International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:6, No:8, 2012

Transcutaneous Inductive Powering Links Based on ASK Modulation Techniques

S. M. Abbas, M. A. Hannan, S. A. Samad, A. Hussain

***Abstract*—**This paper presented a modified efficient inductive powering link based on ASK modulator and proposed efficient class-E power amplifier. The design presents the external part which is located outside the body to transfer power and data to the implanted devices such as implanted Microsystems to stimulate and monitoring the nerves and muscles. The system operated with low band frequency $10MH_Z$ according to industrial- scientific – medical (ISM) band to avoid the tissue heating. For external part, the modulation index is 11.1% and the modulation rate 7.2% with data rate 1 Mbit/s assuming Tbit = 1us. The system has been designed using 0.35-µm fabricated CMOS technology. The mathematical model is given and the design is simulated using OrCAD P Spice 16.2 software tool and for real-time simulation, the electronic workbench MULISIM 11 has been used.

***Keywords*—**Implanted devices, ASK techniques, Class-E power amplifier, Inductive powering and low-frequency ISM band.

I. Introduction

THE implanted biomedical devices are electronics devices such as, peacemaker, retinal implants, cochlear implants, brine peacemaker implants and micro-system stimulator implants. The micro-system stimulators used to stimulate and monitoring the biological signal such as nerves signals, muscles signals, blood pressure, intraocular pressure, etc. [1]. So far, the implanted devices powered using batteries, and because of the limited time-life of the battery, chemical side effect, researchers find several new methods to power and monitoring the implanted devices [2], currently most of the implanted devices powered transcutaneously using inductive coupling links. The system consisted of two parts, external part to transfer data and power inductively to the internal part (implanted devices) which is located within the body, because of weak links between the two parts the system need efficient external part which is consists of battery, modulator and Power amplifier [3]. The modulation technique used in the implanted devices can be an amplitude shift keying ASK, frequency shift keying FSK and phase shift keying PSK. The ASK modulation is widely used due it is simplest architecture, low-power consumption and low cost as shown in the lecturer review [4].

S. M. Abbas is with the Department of Electrical, Electronic & Systems Engineering, Faculty of Engineering and Built Environment, University Kebangsaan Malaysia, 43600 UKM Bangi Selangor, Malaysia; (phone +60176870253 ; e-mail: saadabas@eng.ukm.my).

M. A. Hannan* is with the Department of Electrical, Electronic & Systems Engineering, Faculty of Engineering and Built Environment, University Kebangsaan Malaysia, 43600 UKM Bangi Selangor, Malaysia; (phone+60-3-8921-7014; Fax: +60-3-8921-6146; e-mail: hannan@eng.ukm.my).

A. S. Salina and A. Hussain are with the Department of Electrical, Electronic & Systems Engineering, Faculty University Kebangsaan Malaysia, 43600 UKM Bangi Selangor, Malaysia;(e-mail: salina@eng.ukm.my ; aini@eng.ukm.my)

In this paper the improved ASK modulator will be presented with low frequency 80 KH_Z and efficient class-E power amplifier operated with low band carrier frequency $10MH_Z$ to avoid the tissue damage according to the industrial-scientific - medical (ISM) band [5], with modulation index 11.1% to achieve 1Mbit/s for the external part. The inductive coupling link will be designed supposing that the implanted electronic device load resistor is 200-350 Ω with fixed value of coupling factor K. The system has been designed using 0.35-µm fabricated CMOS technology. The mathematical model will be given, and the design will be simulated using OrCAD P spice 16.2 software tools, and for real time simulation the electronic work bench MULISIM 11 was used. The outlined for this paper as follows. Section II, presents the overview system architecture, and the main elements and parameters are used in the system. Section III, explains the model for the ASK modulator. Section IV, presents the method and design for class-E power amplifier with calculated parameters and values. Section V presents the inductive coupling links with mathematical models. Section VI. Simulation and results discussion will be presented, and in section VII, the conclusion is given.

II. System Overview

The digital data and power transmission block diagram for wireless implanted devices (IMD_S) is represented in fig. 1. The system is consists of two parts, the external part located outside the body and consisted of power supply, binary data generator, ASK modulator and power amplifier. The internal part consists of received coil behaves as a received antenna, rectifier to extract the data and convert RF signal into DC voltage, voltage regulator to provide a stable DC voltage to

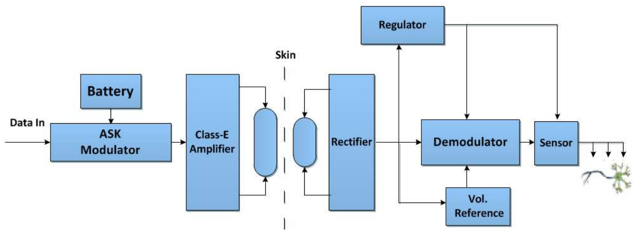


Fig. 1 Block diagram for inductively power transmission.

the implanted device and ASK demodulator to demodulate the output signal. The inductive links Consists of two RLC circuits, and to have better power transfer efficiency both circuits tuned at the same resonant frequency. The external RLC circuit tuned at serial resonant to provide a low-impedance load, whereas the internal RLC circuit tuned at parallel resonant [6 and 7].

International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:6, No:8, 2012

The energy is needed to be transfer efficiently from external to internal part, and to achieve efficient transmission, an efficient class-E power amplifier will be used. The circuit design for the external part shown in fig. 2.

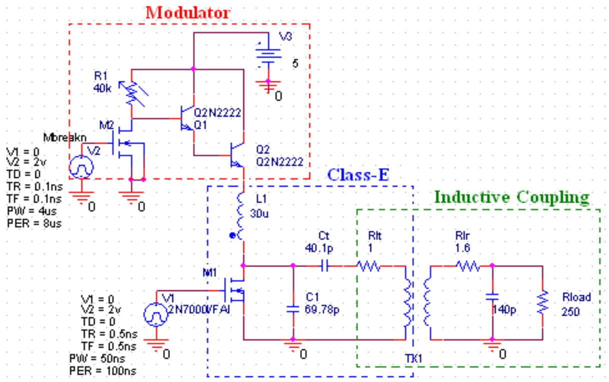


Fig. 2 Block diagram for external part and inductive link

III. ASK Modulator Design

The modulator is an electronics device used to modulate the binary signals. Modulation techniques used in the implanted devices, and bio-telemetry systems are ASK, FSK and PSK; each of these modulation techniques has advantage and disadvantage. ASK modulation will be used in our work due.. it's simplest, low power consumption and low cost. The transmitted data rate can be improved by improving the electronics sub-circuits design. The ASK modulator used in this work consists of fabricated switching NMOS transistor based on 0.35um technology with proposed edited parameters, which created using edit Pspice mode in the software tools. The modulator structure was shown in fig. 2. The bipolar transistor Q2N2222 was used, the variable resistor useing to adjust the modulation index with value 11.1%, modulation rate 7.2%. The binary signal with T_{bit} = 4µs generated using Manchester encoder, shift register 74STD to generate serial digital signals according to the configuration setting which given by the users or using P spice software tools. In this work, the binary signal generated using Pspice function. The modulator powered with V_{dd} =5v and this voltage higher than the voltage which supply the power amplifier in order to compensate the drop voltage in the ASK modulator. Fig. 3 (a), shown the binary data signal for ASK modulator with values "1" and "0". Fig. 3 (b), shown the supply voltage of the class-E power amplifier which is between 2.7 V and 3.7 V depended on switching mode of NMOS transistor. Fig. 3 (c), show ASK modulated signal at the transmitted coil with V_{max} = 60 v and V_{min} = 48 v the modulation index and modulation calculated as given in (1 and 2).

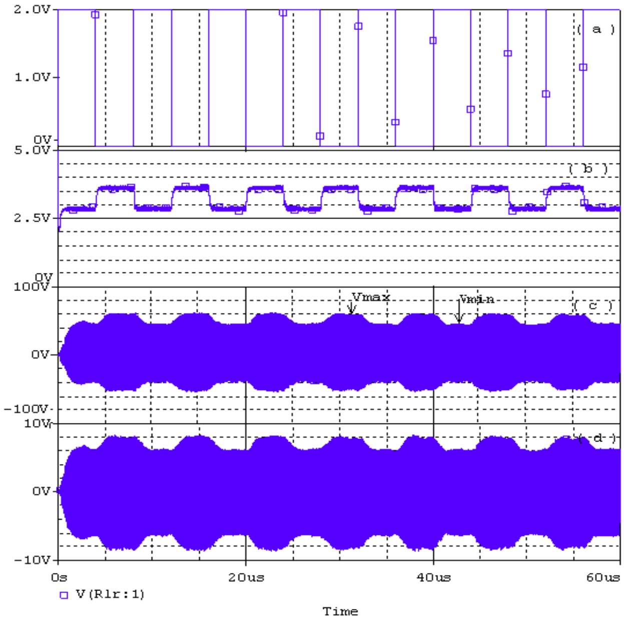


Fig. 3 The binary signals (a, b) and ASK signals (c, d)

$$Modulation\ index = \frac{V_{max}-V_{min}}{V_{max}+V_{min}} \times 100\% \qquad (1)$$

where V_{max} and V_{min} presents the maximum and minimum amplitude for ASK modulation.

$$M = \frac{Data\ rate}{Operated\ frequency} \times 100\% \qquad (2)$$

Fig. 3(d) shows the received ASK modulation at the inductive received coil with V_{max} = 8 v and V_{min} = 6.3 v, we noted that the modulation index for both sides transmitter and received coils has approximately same modulation index.

IV. Method And Design for Class-E Amplifier at 10MHz

Class-E power amplifier is widely used in biotelemetry system and in external part of the implanted devices due to its high theoretical efficiency 90-95 %, simplest (requires only one active device), high-energy transmission and consumes power when used as a modulator because it eliminates the need for a mixer [8]. The class-E power amplifier structure consists of the inductor choke (RFC) with very small resistance to avoid drops in V_{dd} power supply, which supplied from ASK modulator, fabricated single pole NMOSFET switching transistor connected with a parallel capacitor to ensure zero-voltage switching of non-ideal NMOSFT transistor and RLC network tuned at the certain frequency to achieve a constant current from the supply source and converts the digital input signal into a sinusoidal output signal with zero DC offset. The developed class-E power amplifier operated with low band frequency according to (ISM) $10MH_Z$ to avoid the tissue damage [9]. The mathematical model should be calculated as fellows. Suppose that, Pout is 150 mw, f0 is 10 MHz, V_{DD} will be 3.3 V; R_L (load resistor) is 50 Ω, and the Switch with 50% of the duty cycle.

International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:6, No:8, 2012

For optimum power of class-E amplifier we have to find the optimum resistance $R_{L.opt}$. Equation (3) is used to calculate the optimum resistance [10]. Equations (4, 5 and 6) used to calculate values of class-E components as shown in fig 4.

$$P_{out} = \frac{2}{1+\frac{\pi^2}{4}} \times \frac{V_{CC}^2}{R_{L.opt}} \quad (3)$$

$$C_1 = \frac{1}{\omega_{0}R_L\left[\frac{\pi^2}{4}+1\right]\left[\frac{\pi}{2}\right]} = \frac{1}{\omega_0(5.447R_L)} \quad (4)$$

$$L_2 = \frac{QR_L}{\omega_0} \quad (5)$$

$$C_2 = C_1\left[\frac{5.447}{Q}\right]\left[1+\frac{1.42}{Q-2.08}\right] \quad (6)$$

For maximum efficiency the quality factor (Q) should be at maximum value and consistent with the desired bandwidth, and considering that a high-quality factor of the inductive coil should make the output as close to an ideal sinusoidal as possible, and the very high Q factor reduces the effective bandwidth of the system [11]. So, the choice of the quality factor must be realistic according to (7). Then the quality factor Q will be 10.

$$Q \le \frac{\omega L}{R} \quad (7)$$

High efficient class-E power amplifier can be achieved by reducing the transistor switching losses, the MOSFET transistor tuned ON when the drain voltage comes back to zero, reducing the turn ON loss zero voltage switching. The drain voltage is also raised from zero at the time of turning ON which allows for slight returning without losing in the efficiency as shown in fig 5.

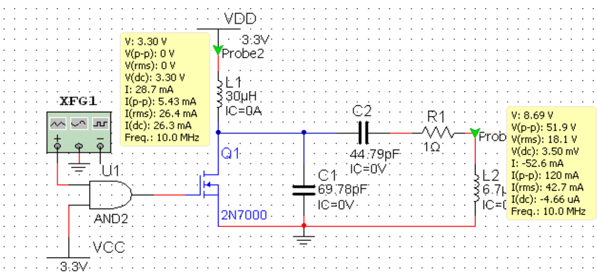
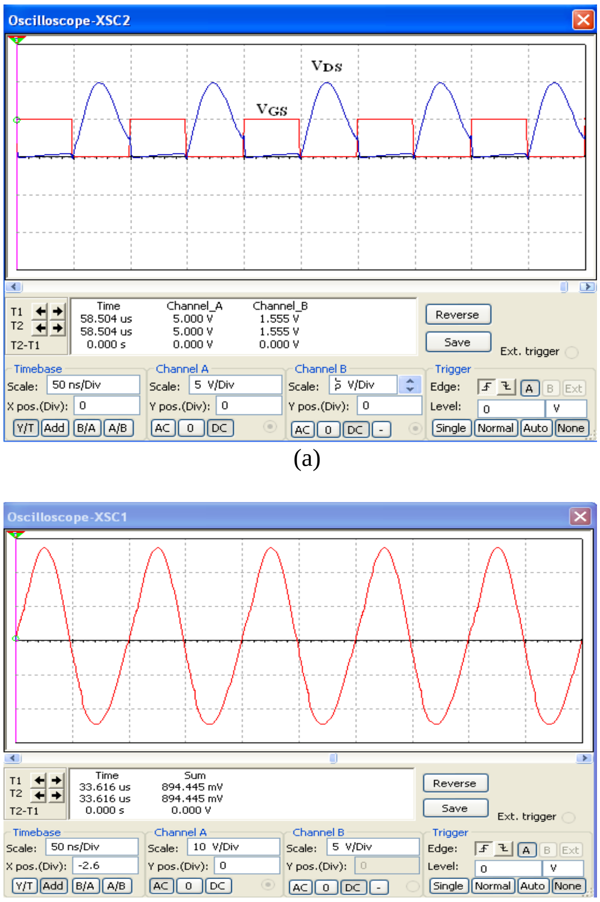


Fig. 4 Block diagram and values for Class-E PA



(a)

(b)

Fig. 5 (a) Drain-Source and Gate-Source in time, and (b) voltage output signal

V. INDUCTIVE POWERIN LINKS

Currently most of the implanted devices powered inductively, which is a suitable method for powered and transfer data at a short range. In general, the inductive coupling link consists of two resonant network circuits RLC as shown in fig. 6. [12], the first one located outside the human body called primary part, external part or in vitro part, this part driven by efficient power amplifier. The second part located within the human body called secondary part, internal part or in vivo part and powered from external part where a portion of generated magnetic flux from the external part is coupled to the secondary coil and inductee voltage there, this coil act as an antenna. To get better power transfer efficiency, the primary and secondary coils tuned at the same resonant frequency. The inductive coupling link variables as, primary coil inductance Lt, secondary coil inductance Lr, resonant frequency f_0, mutual inductance M, and coupling factor (coupling coefficient K must be 0< K <1), these variables have direct effect on the coupling link efficiency. The coupling factor K is the main factor used to determine the amount of power that can be delivered to the implanted devices [14 and 15].

In this section, a new relationship is discussed and analyzed between the voltage gain V_{gain} and other variables such as coupling coefficient K and resistive load R_{load} (Implanted devices). The mathematical model for the inductive coupling link will be calculated as a fellow. The coupling factor K defined as the ratio of the flux linking the secondary coil from the primary coil, as given in (8).

$$K = \frac{M}{\sqrt{L_t L_r}} \tag{8}$$

The primary capacitance Ct is calculated in section IV as given in (4), and the secondary capacitance Cr calculated as in (9).

$$C_r = \frac{R_{load} + \sqrt{R_{load}^2 - 4\omega_0^2 L_r^2}}{2\omega_0^2 R_{ioad} L_r} \tag{9}$$

Where R_{load} is presents the implanted resistance [12], and it should be > 2ωLr.

The simulation in fig. 7 shows that the both coils tuned at the same resonance frequency, and the inductive links consider as a pass band filter at central frequency $10MH_Z$. The simulation in fig. 8, shows the relationship between the constant load resistor at value 250Ω with different coupling factors (K = 0.2, K = 0.3, K = 0.4, K = 0.5, K = 0.6, K = 0.7) where the best voltage gain is achieved when K= 0.3. Fig. 9, shows the relationship between constant coupling factor K=0.3 and variables load resistors (R_{load} = 200Ω, R_{load} = 250Ω R_{load} = 300Ω, R_{load} = 350Ω, R_{load} = 400Ω). The results show that this design is suitable to be powered implanted devices with resistance load 200Ω to 450Ω and the value of the implanted resistance R_{load} act as a function of the amplitude of the received voltage at the secondary coil, and the larger of this voltage meaning more of power dissipations.

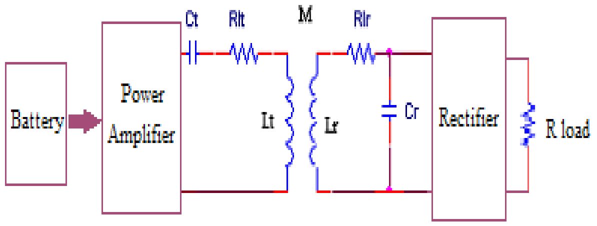
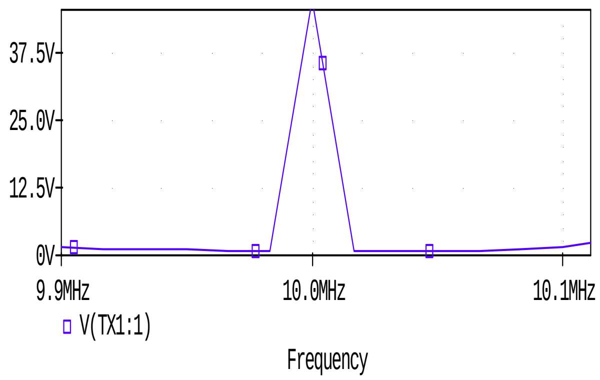
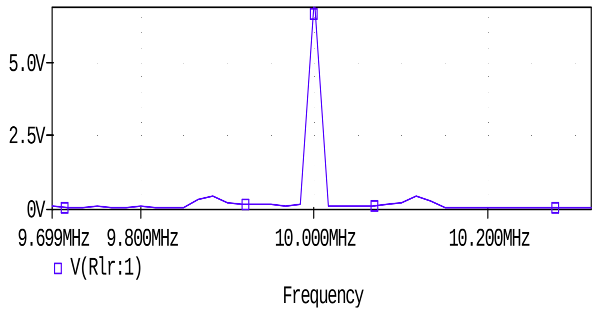


Fig. 6 Block diagram for transcutaneous inductive coupling link



(a)



(b)

Fig. 7 Primary and secondary coils (a and b) tuned at the same frequency

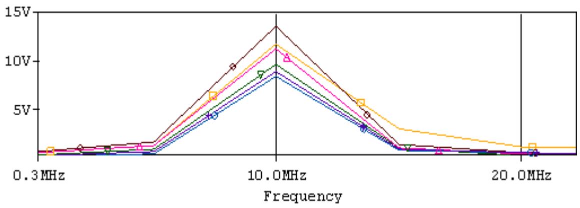


Fig. 8 Voltage gain with constant load resistor R_{load}=250Ω and Variable coupling factors

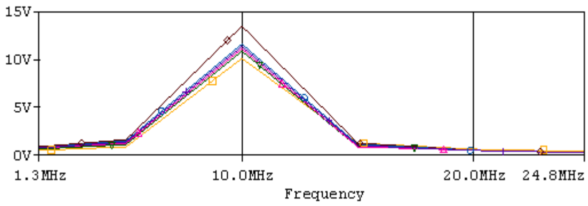


Fig. 9 Voltage gain with constant coupling factor K =0.3 and variables load resistors

VI. Simulation Model And Results

The simulation in this paper was presented using P Spice software tool 16.2 and electronic workbench MULISIM 11. Fig. 3, was simulated by P Spice (a) show the binary data signal with "1" and "0" values provided to ASK modulator with rising time and fail time equal 0.1 ns with frequency $80KH_Z$, (b) show the power supply provided to the class-E power amplifier, this voltage is equal 2.5 V_{DD} to 3.7 V_{DD} and these voltages are sufficient for operating the power amplifier, (c) shows the ASK modulated signal on the transmitter coil with V_{max} = 60 v and V_{min} = 48 v, (d) show ASK modulated signal at the received coil with V_{max} = 8 v and V_{min} = 6.3 v, both transmitted and received signal have modulation index 11.1%. and modulation rate 7.2%. Fig. 5 simulated by Multisim 11, in order to simulate and determine the NMOS transistor switching of class-E in real-time and show the ON, OFF transistor switching, when V_{GS} = 0 the drain-source voltage V_{DS} in maximum value and when V_{DC} = 0 the gain-source voltage V_{GS} in maximum value, and show the output signal of the power amplifier with high efficient more than 87%, the class-E PA provided a stable sinusoidal signal to the inductive coupling link to increase the overhaul system efficiency.

Fig. 7 shows that the transmitter and receiver coils tuned at same frequency $10MH_Z$ and this gave the system more efficiency. Fig. 8 and 9, shows the relationship between coupling factor, implanted load resistance and voltage gain, the result shows that at fixed load resistance (implant resistance) 250Ω and coupling factor K = 0.3 the voltage gain will be in maximum value. Notably, that the value of the implanted resistance R_{load} act as a function of the amplitude of the received voltage at the secondary coil, and the larger of this voltage meaning more of power dissipations

VII. Conclusion

In this paper, the design of the external part to transfer power and data to the implanted devices with 10 MH_Z using ASK modulation technique was presented. The three parts of the external system was designed and simulated with OrCAD Pspice 16.2 software tools, and Multisim 11. The results show that the system can transfer the efficient power to the implanted devices with data rate 1 Mbit/s and modulation index 11.1%. This system is suitable for micro-system implants, which have a resistance 200-350Ω.

References

[1] M. Ghorbel, M. Samet, A. Bhamida, and J. Tomas, “An Advanced Low Power and Versatile CMOS Current Driver for Multi-Electrode Cochlear Implant Microstimulator,” Journal of Low electronics. Vol 2, No. 3, December 2006. P.p 1-14.
[2] S. Atluril, M. Ghovanlool, “A Wideband Power-Efficient Inductive Wireless Link for Implantable Microelectronic Devices Using Multiple Carriers,” On Proceeding of IEEE international conference on circuits and system (ISCAS), 21-24 May 2006, Kos, Greece.
[3] G. B. Hmida, M. Dhieb, H. Ghariani & M. Samet, “Transcutaneous Power And High Data Rate Transmission For Biomedical Implants," IEEE International conference on design and test of integrated system in nanoscale technology, 5-7 September 2006, Tunisia.
[4] M. A. Hannan, S. M. Abbas, S. A. Samad and A. Hussain, “Modulation Techniques for Biomedical Implanted Devices and Their Challenges," sensor. 2012. Vol. 12, pp. 297-319.
[5] F C C Rules and Regulations, “MICS Band Plan,” Table of Frequency allocations, Part 95, January 2003.
[6] J. F Gervais, J. Coulombe, F. Mounnaim and M. Sawan, “Bidirectional high data rate transmission interface for inductively powered devices,” Proceedings on IEEE International Conference on Electrical and Computer Engineering, 4-7May 2003, pp: 167-170, Canada.
[7] K. M. Silay, C. Dehollain, M. Declercq, “Improvement of Power Efficiency of Inductive Links for Implantable Devices,” IEEE International conference Proceedings on Research in micro-electronics and electronics, 22 June-25 April 2008, pp. 229-232, Istanbul, Turkey.
[8] F. H. Raab, “Effects of circuit variations on the class E tuned power amplifier,” IEEE Journal. Of Solid State Circuits ,vol. 13, pp. 239-247.
[9] IEEE standard for safety levels with respect to human exposure to radio frequency electromagnetic fields, 3 kHz to 300 GHz, 1999.1978.
[10] S. Mutashar, M. A. Hannan and A. S. Salina, “Efficient Class-E Design for Inductive Powering Wireless Biotelemetry Applications,” IEEE International Conference on Biomedical Engineering (ICoBE), 27-28 February 2012. P.p 445-449. Perlis. Malaysia.
[11] B. Lenaerts, R. Puers,“Omni directional inductive powering for biomedical implants,” Analog circuits and signal processing. Springer, 2009.
[12] M. Qingyun, R. Mohammad, M. R. Haider, K. Islam, and S. Yuan, “Power-Oscillator Based High Efficiency Inductive Power-Link for Transcutaneous Power Transmission,” Proceedings of 53rd IEEE International conference on circuits and system, 1-4 August 2010, pp. 537-540, Seattle, USA.
[13] K. V. Schuylenbergh and R. Puers, "Inductive powering-Basic theory and application to biomedical systems," 2009 Springer Science and Business.
[14] S. Mutashar, M. A. Hannan, A. S. Salina and A. Hussain, “Analysis of Transcutaneous Inductive Powering Links,” The 4th IEEE International Conference On Intelligent and Advanced System (ICIAS), 12-14 Jun 2012. P,p 553-556. Kualalambur-Malaysia.
[15] G. Simard, M. Sawan and D. Massicotte, “High-Speed OQPSK and Efficient Power Transfer through Inductive Link for Biomedical Implants," IEEE Transactions on biomedical circuits and systems, Vol. 4, No. 3, June 2010.