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LOW-POWER RECOVERY SYSTEM DESIGN FOR IMPLANTED BIOMEDICAL DEVICES

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ABSTRACT

This paper presented a modified low-power recovery system for implanted micro-system devices to stimulate nerves and muscles. The modified system based on ASK modulation techniques and efficient class-E power amplifier, and operated at low-frequency band 13.56 MH_Z to avoid the tissue damage according to the industrial, scientific, medical (ISM) band, with low modulation index 15.6% to achieve minimum power consumption. The improved inductive power link, self-threshold voltage cancellation's rectifier and efficient voltage regulator are presented to offer a very stable low-power supply 1.8 DC voltage to the implanted devices even in any change of implanted resistance. The design based on 0.35 CMOS technology. The mathematical model is given. The design is simulated using OrCAD PSpice 16.2 software tools and for real-time simulation, the electronic workbench MULISIM 11 has been used to simulate the class-E power amplifier.

Key Words: ASK modulation, Class-E power amplifier, Inductive powering links, Rectifiers, Bio-implanted devices and low-frequency ISM band.

INTRODUCTION

The biomedical implanted devices are electronics devices. So far, most of the implanted devices such as, cochlear implants, peacemaker, brine peacemaker implants, micro-system stimulator

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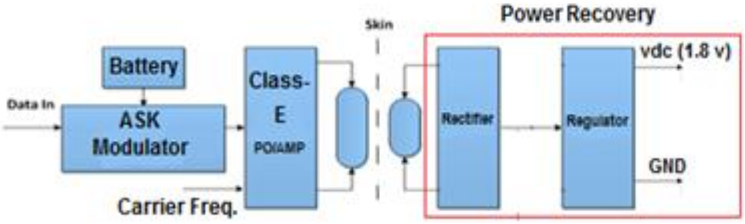
implants powered using weirs penetrates living tissue, and this cases hazards and skin infections. Researchers developed the implanted and used the batteries, and because of the limited time-life of the battery, chemical side effect and large size, researchers find several new methods to power and monitoring the implanted devices (Atluril 2006), currently most of implanted devices powered transcutaneously using inductive coupling links. The power recovery system consists of two parts, external part and internal part as shown in figure 1, the external part transfer power inductively to the internal part (implanted devices) which is located within the body, because of weak links between the two parts the system needs efficient sub circuit electronics devices. The external part consists of battery, modulator and Power amplifier (Hmida 2006), whereas the internal part should be with low power consumptions and consists of rectifier, voltage regulator and demodulator. The micro-system stimulators used to stimulate and monitoring the biological signal such as muscles signals, nerves signals, blood pressure, intraocular pressure, etc. The modulation technique used in the implanted devices can be amplitude shift keying ASK, frequency shift keying FSK and phase shift keying PSK. The ASK modulation is widely used due to it is simplest architected, low-power consumption and low cost (Hannan 2012) In this paper the low-power recovery system provides very stable 1.8 DC voltages was designed and developed, included external and internal parts. The improved system operated with 13.56 MH_Z with modulation index 15.6%. The design is simulated using OrCAD PSpice 16.2 software tools, and for real-time simulation, the electronic workbench MULISIM 11 has been used to simulate the class-E power amplifier.

Figure-1. Power Recovery System for Implanted Micro-system



SYSTEM ARCHITACTURE

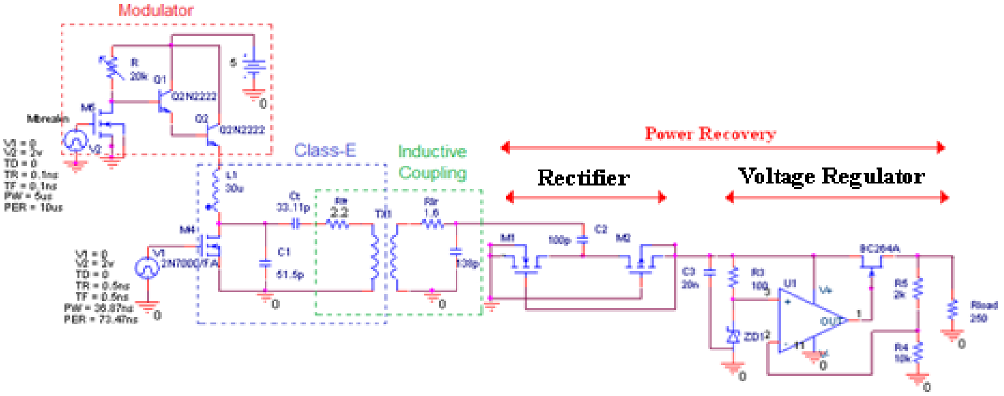
The inductive powering link transmission system for biomedical implanted micro-system device used to stimulate nerves and muscles. Figure 2 shows the developed power recovery system design which consists of two parts, the external part located outside the body and consists of battery, binary data generator, ASK modulator and efficient class-E power amplifier included the transmitter coil, whereas the internal part consists of received coil, rectifier to convert RF signal into DC voltage, low-pass filter and voltage regulator to provide a stable 1.8 DC voltage to power the implanted device. The inductive link between the two parts separated with air and human tissue, and consists of two RLC 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 (Gervais 2003) and (Silay 2008). The modulation index is 15.6% as given in (1).

The power efficiency system is 66% calculated according to (2), where input powered P_{dc}=250 mW, and output power indicated on R_{load}=165mw.

$$Modulation\ index = \frac{V_{max}-V_{min}}{V_{max}+V_{min}} \times 100\% \ = 15.6\% \qquad (1)$$

$$\eta = \frac{P_{out}}{P_{dc}} x100\% \quad = 66\% \qquad (2)$$

Figure-2. Full circuit power recovery system for implanted micro-system



EXTERNAL POWER RECOVERY

The external part consists of four sub-electro circuits, included power supply (battery), ASK modulator, class-E power amplifier and external coil acts as a transmitted antenna as shown in figure 2. The ASK modulator used to modulate the binary signals, and consists of single-pole switching NMOS transistor based on 0.35um technology, two bipolar Q2N222 transistors and variable resistor to adjust the modulation index with value 15.6%. The ASK modulator powered with V_{DD}= 5 DC voltages from external battery, which is higher than the requirement of the class-E power supply 3.3 DC voltages in order to compensate the drop voltage on the modulator and offers 2.7 to 3.7 DC voltages, which are enough to power class-E power amplifier as shown in figure 3(b). The third sub- electronic circuit is the class-E power amplifier which is widely used to drive the inductive power links due to its high efficient 90-95% (Sokal 1975). The supply voltage is 3.3V with 50% duty cycle, and the single pole MOSFET transistor was selected type (3TEN-2N7000). The high efficiency of class-E power amplifier can be achieved by reducing the transistor switching losses, otherwise the components of class-E must be calculated on the values that satisfy the transistor switching, all class-E component was calculated according to equations as given in [Abbas 2012]. Table 1 shows the component values of class-E. The simulation and results in Figure 4 shows the output waveform, and the Drain-Source voltage (V_{DS} = 0) when the switch is active state (1) and V_{GS}=1 when the switch in the state (0), where this will reduces the power consumption of the system. The fourth sub-circuit is an inductive link, which consists of two RLC parts, tuned at the same resonance frequency 13.56 MH_Z. The primary coil tuned in series resonant, whereas the secondary coil tuned in parallel resonant as shown in figure 2. At the primary and secondary coils value was calculated according to equations given in [Mutashar 2012], and figure 5(A) shows the transmitted ASK modulated signal atthe primary coil, whereas figure 5(B) shows the received ASK modulated signal at the secondary coil with 15.6% modulation index. Table 2 shows the inductive coupling links values. Notably, the inductive links acts as a band pass filter.

Figure-3. (A) The binary data in. (B) Power voltage delivered to class-E

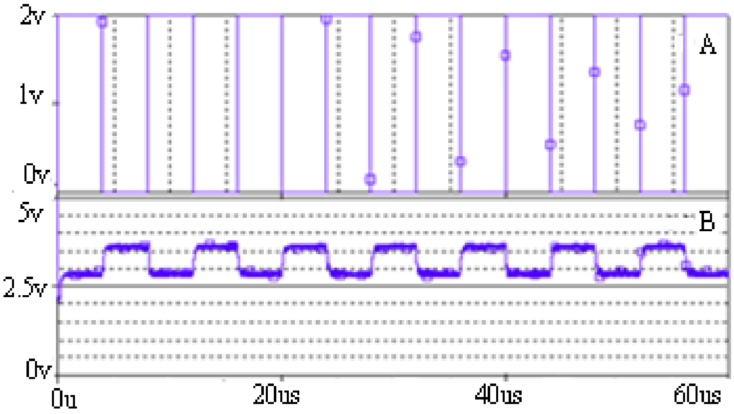
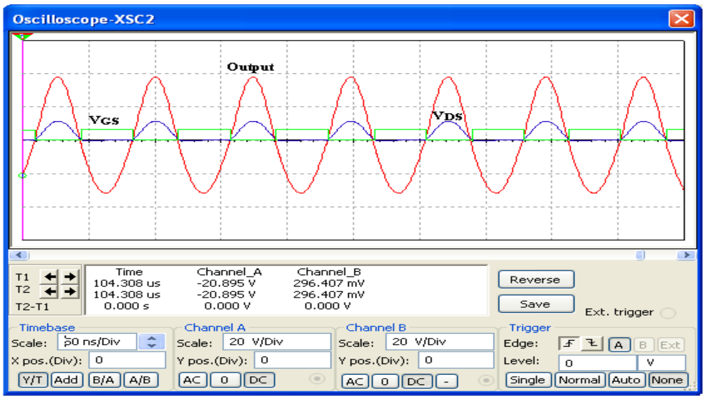


Figure-4. The Voltage output signal. Drain-Source and Gate-Source in time



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      Time          Channel_A     Channel_B
T1    104.308 us    -20.895 V     296.407 mV
T2    104.308 us    -20.895 V     296.407 mV
T2-T1 0.000 s       0.000 V       0.000 V
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Timebase
Scale: 50 ns/Div
X pos.(Div): 0

Channel A
Scale: 20 V/Div
Y pos.(Div): 0

Channel B
Scale: 20 V/Div
Y pos.(Div): 0

Trigger
Edge: A
Level: 0 V

Table-1. Class-E power amplifier values.

Description	Resonant Freq. MH_Z	RFC Inductance	Primary Inductance	Primary Resist.	Primary Capacitance	Shunt Capaci.
Symbol	F_0	L_{choke}	L_t	R_t	C_t	C_{shunt}
Value	13.56	30 µH	4.92 µH	2.2 Ω	33.11 PF	51.5 PF

Figure-5. (A) The transmitted ASK signal, (B) The received ASK signal.

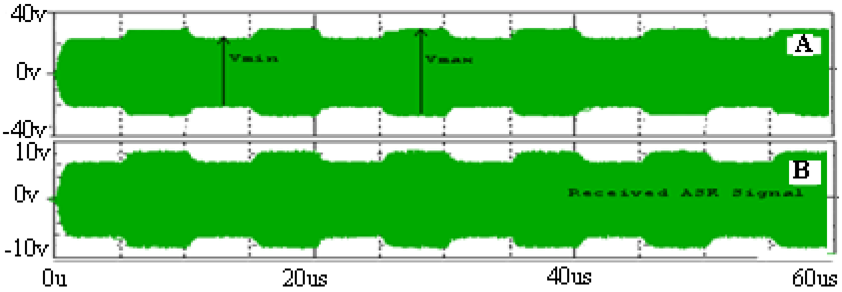


Table-2. Inductive coupling links values.

Description	Inductance	Capacitance	Resistance	No. of Turns	Coupling Factor	Quality Factor
Primary Part	4.92 μH	33.11 PF	2.2 Ω	30	0.3	190
Secondary Part	1 uH	140 PF	1.6 Ω	8	0.3	53

INTERNAL POWER RECOVERY

The internal power recovery consists of two sub-electronic circuits. The first sub-circuit is the rectifier who used to convert the RF signal into DC signal. One of the main incentives of power consumption and occupies a large area in implanted bio-micro system is the rectifiers due its channel size (switching loss) and time response, where the received RF signal is low and drop of the output voltage below the threshold voltage, this kind of rectifiers causes to reduce the efficiency of the implanted devices such as Schottky diode rectifier and full wave rectifier (Finkenzeller 1999). To improve and develop the rectifier efficiency, the threshold voltage should be considered. In this paper, the voltage doubling rectifier using low-drop voltage with low-leakage CMOS diodes by using self-threshold voltage cancellations techniques will be used (Kotani 2007). The rectified voltage is stepped down due to its voltage drop as given in (3).

$$V_{rect} = V_{RF} - V_{DROP} \quad (3)$$

The maximum power obtained in voltage doubling rectifier is 2X more than the maximum power obtained in full wave rectifier as given in (4 and5).

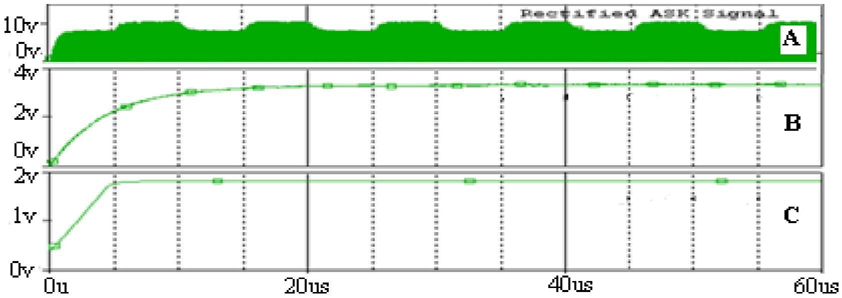
$$P_{rect.bridge}(\max) = C_r(V_{RF} - 2V_{DROP})^2 \times f \quad (4)$$

$$P_{rect.doub.}(\max) = C_r(V_{RF} - V_{DROP})^2 \times f \quad (5)$$

The proposed rectifier was shown in figure 2. The rectified ASK signal is shown in figure 6(A) where V_{MAX}= 8.5 V and V_{MIN}=6.2 V, the small capacitor C_3 used to smooth the output DC=3 V with very small ripple voltage as shown in figure 6(B). The second sub-circuit is the voltage regulator, so in this paper the voltage regulator with zener diode acts as voltage reference to offer

1.5 DC Voltage integrated with CMOS operational amplifier with series-pass NMOSFET transistor is presented as shown in figure 2 (Milliken 2007 and Mutashar 2012). The proposed regulator offers very stable 1.8 DC voltage to power the ASK demodulator with very small ripple voltage approximate zero as shown in figure 6(C), which reduces the power consumption for the implanted devices.

Figure-6. The external power recovery output, (A) ASK rectified signal, (B) the smoothed rectified signal, (C) the regulated output voltage.



RESULTS AND DISCUSSION

This paper presents the low-power recovery system design for implanted biomedical micro-system. The proposed system consists of two parts, external part and internal part as shown in figure 2, where the external part consists of power supply (battery), ASK modulator and class-E, power amplifier included transmitted coil to transmit the power and data. Whereas the internal part consists of received coil, the voltage doubling regulator with self-cancellation threshold voltage and voltage regulators based on a series-pass NMOST transistor to step down the rectified ASK signal to fix 1.8 DC voltages without ripple voltage to power other parts of the implanted device. The system operated with a low-frequency band 13.56 MH_Z according to the ISM band to avoid the tissue damage. The ASK modulator used to modulate the input signal and provide 2.7 to 3.7 DC voltage to power the class-E power amplifier as shown in figure 3(A). The class-E, power amplifier operated with 13.56 MHz which is designed with minimum switching losses, low-power consumption. The output waveform, and the Drain-Source voltage ($V_{DS} = 0$) when the switch is active state (1) and $V_{GS}=1$ when the switch in the state (0), and offer stable sinusoidal wave signal to the transmitted coil as shown in figure 4. The asset value of the power amplifier was calculated as given in table 1. The transmitted coil acts as an antenna to transmit the modulated ASK signal with $V_{MAX}=28$ V and $V_{MIN}=20$ V as shown in figure 5(A). The received coil in the internal part receives the ASK modulated signal inductively, and because of weak coupling between the external and internal coils, then the inductive coupling links should be designed to be able to transmit the power with high efficiency, with values as given in table 2. Figure 5(B) shows the received ASK modulated signal with $V_{MAX}=8.5$ and $V_{MIN}=6.2$ V with modulation index 15.6%. For the internal power recovery, the proposed voltage doubling rectifier with self-cancellation threshold voltage used to rectified the ASK signal with low-drop voltage as shown in figure 6(A) and offer a stable rectified 3DC voltage, which smoothed with small capacitor C_3 with very small ripple voltage as shown in figure 6(B). The rectify signal was stepped down and regulated using proposed voltage regulator based on a series-pass NMOST transistor to provide very fixed and stable 1.8 DC voltages as shown in figure 6(C) which satisfy the requirement of the implanted device. The power efficiency is 66% where from the simulation the input power is 250 mw and the output power is 165 mW. This system may be used for implanted micro-system devices to stimulate the nerves and muscles.

CONCLUSION

In this paper, the design of the low-power recovery system for implanted micro-system is presented. The system operated with ISM low-band frequency 13.65 MH_Z and simulated using OrCAD PSpice 16.2 software tools and electronic workbench MULISIM 11. The high efficient class-E, power amplifier and efficient inductive link were used to transmit the ASK signal to the implanted device. The proposed rectifier and voltage regulator used to offer low-power supply 1.8 DC voltages to power the implanted sensor. The total power efficiency is 66% with modulation index 15.6%. This design is may be suitable for implanted sensors with resistance 200-400 Ω.

REFERENCES

Atluril, S., Ghovanlool, M (2006) "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), pp.21-24 May Kos, Greece.

Hmida, G., Dhieb, B., Ghariani, M. H., & M. Samet (2006) Transcutaneous Power And High Data Rate Transmission For Biomedical Implants, IEEE International conference on design and test of integrated system in nanoscale technology, Tunisia.

Hannan, M. A., Abbas, S., M. Samad, S. A., and A. Hussain (2012) "Modulation Techniques for Biomedical Implanted Devices and Their Challenges" sensor, Vol.12, pp. 297-319

Gervais, J. F., Coulombe, J., Mounnaim, F. and M. Sawan (2003) "Bidirectional high data rate transmission interface for inductively powered devices" Proceedings on IEEE International Conference on Electrical and Computer Engineering, pp.167-170, Canada.

Silay, K. M., Dehollain, C., and Declercq, M (2008) "Improvement of Power Efficiency of Inductive Links for Implantable Devices" IEEE International conference Proceedings on Research in micro-electronics and electronics, pp.229-232, Istanbul, Turkey.

Sokal, N. O., Sokal, A. D. (1975) "Class-E a new class of high efficiency tuned single-ended Switching power amplifiers" IEEE Journal of Solid-state circuit, Vol.**10**, pp.168-176, Jun

Abbas, S., Hannan, M. A. and Salina, A. S (2012) "Efficient Class-E Design for Inductive Powering Wireless Biotelemetry Applications" IEEE International Conference on Biomedical Engineering (ICoBE), pp.445-449. Penang, Malaysia.

Mutashar, S., Hannan, M. A., Samad S. A. and A. Hussain (2012) Analysis of Transcutaneous Inductive Powering Links, IEEE 4th International Conference on Intelligent and Advanced Systems (ICIAS). Pp.553-556. Kualalambur, Malaysia.

Finkenzeller, K (1999) Fundamentals and Applications in Contact Less Smart Cards, Identification. 2nd Edition.

Kotani, K. and Ito, T (2007) High Efficiency CMOS Rectifier Circuit with Self-Vth-Cancellation and Power Regulation Functions for UHF RFIDs, IEEE Asian International Conference on Solid-State Circuits Conference. Jeju, Korea

Milliken, R. J., Martínez, J. S., and Sinencio, E. S (2007) "Full on-chip CMOS low-dropout voltage regulator" IEEE Trans. on Circuits and Systems – I, Vol.54, Issue 9, pp.1879-1890

Mutashar S, Hannan M. A, Salina A. S, and Aini H (2012) "Efficient data and power transfer for bio-implanted devices based on ASK modulation techniques" Jou. of Mech. in Medi. And Biology. Vol.12. No, 5.