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A MICS Telemetry Implant Powered by a 27MHz ISM Inductive Link

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Abstract— **An implantable telemetry device is presented, inductively powered by a 5.8mW 27MHz ISM-band supply and received with a stacked-spiral implantable power coil. A 15th harmonic 405MHz MICS-band data carrier is generated from the power signal, data-modulated, filtered and sent to a receiver via a wireless data link. The implantable module is tested in a biological environment, successfully proving the concept.**

I. INTRODUCTION

The ability to monitor vital health indicators such as the electrocardiogram (ECG), body temperature and blood pressure information via medical telemetry may offer adequate tools to view logged or real time data for vulnerable patients, especially the elderly. Miniaturising this technology will also open new opportunities to access more biological information. Growing telecommunications infrastructure with increasing sophistication is opening new possibilities with regards to medical telemetry, making it theoretically possible for patients to carry out their daily tasks while being remotely monitored by doctors. Implantable electronics has become a topic of considerable research, with the implementation intelligent prosthetics, in addition to intelligent telemetry devices. Implantable telemetry is also used in biomedical research to identify the physiological activity of laboratory animals in a confined laboratory environment.

The general architecture of implantable telemetry devices comprises a power transmitter, implant and data receiver. The implant's structure generally involves rectifying received inductive power, sensing from the body, modulating the converted digital signal using a local oscillator within the implant, and transmitting information to a data receiver external to the body.

This paper presents new techniques for data and power transfer applied to implantable devices in the body. These developments are presented through the explanation of a newly developed implantable telemetry system, which includes a number of innovations through different elements of the system, including inductive power transmission, implantable coils and the generation of data frequencies within the implant.

II. WIRELESS POWER TRANSMISSION

The telemetry implant presented in this paper is powered through magnetic induction, which involves the consideration of many design elements, including inductive power transmitters, transmission coils, path analysis and power receiving coils. This section will outline design considerations and innovations for these elements.

A. Power Transmitter Circuit

Inductive power transfer is more efficient at lower frequencies [1]. However, lower transmission frequencies use larger circuit components, especially transmission coils. From the perspective of implantable devices, space is important and this requires the design of highly efficient transmission circuits at higher frequencies.

Switching power amplifiers have been a popular choice for the transmission of wireless power. The Class-E power amplifier was introduced by Sokal et al. [2]. It has been applied to a number of wireless applications, however its relevance to biomedical engineering is its use as a power transmitter to transfer inductive power as well as data [3].

Oscillators and power amplifiers are considered as two separate blocks in wireless power transmission. By combining these topologies into a self-oscillating power transmitter, greater efficiency has been achieved. A crystal feedback network provides both accuracy and high output power, therefore a newly developed crystal feedback 27-MHz ISM-band Class-E power oscillator is used as the power transmitter [4]. Its output signal is shown in Fig. 1(a).

B. Power Transmitting Coil L_2

The inductor L_2 in the Class-E oscillator shown in Fig. 1 forms the inductive power transmitting coil for the implantable device.

If a spiral coil is to be considered as the primary coil for the transmission of inductive power in a pre-clinical experiment, it is interesting to consider the fact that the magnetic field produced by the coil will not be uniform. This leads to the idea of producing an array of several small coils, connected in series or parallel networks, depending on the desired arrays impedance. This arrangement has the effect of creating a more uniform distribution of energy across the surface area of the enclosure. An example of such an array is shown in Fig. 8.

C. Power Receiving Coil L_3

The biological environment offers a number of additional challenges when considering power-receiving implantable coils. Due to the equivalent spatial requirements of spiral coils for implantable devices, wound coils are often implemented in implantable electronic devices.

The permittivity of a material reduces with an increase in frequency resulting in an increase in conductivity, thus allowing the absorption of more energy [5]. Operating at

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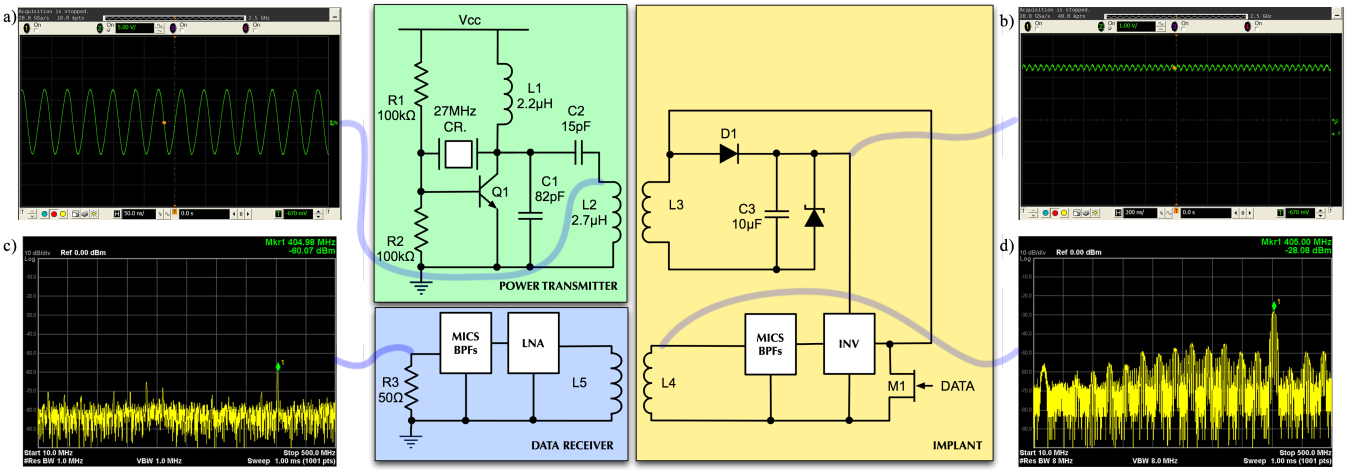

Fig. 1. Circuit diagram of the implemented Telemetry System with measured signals: a) Class-E power oscillator output on L_2, b) rectified signal in the implant, c) received data spectrum and d) output signal before the output antenna L_4

Fig. 2. A photo of the stacked spiral power receiving coil L_3.

lower frequencies avoids this problem, however this requires the use of larger inductors to transfer energy, which presents a problem for smaller implants. As a result of the trend to miniaturise implantable devices, inductive links have been designed to operate at increasingly higher frequencies such that the spatial requirements of internal coils are reduced [6].

One possible solution to this problem is to construct one spiral to be a combination of several smaller spirals which are connected in series and stacked on top of each other, summing to equal the equivalent larger inductance value and ensuring that the flux lines of each layer point in the same direction. The concept of stacking spiral inductors has been applied in integrated circuit technology mainly for the purpose of miniaturisation [7]. An implantable stacked dipole antenna for data transfer in biomedical telemetry has also been used [8]. The device presented in this paper employes a spiral stacking technique for the receipt of inductive power within the implantable environment. The stacked spiral is shown in Fig. 2, and its dimensions are 10x10x4.5mm with two double-sided FR-4 boards and designed to receive power within the ISM range at 27MHz, the details of which can be found in [9].

III. MICS BAND DATA LINK

It is generally preferred that the power and data signals for telemetric implants are supplied at two different frequencies due to different tissue absorption levels at different frequencies. An implant's data carrier frequency is traditionally generated by an oscillator block within the implant [10]. At higher frequencies such as the Medical Implant Communication Service band (MICS: 401-406MHz) this can potentially require a significant amount of power. This section will outline a harmonics based telemetry system for implantable devices.

Harmonic components are often avoided in electronics design, and therefore electronic implants. Most analyses related to harmonics are derived to account for possible errors in a circuit's performance. Harmonics can be understood with Fourier transform theory. Any periodic signal $f(t)$ may be represented as a sum of several sinusoidal elements with varying amplitudes respectively. The frequency of each sinusoidal element is an integer-multiple of the fundamental frequency of $f(t)$. Some harmonic elements are more dominant than others, and the amplitude of each harmonic is dependant on the shape of $f(t)$.

Square-waves consist of very sharp transitions between low and high, and in practice it is very difficult to achieve such quick transitions. A signal worthy of consideration is therefore the trapezoid-shaped signal (practical square wave). It is produced by finite rise and fall times in semiconductor devices. This signal is illustrated in Fig. 3 . The trapeze function's variables may be manipulated to determine the harmonic coefficients of several commonly used waves, including the square-pulse wave or triangular-pulse wave, each with varying duty cycles.

The distribution of power across different harmonic frequencies can vary significantly as the parameters of the trapeze function are varied. For example, the theoretical magnitudes of each harmonic coefficient for a 27MHz trapeze wave of magnitude 1V, 4ns rise and fall times and a duty cycle of 0.17 is plotted in Fig. 4. Compared with the traditional sinc envelope that exists in the spectra of strictly-square 0.5 duty cycle signals, this plot shows that finite rise and fall times and narrower pulses will distribute energy across odd and even harmonics as well as distributing more energy to higher harmonic frequencies.

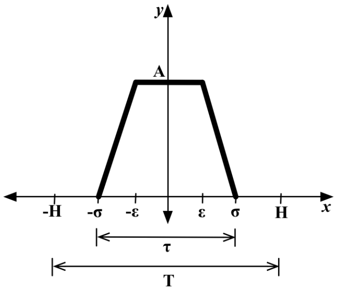

Fig. 3. Diagram of a trapeze function, or a practical square wave with finite rise and fall times $(\sigma - \varepsilon)$.

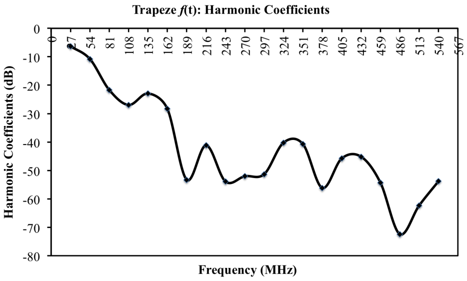

Fig. 4. Spectrum of a trapeze wave with 0.17 duty cycle

If it is possible to generate harmonics from the sinusoidal power signal, an oscillator circuit need not be implemented within the implant itself. A high frequency carrier signal can be generated by producing harmonics from the received power signal itself, allowing the incoming power signal to serve two purposes rather than one [11], [12], [13].

IV. ISM-MICS HARMONIC PROTOTYPE

A harmonic-based telemetry system shown in Fig. 1 was built and tested based on this system. The figure shows the incoming 27-MHz ISM-band signal from the power coil branching off to two units of the implanted device, one to the rectifier, and one to the non-linear block, which in this case is an inverter (NC7WZ04). The half-wave rectifier comprised a Schottky diode, $10\mu F$ capacitor and zener diode in order to minimise components and voltage drops across additional diode junctions.

A MICS-band 405MHz signal– or the fifteenth harmonic– is isolated from the 27MHz square wave output of the inverter using bandpass filters (RF1419D). The transmission antenna L_4 is designed to operate in the MICS band in biological tissue according to [14]. This antenna is manufactured in-house based on these specifications, using 0.635mm thick two-layer Rogers duroid 6010.2LM board, shown in Fig. 5. The scattering parameter $|S_{1,1}|$ shown in Fig. 6 is measured while the antenna was embedded between two pieces of 14mm beef. The antenna behaves as predicted, with a trough at the 403.5MHz mark.

The power-receiving coil in the implant is the stacked-spiral shown in Fig.2. Both the power and data coils of the implant are implanted in biological tissue, specifically lean beef as shown in Fig. 8. The path loss between the external

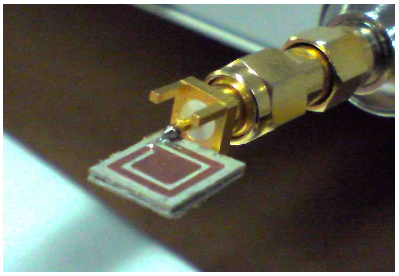

Fig. 5. MICS-band antenna designed for operation in biological tissue

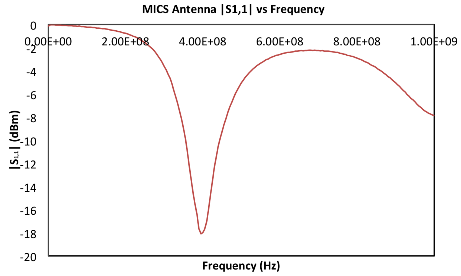

Fig. 6. $|S_{1,1}|$ scattering parameter for the MICS-band antenna.

and implanted power coils at 27MHz with a variation in beef thickness is presented in Fig. 7. The plots indicate that as thickness increases, path loss also increases. A comparison of the three curves indicates that path loss is decreased when the secondary coil is completely implanted in the biological medium, allowing it to absorb more energy from both sides of the coil as the thickness of beef on the opposite side increases.

The scenario used for the implementation of the prototyped MICS telemetry system involves a 14mm-thick piece of beef between the power transmission coil and power receiving coil, with an additional piece of 14mm thick beef above the receiving coil as shown in Fig. 8. A 7.65dBm (5.82mW) signal is transmitted from the Class-E self-oscillator mentioned in Section II-A and -4.43dBm (0.36mW) of power is received on the stacked spiral power receiver.

On-Off Keying (OOK) is a modulation technique whereby an on-bit is indicated by the transmission of a signal, and an off-bit is indicated by the absence of a signal. It is perhaps the simplest method of digital data modulation

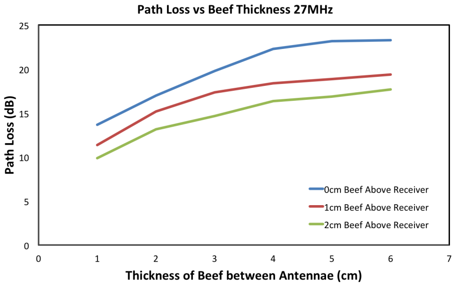

Fig. 7. Plot showing path loss vs beef thickness at 27MHz.

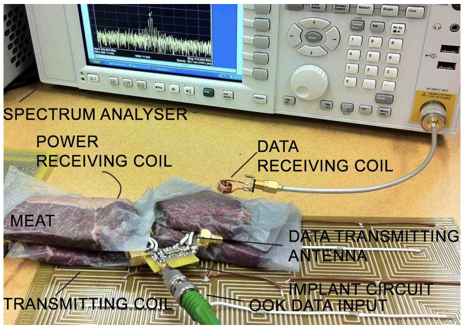

Fig. 8. A Photo of the system, including the power supplying spirals and implant embedded in meat.

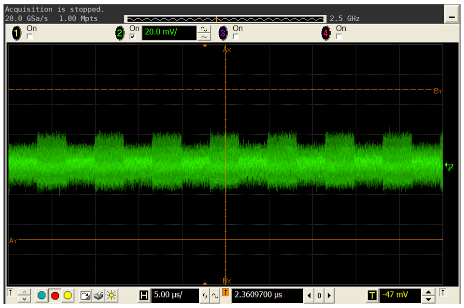
Acquisition is stopped.

Fig. 9. Output Signal before the Antenna

and it is employed in this harmonic telemetry system. In order to minimise power consumption, a transistor is used to switch the transmission on and off according to the data signal supplied at the gate of the device. The circuit theoretically works whether the data modulation switch is connected before the non-linearising harmonic generating device (inverter) or after. From a practical perspective, the final signal becomes less noisy if data is modulated prior to the generation of harmonics, as indicated in the circuit system diagram of Fig. 1.

Fig. 9 shows the time-diagram of the data-modulated signal after passing the BPFs, which was selected according to the bandwidth restrictions of the MICS band. The spectrum of this signal is shown in Fig. 1(d). The plot shows a clear 150kHz data modulated signal at 405MHz, which is the 15th harmonic of the power transmission frequency 27MHz. The signal to noise ratio is 20dB.

The receiver comprises a wound coil optimised for 405MHz, and two SAW bandpass filters (BPFs) identical to those used in the implant. The spectrum after the LNA and BPFs is shown in Fig. 1(d). The BPFs are employed to eliminate the strong interference for both the data transmitter and receivers.

The proposed system not only generates far higher harmonic frequencies, but also fits within allocated industrial and medical frequency bands. The generation of 405MHz from a 27MHz power signal means that a fifteenth harmonic has been generated, and both the power and data frequencies adhere to MICS and ISM band standards respectively.

V. CONCLUSION

This paper presents an implantable telemetry device, inductively powered by a 27MHz ISM-band supply based on a Class-E self-oscillating crystal feedback architecture. The implanted power receiving coil is an implantable stacked spiral inductor which is capable of operating well at lower frequencies given its size.

In most implants, wireless power and data links operate at two frequencies, which usually rely on implanted local oscillator blocks to generate the data frequency. In the presented system a 15th harmonic 405MHz MICS-band data carrier is in fact generated from the power signal, data-modulated, extracted and sent to a receiver via a wireless MICS data link. This avoids the need for a dedicated local oscillator within an implant, saving size and power.

The prototyped system is tested, with the implantable module implanted in a biological environment, successfully proving the concept.

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