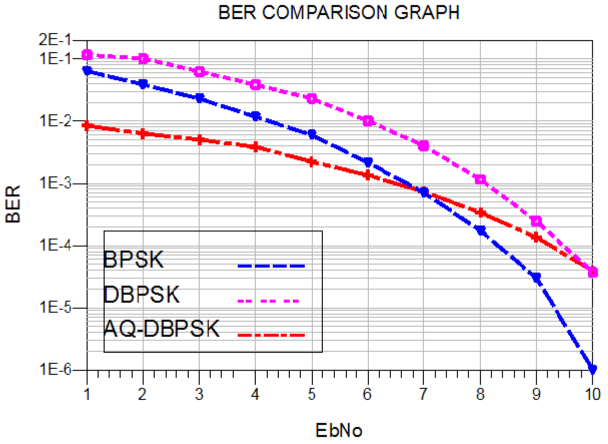

Fig. 6. BER comparison graph

Though BPSK shows better bit error rate performance for SNR > 7dB, the phase ambiguity problem and complex synchronization are major drawbacks. The DBPSK scheme excludes the phase ambiguity and need for phase acquisition and tracking but it has lower energy efficiency than BPSK. In AQ-DBPSK, though the BER is higher compared to BPSK, for higher SNR values, the reduction of phase shift between adjacent signals from 180° to ±90° reduces the side-lobe regeneration. This leads to better utilization of transmitter power compared to BPSK and DBPSK. For indoor applications, the AQ-DBPSK modulation performance in Rayleigh fading channel was also simulated as shown in Fig.7.

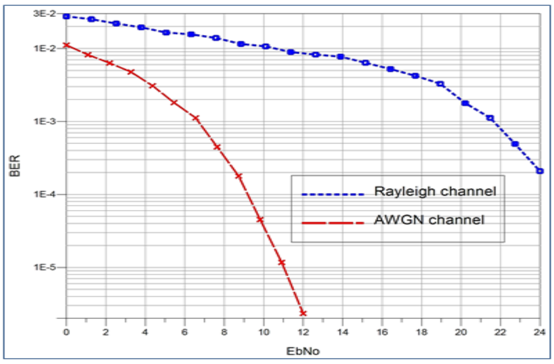

Fig.7. BER performance of AQ-DBPSK in AWGN and Rayleigh Fading Channel

To achieve the same BER of 10^{-3}, the Eb/No required in Rayleigh Fading channel is 21.6 dB. The poor error performance is due to the non-zero probability of deep fades when instantaneous BER can become very low.

5 Performance using Pulse Shaping filters

As shown in Fig.8, the Phase Shift Keying (PSK) spectrum consists of a main lobe representing the middle of the spectrum and various side lobes located on either side of the main lobe. Using a pulse shaping filter at the baseband provides frequency limitation by generating band limited channel [16]. It also reduces the Inter Symbol Interference (ISI) from multiple signal reflections. So, selection of a proper pulse-shaping filter with an appropriate value of excess bandwidth would limit bandwidth of the channel with a moderate value of ISI. Though theoretically, the sinc filter is an ideal pulse shaping filter, it is non-causal with slowly decaying tails. So it cannot be implemented precisely. The raised cosine filters are practical to implement and is in wide use. These filters exhibit zero impulse response at the zero crossing points. Thus, if the transmitted signal is correctly sampled at the receiver, the original symbols can be recovered. The root raised cosine filter is used in series pairs, so that the total filtering effect is that of the raised cosine filter. This configuration sets up a matched filter, maximizing signal to noise ratio while minimizing ISI. Raised cosine filters have configurable excess bandwidth, so that tradeoffs can be made between spectral efficiency, simplicity and energyefficiency.

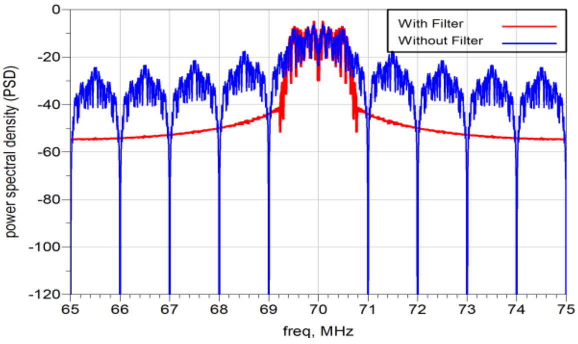

Fig.8. Power spectral density of BPSK signal

The Agilent Vector Signal Generator (VSG) was used to generate the BPSK and DBPSK signals. The results were measured at 70 MHz intermediate frequency and 1 MHz data rate. The results were analyzed using Agilent Vector Signal Analyzer (VSA). Various communication metrics such as magnitude error, phase error, bandwidth efficiency and BER for different values of excess bandwidth is plotted for both raised cosine and root-raised cosine filtering. In this paper, the normalized value of excess bandwidth is considered. This graphical comparison would provide selection criteria for the pulse-shaping filter excess bandwidth with respect to the different performance metrics.

5.1 Phase Error and Magnitude Error

Magnitude and phase errors are indicators of the quality of the amplitude and phase of the modulated signal. Fig.9 and Fig.10 show the phase error and magnitude error curve for the BPSK, DBPSK and AQ-DBPSK systems. For all these modulation schemes, the phase error and magnitude error curve fall rapidly in the range of excess bandwidth between 0.1 to 0.2. The curve falls very slowly between 0.2 to 0.5. For, excess bandwidth having 0.5 to 1.0, the value is almost constant. AQ-DBPSK with RRC filter provides the lowest phase error with excess bandwidth value between 0.2 to 0.5 whereas, with RC filter it provides lowest phase error with excess bandwidth = 0.35.

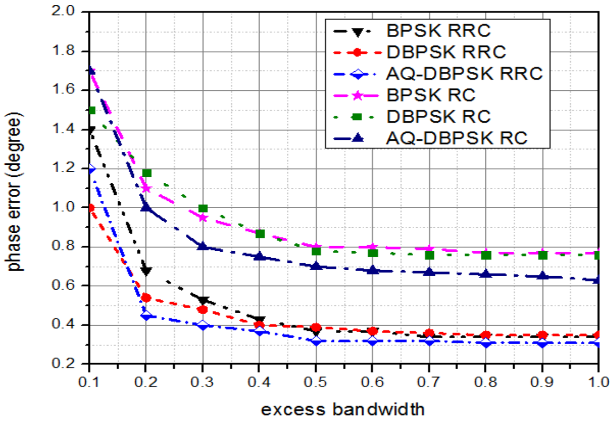

Fig. 9. Phase error curve for different modulation schemes

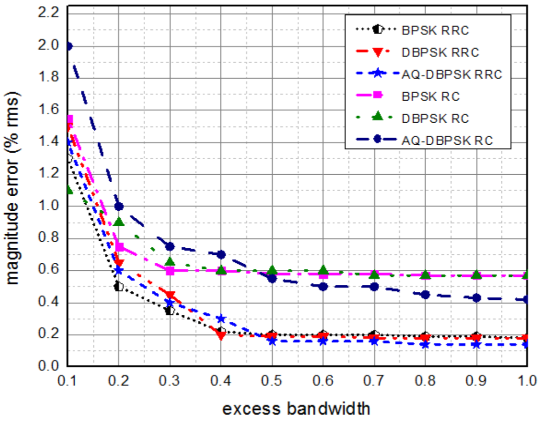

Fig.10.Magnitude error curve for different modulation schemes

In regard to magnitude error the AQ-DBPSK provides lowest magnitude error with excess bandwidth = 0.5 with RRC filter. Considering, magnitude error parameter, AQ-DBPSK format with RRC filter having excess bandwidth = 0.5 and with RC filter having excess bandwidth = 0.6 to 0.7 provide the lowest magnitude error.

5.2 Bit error rate measurement for different excess bandwidth

The variation of BER with excess bandwidth has been presented in Fig.11. The BER curve in Fig.12. shows that for AQ-DBPSK modulation, RRC filter with excess bandwidth =0.5 and RC filter with excess bandwidth=0.6 provide the lowest value of BER. For DBPSK modulation RRC filter provide minimum value of BER for excess bandwidth between 0.5 and 0.6.

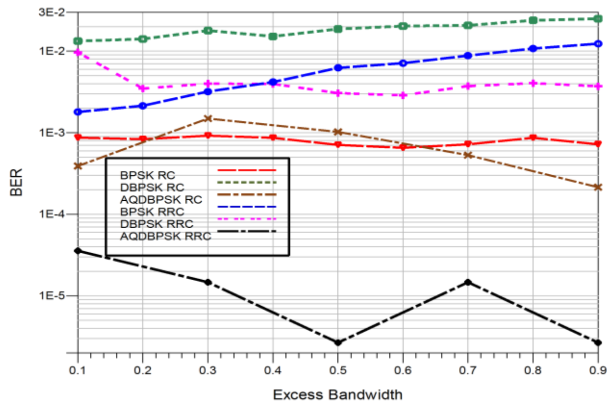

Fig. 11. BER curve for different Excess bandwidth

5.3 Bandwidth Efficiency Measurement

The power spectral density of the AQ-DBPSK modulator output was measured using Vector Signal Analyzer (VSA). The occupied bandwidth or Overall Bandwidth (OBW) is the bandwidth which contains 99% power. From this, the Bandwidth efficiency is calculated using equation (11).

$$Band\ width\ efficiency = \frac{data\ rate(bps)}{OBW\ (Hz)} \qquad (11)$$

The output power spectral density of the BPSK, DBPSK, AQ-DBPSK modulators were displayed using VSA. Then the value of OBW for various values of excess bandwidth for each modulation technique was tabulated as shown in Table 1. The bandwidth efficiency for each modulation scheme was calculated from the measured OBW for a data rate of 1Mbps and plotted against excess bandwidth as shown in Fig.12.

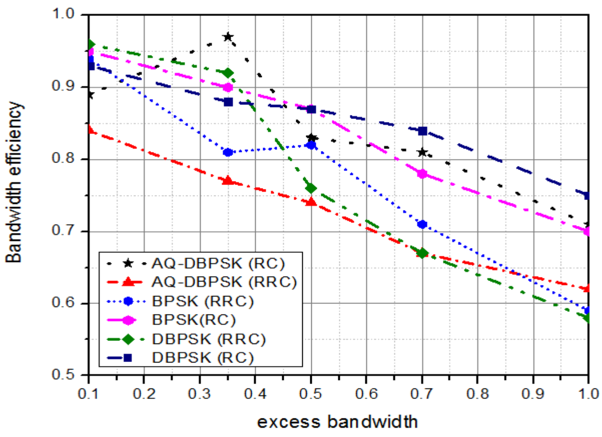

Fig. 12. Bandwidth efficiency for different excess bandwidth

As expected with increase in excess bandwidth, the bandwidth efficiency reduces. Since the other performance metrics remain stable for excess bandwidth greater than 0.5 to 1.0, the selection of bandwidth efficiency is made by comparing its value up to 0.5. DBPSK and BPSK with RC filtering shows high bandwiddth efficiency.

Table.1 Measured OBW And Calculated Bandwidth Efficiency With Different Excess Bandwidth

Excess Bandwidth	AQ-DBPSK			
	Raised-Cosine Filter		Root-Raised Cosine Filter	
	OBW (MHz)	BW Efficiency (bps/Hz)	OBW (MHz)	BW Efficiency (bps/Hz)
0.10	1.12	0.89	1.18	0.84
0.35	1.03	0.97	1.29	0.77
0.5	1.20	0.83	1.35	0.74
0.7	1.22	0.81	1.49	0.67
1.0	1.30	0.71	1.61	0.62
	DBPSK			
0.10	1.07	0.93	1.04	0.96
0.35	1.13	0.88	1.08	0.92
0.5	1.14	0.87	1.30	0.76
0.7	1.19	0.84	1.48	0.67
1.0	1.32	0.75	1.72	0.58
	BPSK			
0.10	1.05	0.95	1.06	0.94
0.35	1.10	0.90	1.22	0.81
0.5	1.14	0.87	1.21	0.82
0.7	1.28	0.78	1.4	0.71
1.0	1.41	0.70	1.68	0.59

The AQ-DBPSK spectral efficiency is poorer compared to DBPSK and BPSK. In AQ-DBPSK, the data is carried in alternate bit periods. So, the use of the narrow pulse shaping filters result in increase in ISI because more symbols can contribute. So this tightens the requirements on clock accuracy. Also it results in more peak carrier power due to higher overshoots.

The critical analysis of the results as discussed above is summarized in Table 2. The best choice of modulation format along with the proper pulse shaping filter and its excess bandwidth for each performance metric is given. It is apparent that the ultimate selection of the type of modulation and pulse shaping filter with proper excess bandwidth is made by appropriate trade off among the performance metrics.

Table.2 Performance Comparison of BPSK, DBPSK, AQ-DBPSK Modulation in Regard to Pulse Shaping Filters

Performance metric	**Choice**
Magnitude error	DBPSK, BPSK, AQ-DBPSK with RRC filter (excess bandwidth=0.5)
Phase error	DBPSK or AQDBPSK with RRC filter (excess bandwidth=0.5)
Band width efficiency	DBPSK, BPSK with RC filter (excess bandwidth = 0.4)
Bit error rate	AQ-DBPSK with RRC filter(excess bandwidth = 0.5)

6. Conclusions

In WSC based wireless networks, energy efficiency is of paramount importance in extending the lifetime of the node. This paper analyzes the performance of AQ-DBPSK modulation scheme under AWGN channel and Rayleigh fading conditions. The BER performance is shown to be superior to BPSK and DBPSK schemes. This makes it a good choice for energy efficient communication systems. Also since pulse shaping circuits influence the behavior of a modulation scheme, we have presented the analysis of different performance metrics such as magnitude and phase error, Bandwidth efficiency and BER of the BPSK, DBPSK and AQ-DBPSK techniques. The graphical representation of the results and its critical analysis could be used by system designers for choosing a proper modulation format with suitable pulse shaping filter. For wireless communication system designers, looking to maximize power and bandwidth efficiency, this work is beneficial from the system design point of view.

Acknowledgment

Authors are very much appreciative to the Department of Science and Technology (DST), Government of India for providing financial backing in accomplishing this research work.

References:

[1] Ian.F.Akyildiz, Weilian Su, Yogesh Sankarasubramaniam, Erdal Cayirci, “A survey on sensor networks,” *IEEE Communications magzine*, Vol. 40, 102–114, August. 2002.

[2] F. Costa, H. Ochiai, “Energy optimization for reliable point-to-point communication in energy-constrained networks,” in *Proc. IEEE 2010 Vehicular Technology Conference*, VTC Spring, 1–5, May 2010.

[3] J.M. Rabaey, J. Ammer, T. Karalar, S. Li, B. Otis, M. Sheets, T. Tuan, "Pico Radio for wireless sensor networks: the next challenge in ultra-low power design," in *Proc.IEEE International Solid-State Circuits Conference: (ISSCC) Dig. Tech. Papers*, 200-201, 2002.

[4] Yefim S. Poberezhskiy, “Novel Modulation Techniques and Circuits for Transceivers in Body Sensor Networks,” *IEEE Journal on Emerging and Selected Topics in Circuits and Systems*, Vol.2, No.1, 96-108, March 2012.

[5] Y.S.Poberezhskiy, “Modulation and Spreading techniques for burst transmission,” in *Proc. IEEE Aerospace Conf. BigSky MT*, 1-11, March 2007.

[6] T.K. Sarkar, Zhong Ji; Kyungjung Kim; A. Medouri, M. Salazar-Palma, ”A Survey of various propagation models for mobile communication,” in *IEEE Antennas and propagation Magzine*, Vol.45, No.3, 51-82, June 2003.

[7] K.A.Qaraqe et al.,”Statistical wireless channel propagation characteristics in underground mines at 900 MHz: A comparative analysis

with indoor channel," *Ad hoc networks*, 2011, doi:10.1016/j.adhoc.2011.01.015.

[8] R. Ganesh, K. Pahlavan, "Statistical characteristics of a partitioned indoor radio channel," in *Proc. IEEE international conf. on communication,* 1252-1256, 1992.

[9] W.K. Tam, V.N. Tran, "Propagation modelling for indoor wireless communication," in *IEEE Electronics and communication engineering Journal*, 221-228, October 1995.

[10] T. Rama Rao, D. Balachander, "RF Propagation Investigations at 915/2400MHz in indoor corridor environments for Wireless Sensor Communications", *Progress in Electromagnetics Research B,* Vol. 47, 359-381, 2013.

[11] John G. Proakis, Masoud Salehi, "*Digital Communication"*, McGraw-Hill,5th Edition, 2007.

[12] B.Sklar "*Digital communication, fundamentals and applications"*, 2nd ed. Upper Saddle River, NJ: Prentice Hall PTR, pp.167-240, 2001.

[13] Kaur Harjot Jain, Bindiya Verma, Amit., "Comparative performance analysis of M-ary PSK modulation schemes using Simulink" *International Journal of electronics and communication technology,* Vol.2, No. 3, 204-209, September 2003.

[14] Chauhan Vikas, Arora, Manoj, Chauhan,R.S., "Comparative BER performance of PSK based modulation techniques under multipath fading," *Advances in Applied Science Research*, 521-527, 2011.

[15] Razavi, B., "*RF Microelectronics"*, Prentice Hall, Upper Saddle River, NJ,1998.

[16] Theodore S. Rappaport, "*Wireless Communications Principles and Practice"*, Pearson, Second Edition, 2002