The Class-E Concept for Efficient Wide-Band Coupling-Insensitive Transdermal Power and Data Transfer

C.M. Zierhofer, E.S. Hochmair Institute for Applied Physics, University of Innsbruck Technikerstr.25, A-6020 Innsbruck, Austria

Abstract - This paper presents an innovative method for the transcutaneous transmission of RF power and digital data via an inductive link. The system is based on the single ended class-E power amplification scheme. A self oscillating class-E tuned power amplifier involving an inductive link permits high-efficiency coupling-insensitive power transmission. The oscillation frequency is not fixed but influenced by the coupling of the coils. Due to the excellent switching characteristics of the oscillator, Amplitude Shift Keying (ASK) may be employed for digital data transmission. Data decoding can easily be achieved by envelope detection. The realization of the system requires a small number of circuit components. It is employed for the transcutaneous transmission of digital data and power in a Cochlear Prosthesis system.

1. Introduction

One way of transcutaneously providing an implanted stimulator with power and signal is to transmit RF power inductively by means of two magnetically coupled coils. An implanted receiver coil is situated a few millimeters below the skin and together with an external transmitter coil a transformer is formed which allows power and signal transfer from the transmitter to the implant. In practical applications of inductive links the transmitted RF voltage amplitude across the receiver coil usually has to be insensitive to variations of the mutual coil position. Therefore the receiver and the transmitter coil are part of a receiver and a transmitter resonant circuit respectively. The tolerance to coil misalignment, in general, results in a reduced efficiency of the power transfer. Inductive links have been broadly discussed with regard to optimization of efficiency and tolerance to coil misalignment [1] - [3]. All these links are designed to operate at a fixed operating frequency.

The overall efficiency \sqcap of an RF-power transmission scheme is defined as the ratio of power delivered to the implant and the overall dc-power consumed by the whole system. The overall efficiency of a conventional transmission scheme consisting of RF-oscillator, power amplifier, and inductive link, including the load, is determined by the power consumption of the RF-oscillator, the efficiency of the power amplifier and the efficiency of the inductive link itself. The approach used here to realize a coupling-insensitive high efficiency power/data link is based on the high efficiency class-E power amplification concept. The idea was to combine a class-E amplifier with a tuned inductive link. In addition, the class-E amplifier is self-oscillating. Oscillation frequency is not fixed, but influenced by the coil coupling. This self oscillating final stage has two basic advantages over a driven RF-amplifier. Firstly, it saves an oscillator necessary to generate an RF-voltage and with it additional power losses. Secondly, the oscillation frequency offset due to coupling variations yields a significantly improved power transmission performance, since the resulting oscillation frequency tracks the absolute transmission efficiency maximum, whose spectral location is dependent on the coil coupling [4].

2. A class-E tuned power oscillator

2.1. Circuit description

An example of a combination of a class-E amplifier and an inductive link is shown in Fig. 1. The series-tuned loadcircuit of a conventional class-E tuned power amplifier is replaced by an inductive link. This circuit is employed for the transcutaneous transmission of signal and power in a Cochlear Prosthesis system [5].

The inductive link consists of the series-tuned transmitter resonant circuit (L_1, C_1) and the parallel-tuned receiver circuit (L_2, C_2) . Transmitter coil L_1 is magnetically coupled to receiver coil L_2 (coupling factor k). The receiver resonant circuit (L_2, C_2) is connected to a rectification and smoothing network consisting of diodes D_{p1} , D_{p2} and capacitors C_{p1} , C_{p2} which provides the positive and negative dc supply voltage rails of the implant. RL represents the ohmic load due to the dc power consumption of the implant.

The class-E amplifier Fig. 1 is self-oscillating. Oscillation is achieved by means of a feedback branch (L_f , C_f , R_f). Coil L_f is coupled to the transmitter coil L_1 (coupling factor k_1). Resistor RB and diode DB and network (R_m , C_m) provide proper bias voltage and ensure easy starting of oscillation. A detailed description of this circuit with respect to power transmission is given in [4].



Fig.1: Self-oscillating class-E tuned power oscillator involving an inductive link

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Besides its advantageous power transmission properties, the class-E-oscillator shows very good switching behaviour. A practical scheme for data transmission is Amplitude Shift Keying (ASK). For ASK the oscillator has to be switched on and off controlled by the binary information signal. Here this is achieved by connecting the information signal directly to the supply voltage U₀ of the oscillator. ASK is especially suited for implant applications, since data decoding in the implant can very simply be achieved by envelope detection.

In conventional class-E amplifiers inductance L₀ is usually operated as a current source at the operating frequency (with a sufficiently large impedance [4]). In the present ASKapplication, good switching behaviour of the oscillator is essential and this requires inductance L₀ to be sufficiently small. Compared with the results in [4], the reduced impedance of L₀ does not have much influence on the circuit performance with respect to tolerance to coupling variations and overall efficiency. In a stable oscillation mode the circuit shows waveforms of currents and voltages which are typical for class-E amplifiers.

2.2 Experimental results

Some measurements have been carried out with the circuit specified in Fig.1. Fig.2 shows an example of the data transmission performance of the system at a data rate of 1 Mbit/s. Using a self-clocking bit-format, the minimum and maximum switching times of the input voltage are 0.5 and 1 μ s, respectively (upper trace). The lower trace shows the resulting transmitted RF-Voltage across the parallel tuned receiver resonant circuit at a coil distance of d=5 mm. The measured turn-on and turn-off time of the osciallator is about 0.2 μ s. By envelope detection the original data sequence can be reconstructed. Waveforms were measured with a HP 1653B oscillocope, using HP 10430A voltage probes.

Fig.3 depicts the measured implant supply voltage V_{DD} as a function of the coil distance for various data rates. This plot shows the desired insensitivity of the inductive power transmission to coupling variations. The data rate does not have much influence on this coupling-insensitivity. The oscillator input voltage U₀(t) is switched between 0 and 3.4 V. In the switched-on mode of the oscillator, the oscillation frequency increases from f₀=10.5 MHz at d=1 mm to f₀=11.8 MHz at d=10 mm. Up to a coil distance of d=8 mm, the mean power efficiency is $\eta \approx 50 \%$.







Fig.3: dc-voltage V_{DD} across load R_L =10 k Ω as a function of the coil distance for various datarates

3. Conclusion

The properties of the system described in the present paper may be summarized as follows:

(1) The system is suitable for the transcutaneous transmission of power and digital information via one RF channel.

(2) The RF voltage amplitude across the receiver coil is extremely insensitive to coil distance variations.

(3) The efficiency of power transmission is high, even for comparatively low coil coupling coefficients (no ferrite-backings are necessary).

(4) The oscillation frequency is not fixed, but influenced by the coil coupling.

(5) Data transfer can be achieved by ASK, since the class-E tuned power oscillator shows excellent switching characteristics. The great advantage of ASK compared with other digital transmission schemes (e.g., Frequency Shift Keying or Phase Shift Keying) is the simplicity of data decoding.

(6) For the realization of the system only a small number of circuit components is necessary.

4. Acknowledgement

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5. References

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