In-body Wireless Communication Made Real.

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*Abstract—**This paper take the principle of wireless communication with body implants to the implementation and testing stage. This paper describes a module that can fit into an implant case and results of testing a wireless link with a body model.***

*Keywords—**Clinical applications, low-power communication, miniaturisation, wireless.***

I. INTRODUCTION

Communication with implanted medical devices is key to effective diagnosis and therapy. There are several critical requirements for an implanted communication system, including size, power consumption and data rate. At BSN 2005 a paper was presented [1] that described the essential features of a communication system. More details are contained in Body Sensor Networks edited by Guang-Zhong Yang [2]. This paper shows the size of real hardware and presents the results of tests using a human body substitute.

The system uses an integrated circuit (IC) that incorporates a media access controller (MAC), a 2.45GHz wake-up function and 403MHz two-way radio frequency (RF) data communication. The 403MHz frequency used for in-body communication is known as the medical implant communication system (MICS) [3].

II. HARDWARE

The implant comprises the therapy or diagnostic function and the communication module. Small size is essential, as there is very little room to fit implants into the human body and some locations pose severe challenges. The hardware needs to be robust to withstand the day-to-day knocks and bumps of human body movement and must also survive transport by land, sea and air.

A wireless communication module can be built using a printed circuit board (PCB), or a ceramic thick film hybrid, as the substrate with small active and passive components attached with solder or conductive epoxy. Large active components, with many connections, are typically fixed to the PCB with epoxy and the connections made with bond wire to the substrate. See Figure 1. To protect the wire bonds a non-conductive encapsulant (“glob”) can be added.

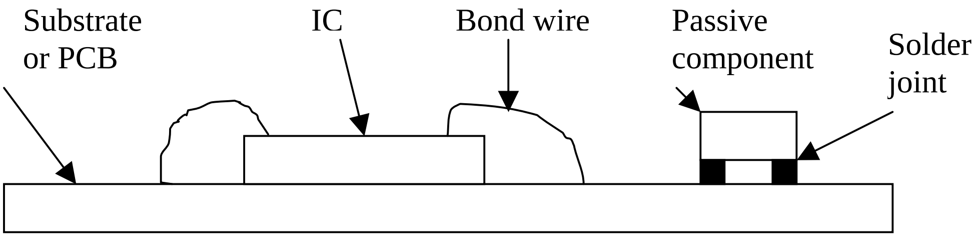

Fig. 1 Module Assembly

The wireless communication module is electrically connected to the other functions of the implant and is part of the same enclosure. Connection to the other parts of the implant can be made with a flexible PCB that is electrically connected to the parent board. This will allow some relative movement between the two PCBs. An alternative approach is to fit solder bumps to the communication PCB such that it can be soldered down to the parent board. The antenna connection must be very short to minimise losses and to keep the impedance at the implant constant.

Figure 2 shows a typical implant board; the communication IC covered in glob, the matching network is to the right and the antenna connections are the two pads in from the edge of the board. Also on the module is the crystal, on the left, that provides the reference for the communication and data handling. In this example the IC is the Zarlink ZL70101. The communication IC has all the functions necessary to establish a wireless link. It is typically controlled by a microprocessor on the parent PCB.

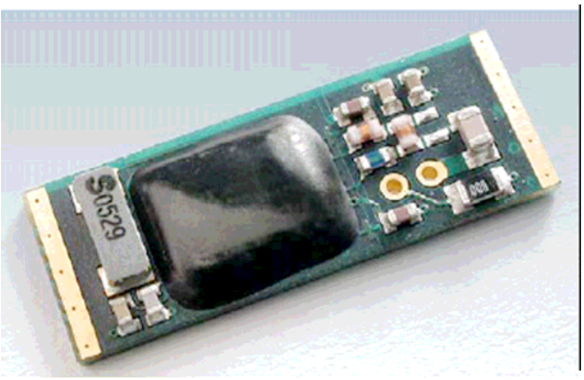

Fig. 2 Implantable RF Communication Module

III. TESTING

To test the performance of the communication link a reference module was powered by a battery. The communication IC (ZL70101) was controlled by a dedicated microprocessor to enable the RF functions and data transfer. The ZL70101 and microprocessor were mounted in a metal enclosure with a 19.5 x 32 mm patch antenna attached; see Figure 3. This was either sealed to make it water tight or enclosed in a thin nonconductive latex bag.

Fig. 3 Implant Case With Patch Antenna Enclosed in Latex Bag

The human body model is defined by ETSI [4] and is made of 10mm thick Perspex. The Perspex model is filled with a liquid that mimics the electrical properties of the human body. For these tests the liquid is valid up to 1GHz, and the recipe is defined by Wojclk [5]. For different frequencies other recipes are available. The implant is suspended in the liquid attached to a PTFE holder. PTFE is chosen, as it will cause the least interference to the radiated signal.

The base-station is controlled by a laptop PC and will generate the signals needed to communicate with the implant. The base-station generates a “wake-up” signal centred at 2.45GHz to get the implant powered up and ready to communicate. The base-station also transmits and receives signals within the MICS band. The wake-up control and communication uses the same IC as the implant.

The power limit for the wake-up transmitter is typically 100mW (country dependant). The power limit for the MICS transmission is 25µW (-16dBm) effective radiated power – this takes account of antenna gain. This 25µW applies to the implant but only at the skin surface. Even if the raw power produced by the communication IC is in the order of 1mW (0dBm), losses through the body will typically reduce the power level to well below the 25µW limit.

The test environment was the anechoic chamber at the University of Bristol. This comprised a screened room that has absorbent cones on the inside to minimise any reflections from walls or the floor that could distort the results. In a real life environment there will be reflections from walls, desks and other equipment and hardware. The body model was mounted on a wood stand (non-conductive). The MICS base-station dipole antenna was mounted on a PTFE stand. The wake-up antenna was on a length of cable to provide freedom of movement. See Figure 4.

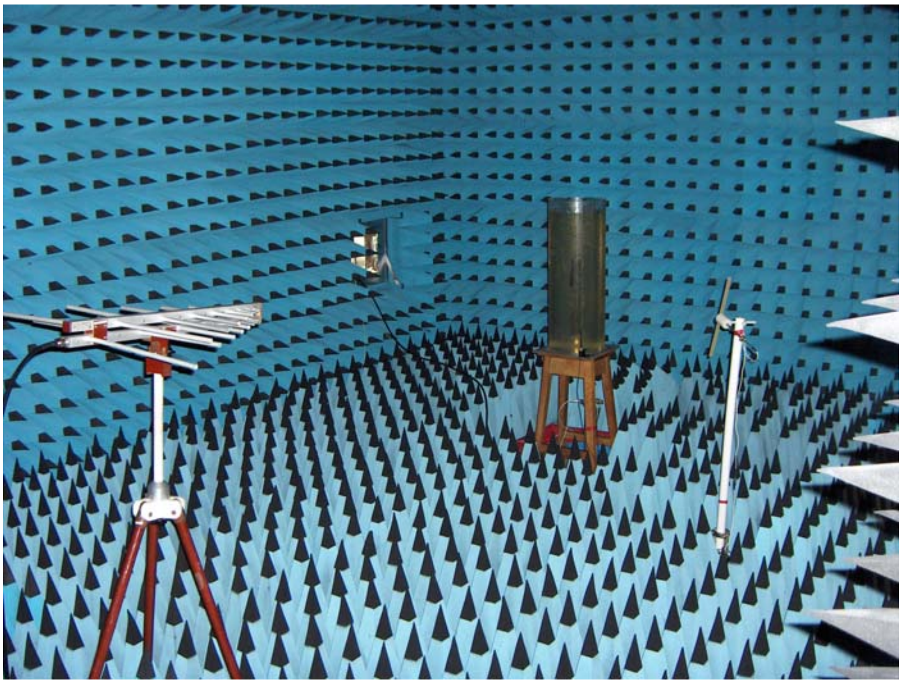

Fig. 4 Anechoic Chamber Showing Body Model (on Wood Stand), Log Periodic Test Antenna (Foreground) and Base-station Dipole (Right)

IV. Results

Once a communication session is established it is possible to perform measurements on the link. These include measurement of effective radiated power from the implant, a measure of the received signal at the implant from the base-station and a measure of the link quality. It is possible to set the implant to transmit a continuous wave (CW) signal so the effective radiated power can be measured. Also the base-station can be set to transmit a CW signal and the implant can measure the relative signal level. These measurements were performed at various depths of the implant in the liquid.

The distance between the implant and either the test antenna or base-station was 3m. The test antenna was a broadband directional log periodic with known characteristics that are necessary to calculate the power radiated from the body model. Depth is the distance from the front of the tank and the implant antenna. Vertical polarisation of the implant is when the long edge of the patch antenna is vertical.

IV. A. Implant Transmitted Power vs. Depth.

Figure 5 shows the effective radiated power (ERP), at the tank surface, versus depth. The ERP is calculated from the measured signal and the test antenna characteristics. As seen, the signal level is dependent on polarisation, and apart from when both implant and test antenna were vertical the power declines with depth.

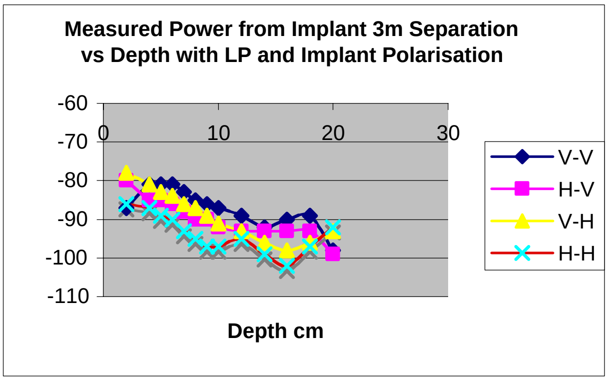

Fig. 5 Effective Radiated Power from the Implant vs. Depth. The Key on the Right Refers to the Test Antenna and Implant Polarisation Respectively

IV. B. Power Received by the Implant vs. Depth.

For this test only the base-station was use, not the antenna. The base-station was set to transmit CW for approximately 30 seconds during which time the implant performed a signal level measurement. This measurement was then transmitted to the base-station. The power at the implant is measured with an internal received signal strength indication (RSSI) function that will give a relative measure of the signal at antenna. Figure 6 shows the RSSI vs. depth for the implant. It can be seen that there is a peak in signal level at about 3-4cm. This is close to the peak in signal level seen in Figure 5.

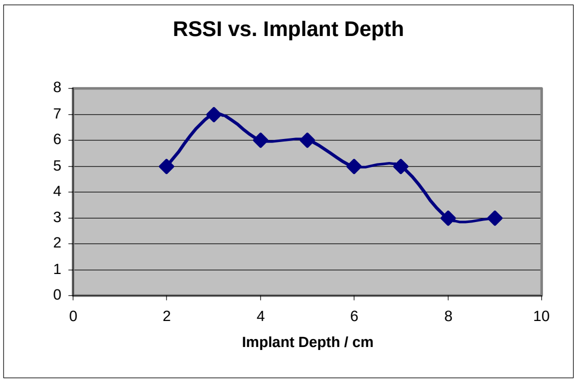

Fig. 6 Implant RSSI vs. Implant Depth

IV. C. Data Transmission.

A link had to be maintained for the above tests or the tests would not have been possible. Signal level is not meaningful unless it can be related to the transfer of data. One way to measure the link is to plot the number of times the error correction code (ECC) or cyclic redundancy code (CRC) needs to be invoked to produce 100 good blocks of data. This test used the base-station and the implant at various depths. The lower the count the better the link is. Figure 7 shows a typical plot.

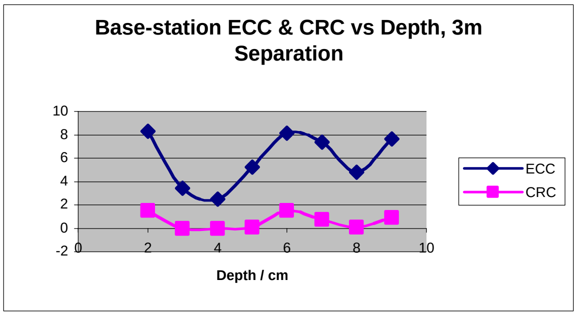

Fig. 7 ECC and CRC Count vs. Implant Depth for 100 Message Transactions

Figure 8 shows that the best performance is obtained when the implant is at 3-4 cm depth that corresponds with the results of the implant power and RSSI results.

V. CONCLUSIONS

The results here are measured and not simulated. The body model provides a reasonable representation of the human body. A data link can be maintained at an implant depth of over 15cm. The link is maintained with a base-station transmit power within the MICS limit. At an optimum depth the body can enhance the signal and thereby the data link, meaning communication with an implant is practical over a distance of 3m with a high data rate.

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