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Signal and energy transmission for implanted systems

Abstract: Aspects and approaches for the design of systems for simultaneous signal and energy transmission for medical implants are presented. The main focus is on the consideration of the mutual influence on both transmission lines. To minimize the influence of capacitive as well as inductive paths, that affect the transmission, reducing the number of components is discussed. In order to increase the degree of miniaturization and reliability, the realization of certain functionalities is based on the so-called parasitics of electrical components. An implementation example is presented.

Keywords: medical implant, MICS, data transmission, data throughput, energy transmission, packaging, impedance matching

https://doi.org/10.1515/cdbme-2017-0152

1 Introduction

Signal (data) and energy transfer is a basic requirement for medical implants. However, high data transmission rates are associated with corresponding power requirements, e.g. multichannel implants require a high data rate, reliable data throughput. Such active implants also need sufficient energy, which must be maintained for a sufficient operating time. This, in turn, requires bulky batteries. In order to avoid large batteries, an alternative is to transmit energy via an inductive link with low energy-buffering capabilities needed. However, the problem arises here that relatively high energy quantities must be transferred by means of an alternating electromagnetic field in the close proximity of RF data transmission in a narrow space. In this situation, a compromise must be found by optimization in each case. For example, the specified potential data rate of 400 kBits/s cannot reliably be implemented. So, the data rate may go down to 220 kBits/s in real-time operation [1]. Consequently, this is usually a trade-off between energy supplies and data generation and transmission. In addition, energy and data transmission modules are located in the respective near field of the energy-transmitting coils and, therefore, influence each other. This also means that one cannot make use of the maximum performance of commercially available circuits [4] with regard to the data rate, since a large redundancy is required in the transmission of data packets.

The approach outlined in the following relates to a method and device for performing the energy intake and high-rate bidirectional data transmission in the MICS band. In order to reduce the amount of electrical and connecting components, a design that takes advantage of natural parasitics to minimize the number of conventional discrete components is described.

2 Methods

2.1 Signal transmission versus energy transmission

Signal transmission can be understood as superordinate term, whereas "signals" being used to control functions of an implanted system, and "data" representing large amounts of information to be transmitted. The task is to effectively decouple the data transmission from the power supply. The spatially close arrangement is also problematic on the extracorporeal side of the transmission paths in case a compact extracorporeal device is to be worn.

There are some orders of magnitude between power transmission and radio transmission. Even harmonics of 125 kHz (energy transmission) interfere with RF transmission or finally reduce the effective data rate (due to high redundancy). In addition, a power reserve is required for ensuring the energy transmission, affected by tilting, general misplacement of the coils. On the other hand, the RF radio transmissions are less sensitive to such geometric displacements. The selection of the frequencies is therefore an essential decision in the design of the system, as are the

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related national radio approval regulations. The respective frequencies should be as far apart from each other as possible.

Since class-D amplifiers are often used to drive the coils, the power amplifiers radiate interference, rather than the transmitting coils themselves. At higher frequencies, the capacitive interference with other function modules as well as high resonance voltages play an increasing role.

As an alternative, an optical signal transmission is also available for spatially narrow construction. This option allows an almost ideal decoupling, but the range in biological tissue is very limited (1...2 cm).

The energy transmission path can also be used for signal transmission. However, a regulatory aspect comes into play. The energy transmission then constitutes a "modulated signal" (see regulations of the German Federal Network Agency), which is then treated like a power transmitter.

In addition to the above aspects, it is also necessary to provide for a hardware- and/or software-based antenna adaptation due to a continuous change in the transmission properties in biological tissue.

2.2 System design requirements and design criteria

The energy and signal transmission system for medical application must often be portable. Here, the gap between energy-transmitting coils is usually within the range of 3...5 cm. Therefore, a suitable external battery is the matter of choice.

In the body, temperature increases are limited to 2 K at maximum, while a higher temperature increase can be permitted outside the body, which, however, should not lead to discomfort or even injury. If, for example, a power of 1 W is available in the implant, 9 W heat is released on the body at a transmission efficiency of 10%.

In the following, questions and approaches are mentioned which influence the signal and data transmission in the design of inductive links. Since such energy transmission systems are usually designed as resonance systems (no voltage transformation ratio as in the case of normal transformers), the technical realization of the requirement to move in the range of technically relevant voltages at a predetermined power is particularly important. This means that the setting of the ratio between inductances and Q factor of the resonance elements must be established by an optimization process.

With high Q factor in the series resonant circuit, resonant voltages can easily increase to several 1000 V. However, in order to achieve a high over-all efficiency of the energy transmission, a high Q factor of the resonant circuit and steep-rising switching edges are desirable. These high voltages not only enhance capacitive interference in the RF-receiving part, but also require the use of high-quality, bulky components in the resonance circuit.

It should be mentioned here, that "optimization" refers to a system (time response of a second-order system) of the extra- and intracorporeal coils, not one coil alone.

Optimization must also be achieved for providing technically relevant voltages, not only with regard to the specified power.

2.3 Extracorporeal device

The device in question is designed as a parallel resonant circuit with an inductance of L ≈ 35 µH. Overall, this inductor consists of 4 nested single coils, whereas only the first can be seen, **Figure 1**. The device is designed for 125 kHz energy transmission frequency. In a parallel resonance circuit, a high resonance current is produced instead of a high resonance voltage. Due to the "low"

Figure 1: Extracorporeal device. Separate calibration circuit (bottom right). The rear SMA connector leads to the class-D amplifier.

inductance, the resonance resistance of the parallel resonance circuit, the (battery) supply voltage and the power requirement can be adjusted relatively comfortably. It is also possible to use the parasitic capacitance of such an arrangement in order to roughly adjust the nominal frequency of 125 kHz. This configuration also allows the manufacture of the coils in the form of simple, reproducible PCBs with few turns.

Figure 1 also shows the calibration circuits to characterize each turn with a network analyzer. For each turn (to be identified at the soldering points along the coil radius), a matching circuit is to be made. Depending on the required frequency adjustment for the RF transmitter/receiver, a suitable loop can be selected.

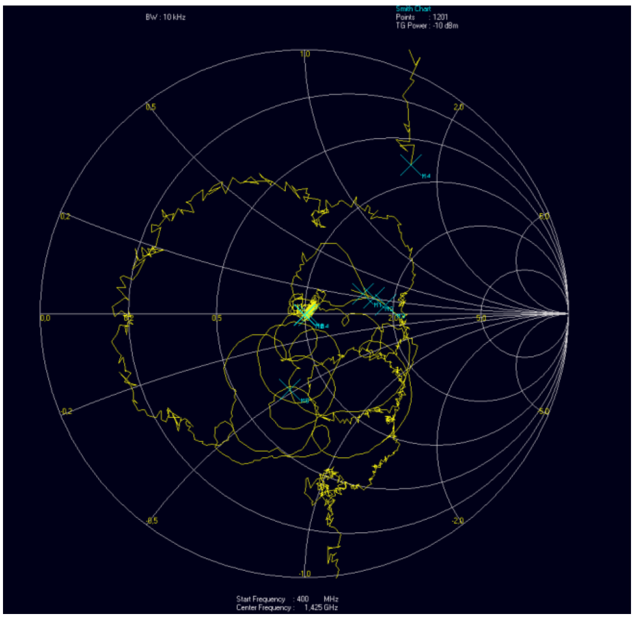

Figure 2: Smith chart of the extracorporeal device with markers (green)

The Smith chart in **Figure 2** illustrates the parasitic resonances of the extracorporeal device shown in **Figure 1** The green markers indicate technically interesting frequencies, such as MICS band, ISM band and 2.45 GHz. In

Table 1: Measured impedances, corresponding to markers in **Figure** . M1 - M3 relate to MICS, M5 to ISM band and M4 to device wake-up frequency

Marker	Frequency in MHz	Impedance in Ω
M1	401.71	77.3 + j12.2
M2	403.42	84.6 + j11.0
M3	405.13	93.9 + j7.37
M4	2450.00	38.5 + j83.5
M5	434.17	37.9 - j24.1

2.4 Implanted device

One solution to reduce the number of components and simplifying the packaging is the so-called "integrated element". The structure consists of a printed circuit board (PCB), whereby antenna matching networks are formed by the PCB design, see **Figure 3**. Moreover, the energy coil forms a low-pass filter for decoupling the radio frequencies.

The procedure for the use of parasitics described in the previous section is applied for the design of implants accordingly. In the following, some special features will be discussed. In addition, the demand for high transmission efficiency is also dictated by the demand for low dissipated heat. The reduction of the complexity is particularly interesting with implants. The "matching networks" for various RF frequencies are also integrated.

In the design process, however, significantly more extensive simulations (field computations, circuit optimization) have to be carried out in implant design. Here, after manufacture, nothing can be measured or changed due to the compactness of the element. Thus, only the overall performance can be tested. Remaining tolerances are balanced with the already existing possibilities for fine tuning (built-in functionality) of antenna tuning in commercially available radio circuits (Zarlink ZL70101, ZL70321 [4]). By selecting suitable conductor loops, analogous to those shown in **Figure 1**, the corresponding RF input/output pads of the chip can thus be connected almost directly to the "antenna".

3 Results

A practical implementation example of such an integrated element for simultaneous signal and power transmission is shown in **Figure 3**. The element consists of six tightly nested single coils (multilayer PCB) to form the energy coil with defined inductance and Q factor as well as the MICS-band antenna.

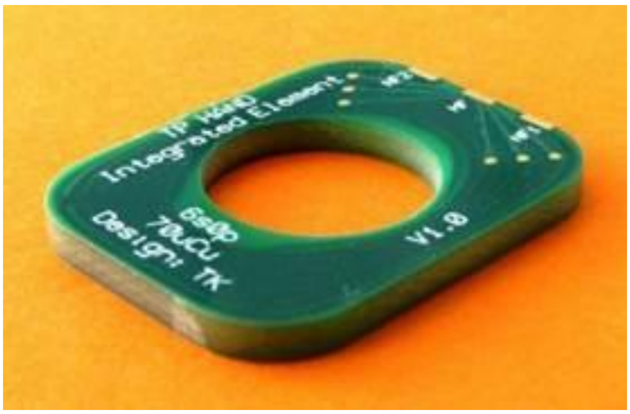

Figure 3: Integrated element 20 x 25 mm. Gold-plated connectors to contact energy coil and antenna on the right short side

This element has been designed for the following parameters:

- 1. Provide 5 V in the implant
- 2. Load resistance 42 Ω (0.6 W)
- 3. Distance between extracorporeal and implanted unit
- 50 mm
- 4. Frequencies 403 MHz for MICS, 125 kHz for energy,

On the right short side of the element with a thickness of 2.5 mm, the gold-plated connectors to contact energy coil and antenna are to be seen.

4 Conclusion and discussion

The concept of using parasitics of electrical components to minimize complexity and increasing reliability was proofed.

By means of the “integrated element”, a technically useful operating voltage is provided for the operation of an implant, as is the radio data transmission in the MICS band. In addition, a wake-up functionality (at 2.45 GHz) is envisaged.

It should be emphasized again that a second-order system needs to be optimized. Therefore, “optimization” refers to the system (time response of a second-order system) consisting of both the extra and intracorporeal coils, not one coil alone. Moreover, simulations have not only to deal with the said second-order system, but with many additional conditions. These conditions, in other words, define many degrees of freedom that should be meaningfully restricted.

The design process may be started by defining the space available for the implant, according to medical considerations. A high efficiency of the energy transfer is also necessary to limit the heating-up of the system. This also means that compliance with regulatory requirements with regard to radio interferences requires more attention the poorer the efficiency of the energy transmission is.

A robust system with minimum number of components, what will contribute to minimizing the volume and, along with that, increasing the reliability of implanted systems.

Naturally, the parasitics of the components are not very precisely determined. In order to control the energy intake into the implant, a closed-loop control can be used. This regulation can simultaneously compensate for the tolerances of the parasitcs and the varying influence of the biological tissue (previous tolerance analysis in the design of the system is highly recommended). In addition, commercial ICs have functionalities for tracking the RF properties [4].

On the extracorporeal side, the inductance should also be designed in such a way that the battery voltage available can be used directly, without additional DC-DC conversion.

Author’s Statement
Research funding: The authors state no funding involved. Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent is not applicable. Ethical approval: The conducted research is not related to either human or animals use

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