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2.4 GHz Transceiver Design for Wireless Sensor Application

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Abstract:
Wireless networks of sensor nodes are envisioned to bedeployed in the physical environment to monitor a wide variety of real-world phenomena. Wireless sensor networks (WSN's) are becoming popular in military and civilian applications such as surveillance, monitoring, disaster recovery, home automation and many others. Wireless sensor networks (WSN) demand low power and low cost transceiver design. The power consumed by node transceiver electronics is non-negligible and has a major impact on battery life. The main objective of this project is to design a low power transceiver for indoor application. This transceiver operates at 2.4 GHz with data rates upto 1Mbit/s and QPSK modulation. The required transmitter power is - 6dBm. The design exhibits a very low noise figure of only 4.2 dB at transmitter side and 4.225 dB at receiver side. The error vector magnitude (EVM) is 9.7% and receiver sensitivity is -96 dBm with bit error rate of 10-3. Agilent Advanced Design System (ADS, Now keysignt technologies) is used for design and performance evaluation of our system.

Keywords: Low power design, Radio transceiver, EVM,wireless sensor network, Agilent(keysignt technologies)ADS.

I. INTRODUCTION

Wireless networks and sensors are seen to play an increasingly important role as key enablers in emerging pervasive computing technologies that are required for the realization of smart homes As social reliance on wireless sensor network technology increases, we can expect the size and complexity of individual networks as well as the number of networks to increase dramatically[1].Due to the rapid advances in wireless communication and information technologies it is now possible to embed various levels of smartness in the home. As technology advances, smart sensor nodes and actuators can be buried in appliances, such as vacuum cleaners, refrigerators, micro-wave ovens and VCRs. These sensor nodes inside the domestic devices can interact with each other and with the external network via the internet or satellite. They allow end users to manage home devices locally and remotely more easily[2]. These smart homes are ones that can interact intelligently with their inhibitors to provide comfort and safe living. This interaction may range from simple control of ambient temperature to context-aware and mobile agent based services. A particularly important performance criteria for the mobile devices and nodes is the data rates and battery life. A long battery life is a must for WSN's due to difficulty in replacing or recharging batteries for hundreds of sensor nodes.

The increasing demand for low-power wireless transceivers operating in the 2.4 GHz band has prompted an extensive research in this area. The constraints of a wireless sensor network are different from other conventional hand-held devices.

They communicate small packet sizes, and the average data rates are low due to low event rate. Also, the traffic is mostly up-link from sensors to the base station with a very short transmission distance. In this paper, the proposed transceiver supports 1Mbps data rates for home automation and other indoor wireless applications. Channel conditions have a very high impact on the power consumed by the transceiver [3]. In indoor environments the propagation conditions are very diverse. Although the sensors in indoor environments can be expected to be at a fixed location, the channel may change due to moving personnel or a change in furniture arrangement. Also radio channel asymmetry has to be considered, i.e. path loss and fading may vary for the same conditions [3]. So two different sensors may see channels with different SNRs at the same time. Selection of the proper transceiver architecture depends on the requirements of the application. Traditionally used narrow band architectures [4] include Super heterodyne, Zero-IF (Intermediate Frequency), Low-IF architectures. Low IF architecture exhibits high integratability and small DC offset. Also, the low cost implementation is highly suited for sensor network applications.

In this paper, we designed the RF transmitter system based on QPSK modulator, with a RF frequency 2.4GHz. The proposed system specifications and link budget calculations are discussed in section III. The RF transceiver analysis is presented in section IV and V. The transceiver is designed and simulated on the system level using agilent ADS.

II. MOTIVATION & EARLIER WORK

The wireless technology standards are everywhere. Bluetooth, Zigbee, RFID, WiFi, and cellular technologies are the most well-known standards. A combination of these standards is envisaged to be used to construct the smart home. Effectively all wireless technologies that can support some form of remote data transfer, sensing and control are candidates for inclusion in the smart home portfolio[5].

The power consumption of a RF transceiver can vary significantly depending on the application. Table I shows the typical power consumption numbers for GSM [6], 802.11b [7], Bluetooth [8] and Zigbee transceivers [9]. Power amplifier efficiency can vary depending on the type, output power, technology and design. For ease of comparison, a fixed realizable power amplifier efficiency of 40% is assumed.

Table.1. Power consumption of short and long range transceivers

	GSM	802.11b	BLUETOOTH	ZIGBEE
PRX + PLO (mW)	240	60	30	14.6
PTX + PLO (mW)	360	100	12	25
PT (mW)	1000	100	1	1
PPA (mW)	2500	250	2.5	1.5
ɳP	32%	24%	2%	1.5%

The GSM transceiver has a transmission range greater than 1km and has the most stringent system specifications. Its transceiver electronics power and RF transmit power are the highest. The 802.11b transceiver has an intermediate range on the order of 10s of meters. The Bluetooth and zigbee transceivers have the shortest transmission range and the most relaxed system specifications. Its power consumption is the lowest. The RF transmit power of Zigbee transceiver is three orders of magnitude lower than that of GSM transceiver due to the reduction in transmission range. But, the reduction in transceiver electronics power is only an order of magnitude. This means that, in the long range transceivers the power is dominated by RF transmit power, but in short range transceivers the power is dominated by circuit electronics. For the systems shown in Table I, the maximum achievable transceiver efficiency is limited by the power amplifier to 40%. Both GSM and 802.11b transceivers have respectable efficiencies, but the Bluetooth receiver has an efficiency of only 2%, which means that transceiver electronics power dominates. By increasing data rate, the ratio of the RF transmits power to the transceiver electronics power improves. In this paper, we have designed the transceiver at 1Mbps, thus ensuring higher energy efficiency.

III. LINK BUDGET AND TRANSCEIVER SPECIFICATIONS

In Home automation system, the link could be between a remote dimming fixture and a lighting fixture or a remote thermostat control and thermostat in another room. The link is characterized by obstructions, multipath losses which add to the path loss and therefore reduce the range. In near ground RF propagation, the signal consists of two component: the direct line of sight (LOS) signal and signal reflected from ground. The phase of the ground bounce is always opposite to LOS signal. The height of both transmitter and receiver

Table.2.Proposed Transceiver Specifications

Parameters	Specification
Range	10m
Modulation scheme	QPSK
Data rate	1Mbps
TX/RX antenna gain	0dB
Receiver sensitivity	-95dBm
Channel bandwidth	1MHz
BER	10^{-3}

determine the range of the link. This is because the ground bounce approximation for path loss improves as square of the height of the antenna. But in home automation application, each height may vary. So to get maximum indoor range, the sensitivity of the receiver should be very good. According to FCC regulation, for unlicensed system not employing spread spectrum techniques, RF power is limited to -1.25dBm or about 0.75mW. Though spread spectrum offers interference rejection and higher RF transmission power, it also entails higher complexity. Most Wireless sensor network (WSN) application in indoor environment, can be reliably serviced by a low power non spectrum radio. To ensure that the home automation application can be reliably serviced by a low power non spread radio, a top level radio link analysis is done. The specifications of the proposed transceiver are summarized in Table II. The unlicensed 2.4GHz band can support 1Mbps data rate with 10 meter range making it suitable for indoor applications. The required signal strength at the receiver input is a function of modulation technique and desired BER. To realize a BER of 10^{-3} at a data rate of 1Mbps, the SNR at input of the demodulator, for QPSK is 14dB as calculated from equation(1)

$$SNR = \left(\frac{E_b}{N_0}\right)\left(\frac{R}{B_T}\right) \quad (1)$$

Where E_b is energy required per bit of information, N_0 is thermal noise in 1Hz of bandwidth, R is system data rate and B_T is system bandwidth Noise power is given by equation (2) and is -111dBm

$$Noise\ power = KTB \quad (2)$$

Where K is Boltzmann's constant ($1.38X10^{-23}$ J/K), T is Temperature in kelvins (290 K) and B is bandwidth in HzReceiver sensitivity (Prx) is given by equation (3)

$$Prx = noise\ power + NF + SNR \quad (3)$$

Propagation loss (L_{fs}) is given by equation (4)

$$L_{fs} = 20\log\left(\frac{4\pi d}{\lambda}\right) \quad (4)$$

Where d is the distance between transmitter and receiver, λ is free space wavelength.

The required transmitter output power (P_{tx}) is given by equation (5)

$$P_{tx} = P_{rx} - G_{tx} - G_{rx} + L_{fs} + Fade\ Margin \quad (5)$$

Where Prx is the receiver sensitivity, Gtx is transmit antenna gain and Grx receive antenna gain, Lfs is the propagation loss and for a simple dipole antenna, G_{tx} and G_{rx} is 0dB. The exact amount of fade margin required depends on the desired reliability of the link, and a fade margin of 30dB is assumed. Tradeoffs exist between receiver sensitivity, receiver noise figure and transmitter output power. To obtain a receiver sensitivity of about -96 dBm as per specifications, we require a transmitter output power of -6 dBm, and the receiver noise figure is about -4dB.

IV.PROPOSED ARCHITECTURE

A block diagram of the transceiver with MODEM block is shown in fig.1. The transceiver operates in a single channel centered at 2.4 GHz and employs QPSK modulation. The modulation block generates the QPSK modulated data waveform to the input of transmitter. Both the transmitter and receiver are designed to maximize energy efficiency. Designing of transmitter and receiver are based on super heterodyne type architecture.

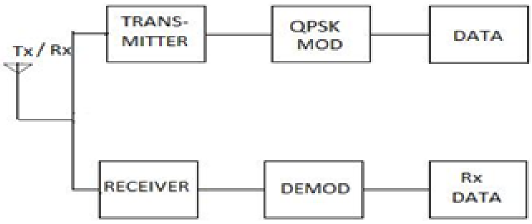


Figure.1. Complete transceiver system block diagram

A. *Modulation*

QPSK (Quadrature Phase Shift Keying) is a phase modulation scheme. Phase modulation is a frequency modulation version where the carrier wave's phase is modulated to encode bits of digital information in each phase change. The "PSK" in QPSK refers to the use of Phased Shift Keying. Phased Shift Keying is a form of phase modulation that is accomplished by using a discrete number of states. QPSK refers to PSK with 4 states. With half that number of states, there is a BPSK (Binary Phased Shift Keying). With twice the number of states as QPSK, there is a 8PSK. The "Quad" in QPSK refers to four phases in which a carrier is sent in QPSK: 45, 135, 225, and 315 degrees. Fig.2 shows QPSK modulation block and this work constellation trajectory and dotted constellation diagram shown in Fig. 3(a) & 3(b).

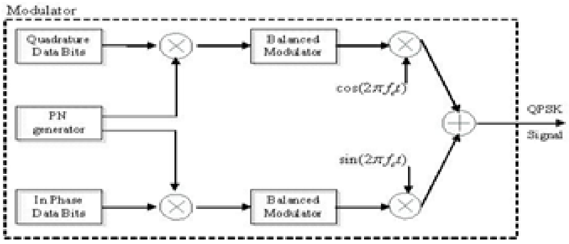
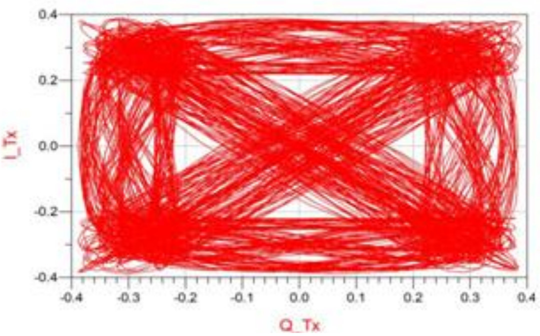
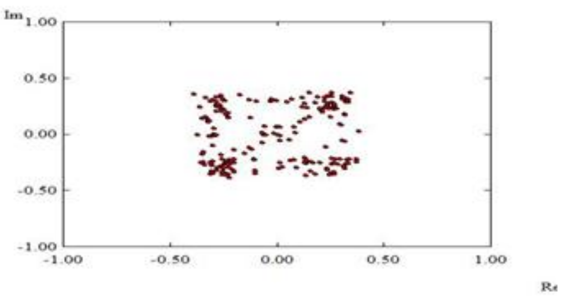


Figure.2. QPSK modulator block



3(a)



3(b)

Figure.4. QPSK constellation diagram shown in figure.3 (a) connected and (b) Dotted

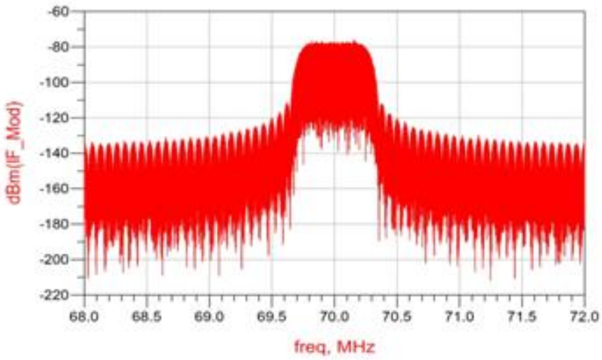


Figure.4. Modulated data spectrum at IF frequency

And the modulated spectrum at the output of modulation block at IF frequency is shown in fig.4

B. *Data Rates*

For sensor network application like home automation and other wireless application, a data rate of only hundreds to thousands of bits per second is required. Wireless sensor nodes are data centric but no need of very high data rates. However, for optimal energy efficiency it is often advantageous to operate the transceiver at a higher instantaneous data rate and turn off the radio periodically.

V. TRANSCEIVER IMPLEMENTATION

A. *Receiver front end*

A detailed block diagram of the receiver front end is shown in Fig 5. The first stage of receiver is a Low-noise amplifier (LNA). LNA is an electronic amplifier used to amplify very weak signals. LNA usually located very close to the detection device to reduce losses in feed line. Mixer is used for frequency conversion and is a critical component in modern radio frequency system. A band-pass filter is a device that passes frequencies within a certain range and rejects (attenuates) frequencies outside that range.

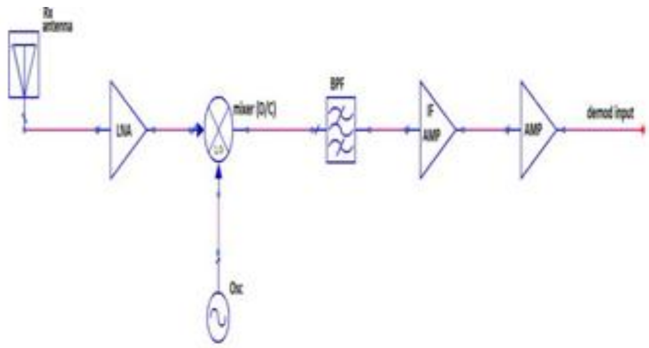


Figure.5. Receiver schematic

An ideal bandpass filter would have a completely flat passband (e.g. with no gain/attenuation throughout) and would completely attenuate all frequencies outside the pass band. A band-pass filter can be characterized by its Q-factor. The Q-factor is the inverse of the fractional bandwidth. A high-Q filter will have a narrow passband and a low-Q filter will have a wide passband. In mixer one is RF input and other is LO input, output of mixer produces two signals whose frequency content lies about the sum and difference frequencies of the center frequency of the original signal and the oscillator frequency. A Local oscillator is used in the receiver to hold the difference-signal center frequency constant as the receiver is tuned. The constant frequency of the down converted signal is called the intermediate frequency (IF), and it is this signal that is processed by the intermediate-frequency amplifier. In this work RF frequency is 2.4GHz and IF frequency is 70 MHz that supports 1Mbits/s of data rates with using QPSK modulation and at receiver side QPSK demodulation the bit error rate (BER) for this system is 10^{-3} for QPSK modulation Eb/No is 14. Fig 6 shows graph between BER and Eb/No. Table II. shows Budget analysis of the Receiver with parameters & values used in ADS simulations

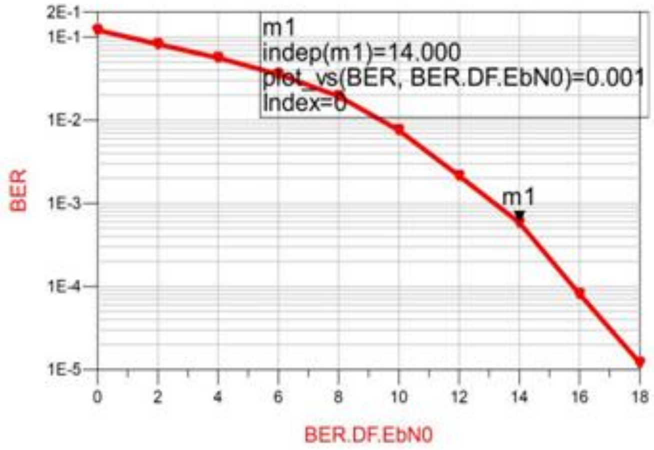


Figure.6. BER vs Eb/No

Table .3. Budget analysis of receiver

System Name	System Value
SystemInP1dB_dBm	-41.156
SystemNF_dB	4.225
SystemPout_dBm	14.340
SystemS21_dB	7.78

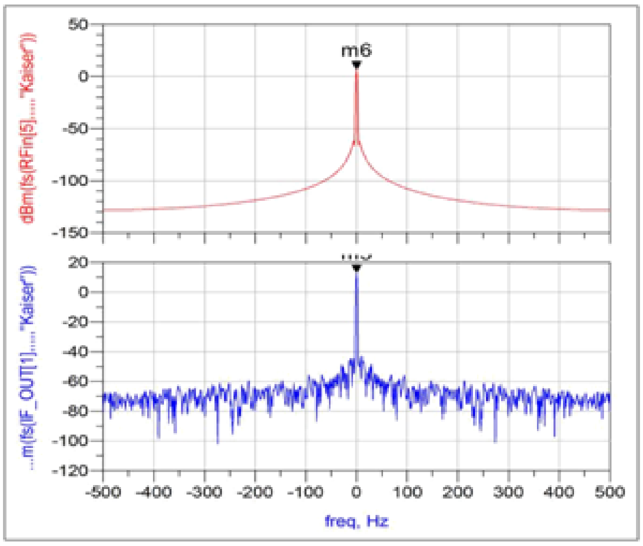


Figure.7. PSD at input and output of receiver

Fig .7 shows the PSD at the input and output of receiver shown below for RFin marker placed at 6.44dBm and for IF_out marker placed at 12.8 dBm.

B. ***Transmitter front end***

Transmitter schematic diagram shown below in Fig.8. Important component in transmitter side is power amplifier, pre amplifier, mixer and oscillator. An RF power amplifier is a type of electronic amplifier used to convert a low-power radio-frequency signal into a larger signal of significant power, typically for driving the antenna of a transmitter. Figure 9 shows PSD at input and output stage of transmitter. Transmitter output stage power is 14dBm. Fig.10 shows output spectrum at the output of Transmitter at RF frequency.

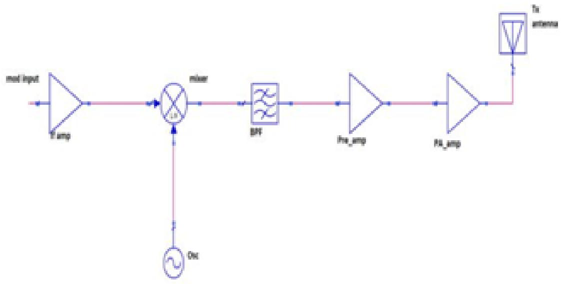


Figure.8. Transmitter schematic

Fig. 11 shows the modulated output spectrum and QAM constellation diagram on Vector signal analyzer (VSA)

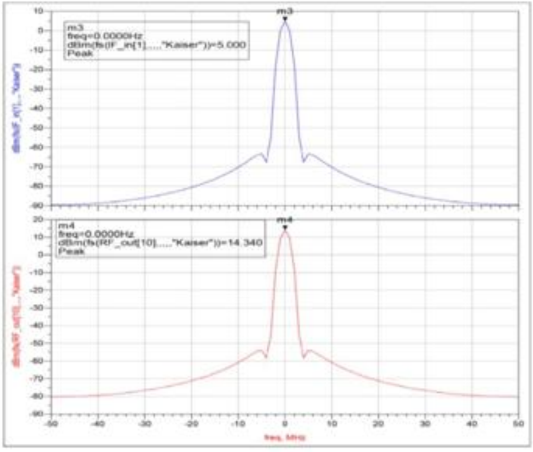


Figure.9. PSD at input and output of transmitter

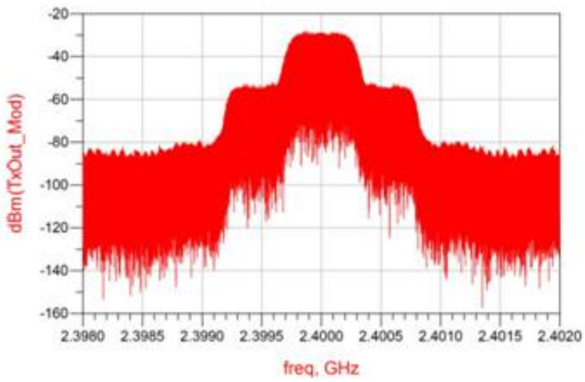


Figure.10. Output spectrum of transmitter

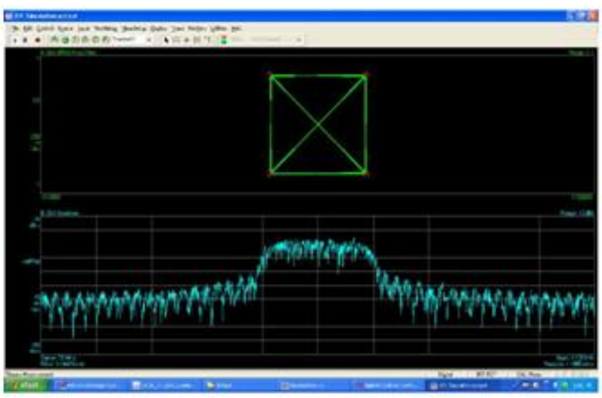


Figure.11. shows the output on VSA

The budget analysis of transmitter shown in Table III, it shows Budget analysis of the Transmitter with parameters & values used in ADS simulations.

Table .4. Budget analysis of transmitter

System Name	System Value
SystemNF_dB	3.057
SystemInTOI_dBm	-31.135
SystemOut1dB_dBm	-40.750
SystemPOut_dBm	12.457

EVM (Error Vector Magnitude) measurements are used to evaluate the modulation accuracy of modulators/transmitters. EVM calculation formula

$$EVM = \frac{\sqrt{\frac{1}{N}\sum_{K=0}^{N-1}|E(k)|^2}}{\sqrt{\frac{1}{N}\sum_{K=0}^{N-1}|S(k)|^2}} \quad (6)$$

Where

$$\sum_{K=0}^{N-1}|E(K)|^2 = \sum_{K=0}^{N-1}\left|\frac{Z(K)W^{-K} - C_0}{C_1} - S(K)\right|^2$$

N is equal to SymBurstLen and C_0 is a complex constant origin offset (in Volts), C_1 is a unit less complex constant representing the arbitrary phase and output power of the transmitter, and E(k) is the residual vector error on sample S(k) (in Volts). In this case EVM is .097 (9.7%).

VI. CONCLUSION

In this work, we have designed and evaluated the performance of 1Mbit/s transceiver at 2.4 GHz utilizing Agilent ADS. The low EVM value of 9.7% at the transmitter shows that the modulation accuracy is good. The required transmitter power is only -29dBm. The receiver sensitivity of -96 dBm was obtained at BER 10^{-3} for short range communication of 10 m. This transceiver can be used to reliably service indoor wireless applications like home automation networks.

VII. REFERENCES

[1]. Shah Sheetal, “Autonomic Wireless Sensor Networks” Viterbi school of engineering, university of southern California, USA

[2]. I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci,” Wireless sensor networks: a survey” Published by Elsevier Science B.V., 2002.

[3]. KatjaSchwieger, Amrit Kumar, Gerhard Fettweis, “On the impact of the Physical layer on energy consumption in sensor networks,”Proc. of Euro workshop on wireless sensor Networks, Feb 2005

[4]. Reza Yousefi and Ralph Mason, “An Energy-Efficient Transceiver Architecture for Short Range Wireless Sensor Applications” IEEE 2009.

[5]. Mahmoud A. Al-Qutayri and Jeedella S. Jeedella” Integrated Wireless Technologies for Smart Homes Application”, Khalifa University of Science, Technology and Research, UAE

[6]. A. Molnar and et al., "A single-chip quad-band(850/900/1800/1900MHz) direct conversion GSM/GPRS RF transceiver with integrated VCOs and fractional-N synthesizer," in IEEE Int. Solid-State Circuits Conf (ISSCC) Dig. Tech. Papers, February 2002, pp. 232-233.

[7]. R. Meyer, W. Mack, and J. Hageraats, "A 2.5 GHz BiCMOS transceiver for wireless LAN," in IEEE Int. Solid-State Circuits Conf: (ISSCC) Dig. Tech. Papers, February 1997, pp. 310-311.

[8]. N. Filiol, N. Birkett, J. Cherry, F. Balteanu, G. Gojocaru, A. Namdar,T. Pamir, K. Sheikh, G. Glandon, D. Payer, A. Swaminathan, R. Forbes,T. Riley, S. Alinoor, E. Macrobbie, M. Cloutier, S. Pipilos, and T. Varelas,"A 22mW Bluetooth RF transeiver with direct RF modulation and on-chip IF filtering," in IEEE Int. Solid-State Circuits Conf (ISSCC)Dig. Tech. Papers, February 2001, pp. 202-203.

[9].Faisal Abdel-Latif Elseddeek Ali Hussein, “ Ultra low power IEEE 802.15.4/zigbee compliant transceiver”, PhD, Dissertation , 2009

[10]. Andrew Yawing, Charles G.Sodini” on the Energy Efficiency of Wireless Transceivers” in IEEE ICC, 2006.