Hybrid RF/IR Transcutaneous Telemetry for Power and High-Bandwidth Data

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Abstract — As neuroprosthetic control systems continue to advance and increase in channel density, there will be a constant need to deliver data at higher bandwidths in and out of the body. Currently, RF telemetry and inductive coupling are the most commonly used methods for transmitting power and electronic data between implants and external systems, and state of the art systems can deliver data rates up to hundreds of kilobits per second. However, it is difficult to operate implanted medical RF links at higher data rates due to Electromagnetic Compatibility (EMC) constraints. In this study, we investigate the potential for hybrid telemetry systems that use constant-frequency RF inductive links for power and transcutaneous infrared (IR) signals for data. We show that with commercially available infrared communication components, data rates of up to 40 Mbits per second can be transmitted out across 5 mm of skin with an internal device power dissipation under 100 mW.

Keywords— Trancutaneous, Telemetry, Electromagnetic Compatibility, RF, Infrared, Neuroprostheses, Electrodes

I. INTRODUCTION

Over the last 20 years, there have been significant advances in the field of neuroprosthetic control systems to replace lost motor function [1], and these systems are recently beginning to be used for clinical therapies. In order to minimize infection risks, totally implantable systems are preferred and some mode of transcutaneous telemetry is required to communicate between implanted devices and external systems.

For intermittently operated telemetry with implants such as implantable cardioverter defibrillators (ICDs), there are RF bands available that can be used to openly transmit and receive low bit rate data. For higher speed interfaces with externally powered devices, such as cochlear implants, close-coupled RF inductive links across the skin are normally used. These antenna and inductively coupled modes can typically be used to reliably transmit hundreds of kilobits of data per second for portable applications.

As neuroprostheses and implantable medical devices continue to grow in channel density and complexity, there will be a constant need for higher-bandwidth data transmission into and out of the body. Unfortunately, current RF systems cannot be directly scaled to higher rates due to the potential for RF interference with other devices and susceptibility for interference. Many implantable RF systems utilize Industry-Scientific-Medical (ISM) bands to avoid interference with other RF devices. However, RF bandwidth is proportional to digital data rate, and the only ISM bands that can practically carry data rates over 10 Mbits per second are the 915 and 2450 MHz bands. These bands are problematic because they are becoming increasingly crowded with wireless protocols such as 802.11 and Bluetooth. If operated outside of ISM bands, devices must be operated at very low RF signal levels to comply with FCC and CISPR regulations and this makes them vulnerable to interference from other RF systems.

In order to avoid the Electromagnetic Compatibility (EMC) issues with RF data links for recording applications such as cortical motor neuroprostheses, we propose the telemetry system shown in figure 1. In this arrangement, power is provided to the implant by a constant-frequency RF inductive link, and data is transmitted out of the body by an amplitude modulated infrared (IR) carrier. Optical and IR telemetry systems have been previously reported [2,3,4], but not for high-bandwidth (>10 Mbps) applications.



system for a cortical recording application.

The primary obstacles for transmission of infrared across the skin are scatter (S) and absorption (K) [2], and the best window for penetration is 850 to 1300 nm (see fig. 2). Fortunately, most commercial infrared transceivers are designed to operate within this range.



Fig. 2. Scatter (S) and Aborption (K) of skin over 300 to 1200 nm. [2]

II. METHODOLOGY

In order to test the ability of commercially available IR transmitters and receivers to transmit digital data across the skin, the devices in Table I were bench tested with optics to maximize their performance through skin models. 10 mm thick Agar samples were used for initial setup and calibration, and 3 mm and 5 mm sections of pig skin were used for final testing. (see figures 3, 5, and 7 for diagrams)

| wavelength | Emitters | Detectors |
|------------|--|--|
| 650 nm | Agilent HFBR-1527 | Agilent HFBR-2526 Hamamatsu G1735 |
| 820-850 nm | Agilent HFBR-1412 Agilent HFBR-1416 Hamamatsu L1915 Hamamatsu L5128 Hamamatsu L5871 Hamamatsu L6486 | Agilent HFBR-2412 Agilent HFBR-2416 Hamamatsu GT4176 |
| 950 nm | Infineon SFH 4203 Infineon SFH 4301 Infineon SFH 4502 Infineon SFH 4503 | Infineon SFH 203 Infineon SFH 5400 Infineon SFH 5440 Infineon SFH5441 |
| 1300 nm | Agilent HFBR-1312 Hamamatsu L7866 Hamamatsu L7850 | Agilent HFBR-2316 |

Table I. Components reviewed in this study.

DC-balanced digital data were transmitted and eye patterns were recorded to estimate channel performance, and a Bit Error Rate (BER) of 10^{-14} or better was considered acceptable. For each data rate tested, the minimum required power dissipation of the emitter assembly was recorded. Emitter power loadings up to 120 mW were evaluated.

III. RESULTS

Different combinations of emitters and detectors were tested for power efficiency at different data rates. Based on these tests, the overall two best emitters and two best detectors for this application were:

- Infineon (Siemens) SFH 4503 Emitter (broad IR emitter with 950nm peak, TO and chip packages)
- Agilent Technologies HFBR-1416 Transmitter (820nm output, in 1mm Plastic Optical Fiber assembly)
- Infineon (Siemens) SFH 203 Detector (broad IR detector, TO and chip packages available)
- Agilent Technologies HFBR-2526 Receiver (650nm - 1200nm range, 1mm Plastic Optical Fiber input)

The configurations with these components that performed best are shown in figures 3, 5, and 7, and their performance plots are shown in figures 4, 6, and 8, respectively. The power levels shown in these plots represent the consumption for the emitter and its driver circuitry, not the optical power produced by the device. For the SFH 4503 and the HFBR-1416 devices, the maximum optical output power was 1 mW when the devices were operated at up to 120 mW.



Fig. 3. Optical arrangement with detector used to directly receive transcutaneous infrared.



Fig. 4. Emitter power consumption for the assembly in Fig 3 as a function of data rate.

With an emitter assembly power dissipation of 120 mW or less, data rates of up to 40 Mbits per second were readily achievable through 5 mm of skin and higher data rates were possible through 3 mm skin samples. Data rates less than 20 Mbits per second were particularly easy to achieve with a variety of components and optics. Receivers typically required alignment to within 1 to 2 mm of center in order to function.

The main limiting factor for performance in this application was scattering, especially in fatty tissue layers. Once light is scattered over a diffuse area, it is difficult to recover, and typical optical recovery factors ranged from 0.5% to 5%. In addition, more light is required at higher data rates to drive capacitances in the detector.

All of the commercial receivers tested had Schmidt processing circuits that tended to work robustly or completely fail, rather than gradually deteriorate. Bit Error Rates for functional links typically exceeded 10^{-20} .

For use with RF powering, the configurations in figures 5 and 7 were tested to look at the feasibility of removing the detector from the RF field via fiber. The configuration in figure 7 also worked by directly placing the ball lens on the skin (no Fresnell lens) with only a 15% performance loss.







Fig. 6. Emitter power consumption for the assembly in Fig 5 as a function of data rate.

IV. CONCLUSION

As neuroprosthetic and other implanted devices increase in complexity, there will always be a need for implanted telemetry systems with faster data rates that can meet medical EMC requirements. This work demonstrates the basic feasibility of creating transcutaneous infrared data links that can operate in the 10 to 100 Mbit per second range using commercially available communication components. The internal power dissipation required to operate these links was between 20 and 120 mW and reasonable for small implantable packages. This approach will be investigated further to determine if it can perform adequately and robustly within specific clinical applications.

Future studies will be needed to evaluate the performance of different NRZ signaling systems such as 8B10B and Manchester coding, to improve the efficiency of the system with better components and optics, and to reduce the sensitivity of the system to alignment issues. The performance of these systems will also need to be evaluated with implant models powered by inductive RF coupling arrangements. [5]



Fig. 7. Optical arrangement with a fiber-optic coupled detector and directly coupled emitter.



Fig. 8. Emitter power consumption for the assembly in Fig 7 as a function of data rate.

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