IN-BODY RF COMMUNICATIONS AND THE FUTURE OF HEALTHCARE

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In-body communications have the potential to dramatically change the future of healthcare. Integrated communications from different in-body implants and on-body sensors will allow hearing for the deaf, sight for the blind, and mobility for the disabled.

In-body communications will also improve therapy and diagnoses. For example, an implanted pacemaker will regularly transmit performance data and the patient's condition to a clinician's office. If the pacemaker detects a cardiac arrest, the device could signal immediately to a base station to alert an emergency response team.

Thanks to its high data rate and low power consumption, advances in Radio Frequency (RF) technology are supporting these healthcare advances. A key element of an RF-linked implant is the in-body antenna, which must meet stringent biocompatible and size-limit requirements. An implanted transceiver also faces numerous RF challenges. Unlike free-air performance, the human body is often an unpredictable and hostile environment for a wireless signal.

RF-linked implants are already in use for a wide variety of applications, and there are numerous new devices currently in development aimed at improving quality of life for patients. For some applications, such as Cochlear hearing implants, the communication needs to be constant. Others, such as pacemakers or bladder control devices, require brief, infrequent data transfer. Regardless of the communication requirements, limited power consumption and space are both critical design factors.

BODY EFFECTS ON RF TRANSMISSION

Before considering any in-body data transmission, the effects of the human body on the RF signal must be understood. Unlike the usual communication through constant air, the various tissues and organs within the body have their own unique conductivity, dielectric constant and characteristic impedance. As a result, signal level and propagation from an implanted device to a remote receiver is unpredictable.

Typical values for the electrical properties of muscle and fat are shown in Table 1. Not only will these values vary from person to person, they will also change as a patient moves, changes weight and ages. The high dielectric constant (εr) works to advantageously reduce the physical size of any antenna.

Frequency (MHz)	Muscle			Fat		
	ε_r	σ (S.m^{-1})	Zo (Ω)	ε_r	σ (S.m^{-1})	Zo (Ω)
100	66.2	0.73	31.6	12.7	0.07	92.4
400	58.0	0.82	43.7	11.6	0.08	108
900	56.0	0.97	48.2	11.3	0.11	111

Table 1: Human Dielectric Constant (ε_r), Conductivity (σ) and Characteristic Impedance (Zo) vs. Frequency. (Source FCC and Dr. William Scanlon, Queens University of Belfast)

Frequency bands and power levels are regulated by the Medical Implant Communication Service (MICS) band [1]. MICS operates in the 402-405 MHz band, with a power level strictly limited to 25μW of effective radiated power (ERP). For an implant, ERP is defined as the signal measured external to the body and not at the implant. This allows the implant itself to operate at a higher power. ERP for an external base station is measured at the transmitting antenna, so the signal at the implant is the sum of a low transmitted power, antenna gain, transmission losses and the high body losses. The base station-to-body path results in the lowest received signal.

The losses through the body come from attenuation by the weakly conductive tissue and reflection at each of the boundries of dissimilar tissue. A loss in the order of 20 dB is typical, but can be compensated for if the implant is transmitting at a higher power than the external 25 μW limit. On the receive end, the power limit is at the base station transmitter. As the distance between the base station and implant may be three meters, the result is a low signal level at the implant. This puts strain on the link budget.

ANTENNA DESIGN

The high dielectric constant enables an antenna to be electrically larger than it would be in free space. For example, in free space a half wave dipole operating at 403 MHz would be 372 mm long. However, in muscle with an εr of 47, the size is reduced to 54 mm. A dipole needs to be separate from the implant for best operation, however this is not always an acceptable option.

Electrically small antennas have several drawbacks, such as poor efficiency, low radiation resistance, narrow bandwidth and a high Q that makes them more difficult to manufacture. A physically small antenna must be used in an implant application. The shape of the implant will also dictate the type of antenna used. A patch antenna may be suitable for a pacemaker application, while a helix antenna is required for a stent or urinary tract implant.

A patch antenna can be incorporated into the shape of the implant and works with a 0V RF backplane. An ideal shape is λ/2, which in free space at 403 MHz translates into an antenna measuring 372 mm. This dimension can be reduced by use of a substrate with a high dielectric constant, such as alumina (εr = 9.6), zirconia (εr =25) or titainia (εr =50 to 85).

The conductor needs to be biocompatible, even if the implant is coated in a passive material. For long-term use, this limits the choice of material to platinum or platinum/iridium, both of which have low conductivity compared to copper, gold or silver. Gold can be used for short-term applications. The shape of a patch is defined by the implant case, as it is not acceptable to have sharp overhanging corners that could cause injury. Given the shape of the patch, the substrate material must be low loss but high dielectric constant. This is to maximize the radiation resistance compared with the conductor loss.

Radiation resistance can be measured with a patch immersed in a body phantom; a perspex cylinder filled with a liquid that mimics the electrical properties of muscle[3]. (Figure 1) The feed point can be altered to change the input impedance but the patch should not be tuned to resonate at the required frequency. Operating at resonance will increase the efficiency, however this frequency will change as the antenna is immersed in the body phantom. The input impedance is measured with a 0.25λ line, as the radiation resistance is so low that network analyzer measurements are unreliable. Once the antenna impedance range is established, a matching network can be designed. Part of this network should include fine-tuning capabilities within the transceiver.

Figure 1: A body phantom is used to test in-body antenna performance

Radiation patterns are made with the body phantom using a self-contained transmitter immersed in the liquid. If the antenna were to be attached to a cable then it would contribute to the radiation pattern. This can be minimized, but not eliminated, with the addition of ferrite beads. The patch attached to an implant case within a body does not have an earth (ground) connection, meaning the case will radiate in anti-phase to the patch. This requires that the patch and case be self-powered and measured as a whole.

The RF feed for the patch is an important consideration, as the case and feed-through must form an impenetrable seal. Feeding the patch through a hole in the substrate (Figure 2) would require a feed-through flat with the upper surface of the case. This would be difficult to implement. An alternative is to use a co-axial feed-through to connect to the patch, similar to those used for other applications such as heart stimulation. (Figure 3)

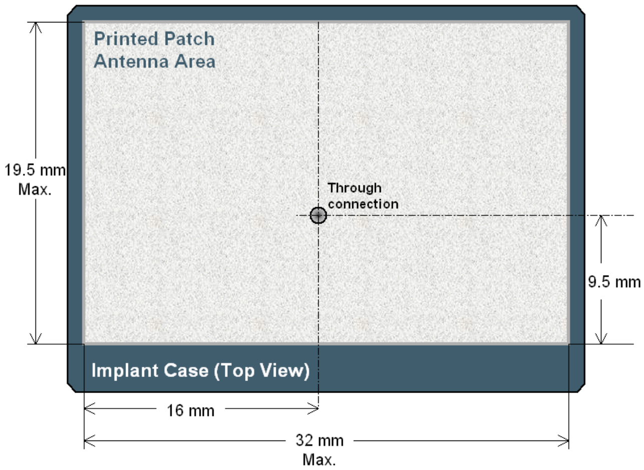

Figure 2: An RF feed-through via a hole in the substrate

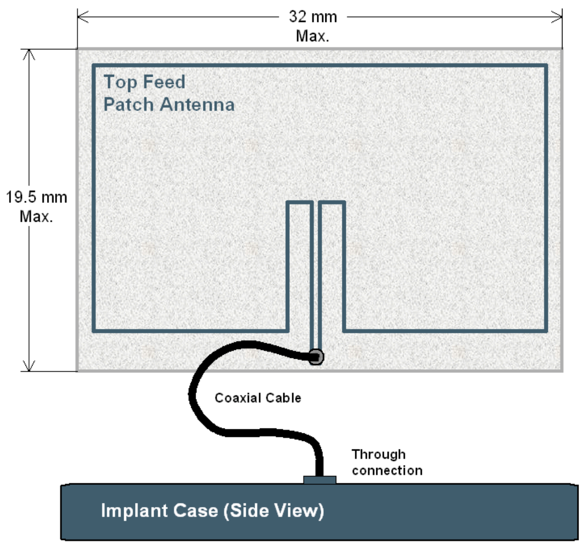

Figure 3: Using a co-axial feed-through to connect to the patch

Patch antennas are not always suitable; consider an RF-controlled valve for bladder control. The valve, electronics, battery and antenna must all fit into a tube 4-6 mm in diameter. The valve is fitted, without surgery, into the urethra and needs to be changed approximately every 60 days. Clearly a flat rectangular patch is not an option, however the tube shape of the valve can be used as the basis for a helical antenna. (Figure 4)

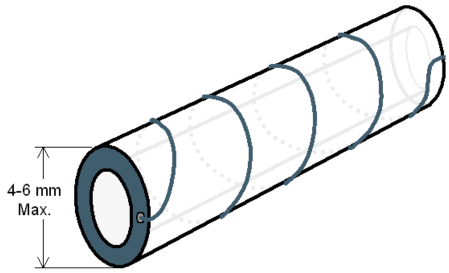

Figure 4: A helical antenna used for RF-based bladder control

Each application is liable to need a different antenna that should be designed together with the case, and not as an add-on device.

IMPLANT TRANSCEIVER

If operated continuously, a transceiver will consume significant current and reduce the operating life of the implant. This would require either a method for recharging the battery by an inductive loop approach, or regular replacement of the implant. Both of these have drawbacks, but may be necessary for applications such hearing restoration.

In some applications, such as pacemaker monitoring, the transceiver only operates intermittently and for short periods. During the interval between communication sessions, the transceiver can be put into "sleep mode" where it draws only a very tiny current but will sense a "wake-up" signal. The wake-up is generated by the external base station, after which data can be transferred. At each wake-up the transceiver should retune the antenna. Following the transfer, the implant transceiver returns to sleep mode. This considerably extends battery life.

The transceiver can operate in a wake-up mode, as described above, or can initiate communication by sending a message to a nearby base station. The use of this mode is limited, but could be useful for providing an early warning that battery life is low. Potentially, an implant could also transmit an emergency signal if it detects a health problem, such as cardiac arrest.

When designing an implant transceiver that relies on a wake-up signal, each device must have its own unique identifier. This ensures the correct device is being interrogated, or the right patient is being treated, in a busy hospital setting.

APPLICATIONS

The transceiver can be integrated with a range of implants for a variety of different uses, including heart pacemaker monitoring, bladder control and Functional Electrical Stimulus (FES). These three applications can use the same transceiver with a choice of antennas.

The performance of a pacemaker can be improved with remote monitoring and re-programming as required. For example, battery status can be transmitted to a base station to provide an early warning of power loss or increase the time between surgical replacement. This application requires a large data transfer in a relatively short time. The data can be stored for several days or weeks before transmission.

Fitting into the urinary tract a radio-controlled valve that is operated on-demand by the patient or a caregiver can restore bladder control. This can greatly improve the quality of life for an otherwise incontinent patient. This type of link will require a small data transfer at regular, widely spaced, intervals. A unique identifier as part of the data link will activate the correct patient's valve.

Using FES to replace lost limb function, for example paralysis as a result of a stroke, requires implant(s) to stimulate muscles or nerves in response to movement detected by sensors elsewhere on the body. (Figure 5)

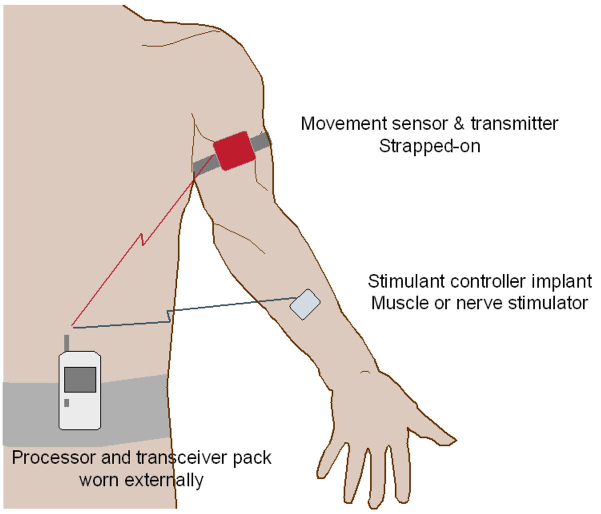

Figure 5: A patient with external sensors transmitting data to a processor pack. Information is then relayed to an implant to activate a muscle.

The patient wears a strap-on motion sensor that transmits data to a processor pack, which is worn by the patient and is similar to a mobile phone. The sensor transmits over a short distance (less than two meters), without the problems or limitations of in-body transmission. Since the device is not an implant, a frequency with a higher power level can be used, such as the Industrial Scientific Medical (ISM) bands.

Operating in real-time, the processor receives signals from the sensors, processes the data and transmits it to the implants to stimulate a muscle or nerve. The processor may have inputs from several sensors and transmit signals to several stimulus implants. The link to the in-body implant will use the MICS frequency, with the implant using an antenna mounted on its case as described above.

The on-body sensor battery is charged overnight or replaced when necessary. The processor will have a battery capacity to operate throughout the day and can be recharged overnight. Because the implant transceiver will be used for long periods the battery needs to be capable of overnight charging through an inductive loop.

A patient using FES may have several RF-linked implants. To ensure the base station is communicating with the correct device, each implant transceiver must have a unique identifier to prevent false wake-up or interrogation.

CONCLUSIONS

RF-linked implants can be used for diagnosis, therapy or to restore lost function. Each application will need to be tailored to the position and frequency of use. A key component of an in-body communications system is the antenna. The antenna must be designed as part of the implant, and not as an add-on or after-thought as this will lead to performance issues.

The use of RF technology in medical applications promises many benefits for patients, including better diagnoses and tailored therapy, fewer hospital visits, and peace of mind that implant performance is being monitoring. For healthcare providers, improved implant monitoring potentially lowers medical costs by extending the time between hospital visits and surgical procedures. We are only just beginning to realize the potential for RF communications in healthcare.

Henry Higgins is with Zarlink's Microelectronics division, and is involved in the design and development of RF links for medical applications that included synthesizer, modulator, amplifier blocks and antennas. Henry holds a Master of Science degree from the University of Bath, and is a corporate member of the IEE.

ACKNOWLEDGMENT

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