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Designing Transcutaneous Inductive Powering Links for Implanted Micro-System Device

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***Abstract*—**This paper presented a proposed design for transcutaneous inductive powering links. The design used 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 13.56 MH_Z according to industrial- scientific – medical (ISM) band to avoid the tissue heating. For external part, the modulation index is 13 % and the modulation rate 7.3% 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. The novel circular plane (pancake) coils was simulated using ANSOFT- HFss software.

***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 and efficient inductive coupling links [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]. In this paper the improved ASK modulator with efficient class-E power amplifier operated with low band carrier frequency 13.56 MH_Z to avoid the tissue damage according to the industrial-scientific - medical (ISM) band [5], with modulation index 13% to achieve 1Mbit/s for the external part. The inductive coupling link with circular plane 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 electronic work bench MULISIM 11, and the coils will be designed using HFss software. 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.

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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, power and data recovery circuits to extract the data which used to stimulate the nerves and muscles.

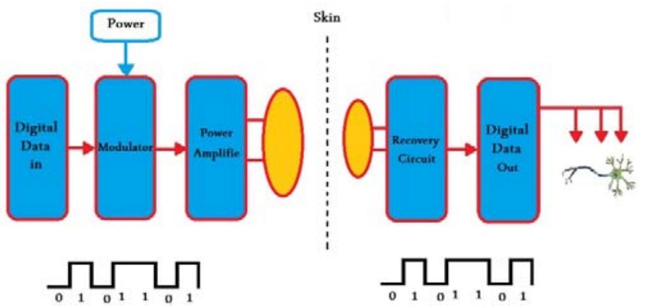


Fig. 1 Block diagram for inductively power transmission

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 - 8]. 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.

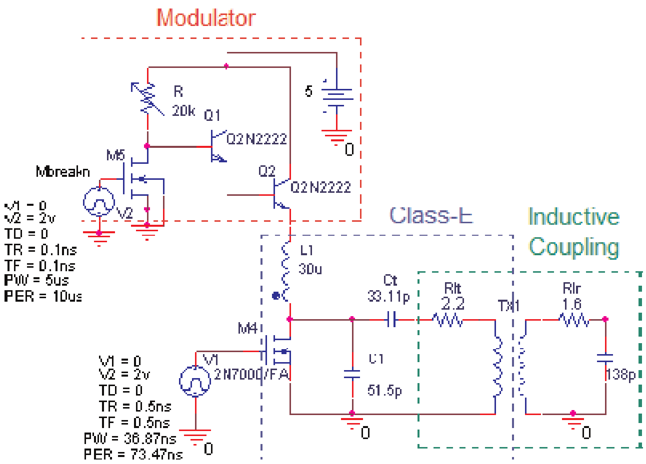


Fig. 2 Block diagram for external part and inductive link

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 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 using to adjust the modulation index with value 13%, modulation rate 7.3%. The binary signal with T_{bit} =4us 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} = 28 v and V_{min} = 19 v the modulation index and modulation calculated as given in (1 and 2).

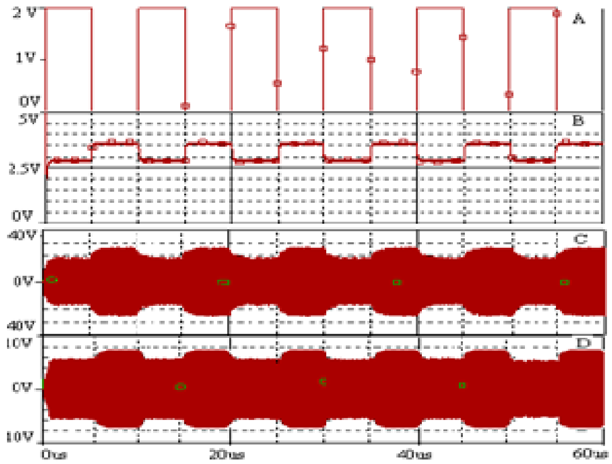


Fig. 3 The binary signals (a, b) and ASK signals (c, d)

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

where Vmax and Vmin 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 Vmax = 7.8 v and Vmin = 6v we note 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 13. 56 MHz

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 [9]. 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 proposed class-E power amplifier operated with low band frequency according to (ISM) 13.56 MH_Z to avoid the tissue damage [10]. The mathematical model should be calculated as fellows. Suppose that, Pout is 150 mw, f0 is13.56 MHz, V_{DD} will be 3.3 V; R_L (load resistor) is 50 Ω, and the Switch with 50% of the duty cycle. 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 [11]. 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 [12]. So, the choice of the quality factor must be realistic according to (7). Then the quality factor Q will be 10.

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

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.

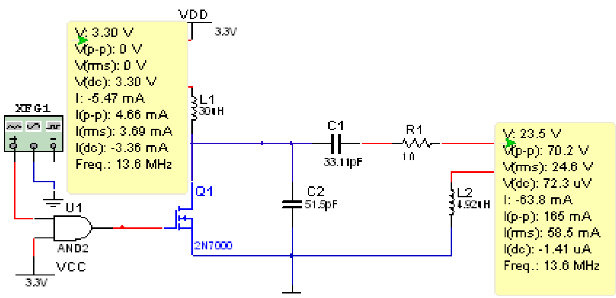
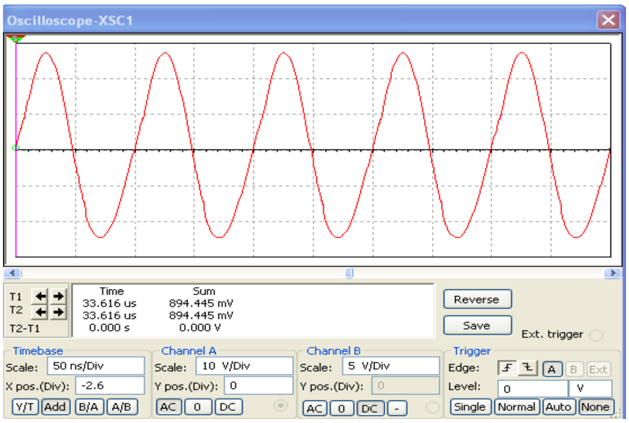


Fig. 4 Block diagram and values for Class-E PA at 13.56 MHz

(a)



(b)

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

V. Inductive Power in 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. [13], 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 [14]. To get better power transfer efficiency, the primary and secondary coils tuned at the same resonant frequency as shown in Fig. 7.

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 [15 and 16]. The coupling factor is calculated as given in (8).

$$K = \frac{M}{\sqrt{L_t L_r}} \quad (8)$$

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

$$C_r = \frac{R_{load}+\sqrt{R_{load}^2-4\omega_0^2 L_r^2}}{2\omega_0^2 R_{load} L_r} \quad (9)$$

where R_{load} is presents the implanted resistance, and it should be > 2ωLr.

In this section, a new proposed an inductive coupling links with external and internal circular plane (pancake) coils was presented and simulated with ANSOFT-HFss software. The external coil (transmitter) and internal coil (receiver) having diameters $d_{avg} \pm (d_{out} - d_{in})/8\sqrt{3}$, where $d_{avg} = (d_{out} + d_{in})/2$, and because of the inductive coupling links can be optimized by making $d_{inT} \approx 0.18\ d_{outT}$ and $d_{inR} \approx 0.75\ d_{inR}$ [17], Then we proposed an external (transmitter) coil to be close to the optimum design by approximately 95% , and the internal (receiver) coil close to the optimum design by 75%. as given in Tables I and II respectively. Both coils printed on PCB substrate regress 4350 (tm) with thickens 1.5mm which has dielectric constant $\varepsilon_r = 4.4$. The external coil dimensions are 56 mm × 10 mm and the internal coil 5 mm × 11.5 mm and simulated with ANSOFT-HFss software as shown in Fig. 8. The 2D radiation patterns and 3D radiation patterns in Figs. 9 and 10 shows, that both circular coils are unidirectional suggesting that they can be integrated with pill shaped bio-implants devices.

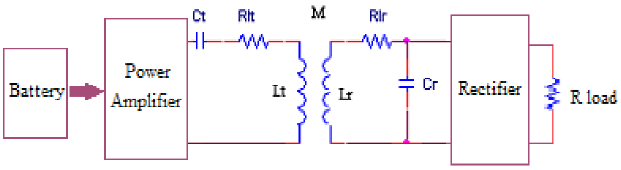


Fig. 6 Block diagram for transcutaneous inductive coupling link

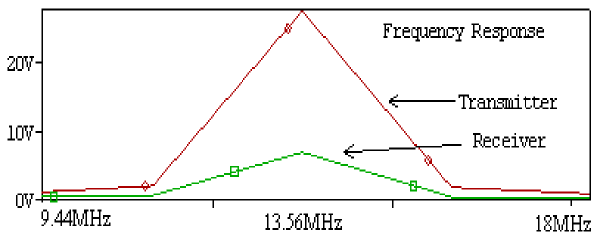


Fig. 7 Primary and secondary coils tuned at the same frequency

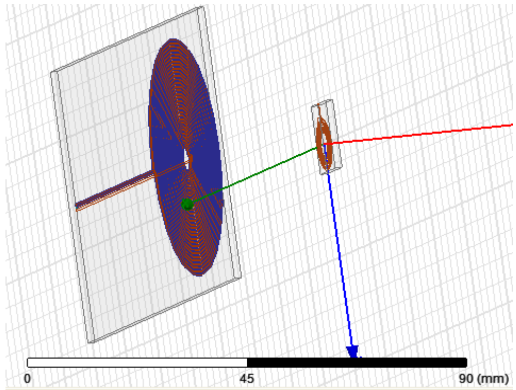
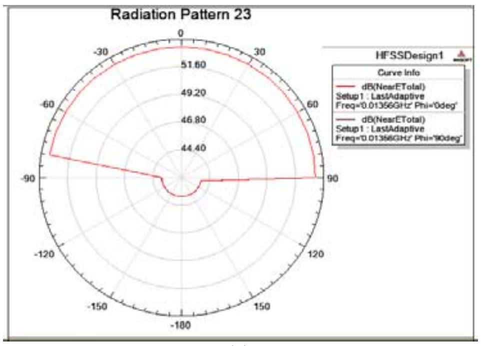
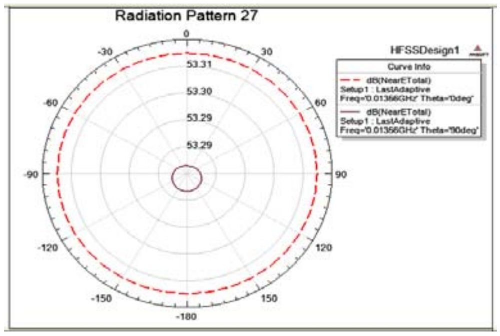


Fig. 8 External and Internal coils in HFss simulation



(a)



(b)

Fig. 9 Simulated total gain patterns of the circular (pancake) coil (a) phi view Φ= 90° and 0° (b) Theta view θ= 90° and 0°

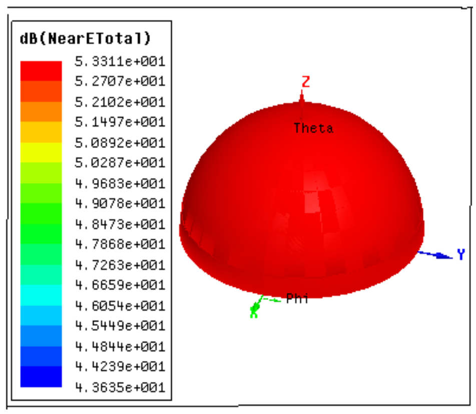


Fig. 10 Total gain in near-field

TABLE I
THE EXTERNAL COIL VALUES

QUANTITY	VALUES
Outer diameter d_{out}	56 mm
Inner diameter d_{in}	10 mm
Number turns N	30
Width Copper	0.5 mm
Each turn separated	0.3 mm

TABLE II
THE INTERNAL COIL VALUES

QUANTITY	VALUES
Outer diameter d_{out}	11.6 mm
Inner diameter d_{in}	0.5 mm
Number turns N	8
Width Copper	0.3 mm
Each turn separated	0.1mm

VI. SIMULATION MODEL AND RESULTS

The simulation in this paper was presented using P Spice software tool 16.2, electronic workbench MULISIM 11and ANSOFT-HFss 13 software. 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) show ASK modulated signal on the transmitter coil with V_{max} = 28 v and V_{min} = 19 v, (d) show ASK modulated signal at the received coil with V_{max} = 7.8 v and V_{min} = 6v, both transmitted and received signal have modulation index 13%. and modulation rate 7.3%. 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 13.56 MH_Z and this gave the system more efficiency. Fig. 8 shows the both external and internal coils simulated with HFss software, and Tables I and II included the values of the proposed inductive coupling links, where the implanted coil occupies very small era which is suitable for implanted micro-system devices. Fig. 9 shows the Simulated total gain in 2D radiation patterns of the circular (pancake) coil (a) phi view $\Phi = 90^o$ and 0^o (b) Theta view $\theta = 90^o$ and 0^0 and Fig. 10 shows the Simulated total gain 3D patterns of the circular (pancake) coil. Hence, both circular coils are unidirectional suggesting that the implanted coil can be integrated with pill shaped bio-implants devices.

VII. CONCLUSION

In this paper, the design of the external part to transfer power and data to the implanted devices with 13.56 MH_Z using ASK modulation technique was presented. And the new design of circular spiral plane (pancake) coil was presented. The three parts of the external system was designed and simulated with OrCAD Pspice 16.2 software tools, Multisim 11 and HFss software. The results show that the system can transfer the efficient power to the implanted devices with data rate 1 Mbit/s and modulation index 13%, and occupies very small era which is suitable for implanted micro-system devices.

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