Abstract—The emerging field of Intra-Body Communication (IBC) will result in the innovation of many health care applications by allowing in-situ monitoring and mobility for the human subjects. We use a technique called Galvanic Coupling (GC) that uses weak electrical currents for the intra-body links, instead of RF, as this is two orders of magnitude superior when comparing energy efficiency. In this work, we demonstrate an experimental setup that can be used to implement and validate physical layer communication schemes and link layer protocols using off-the-shelf hardware and commercially procured synthetic human tissue. Our setup uses Universal Software Radio Peripherals (USRPs) as the transmitter and receiver nodes, with additional interfacing electronics, to allow flexible transmission of signals in the 100 kHz - 1 MHz frequency range. Furthermore, we provide a visual GUI-based configuration as well as demonstration of link quality based results. The complete hardware and software design, as well as an instructional video, are made available license-free for public consumption to stimulate further research in this field.

I. INTRODUCTION

Intra-Body Networks (IBN) promise to provide advanced medical procedures by establishing communication links between miniature embedded sensors. The overall architecture is composed of sensors that gather biological data, and a relay node used to aggregate data and connect the IBN with external networks. This technology can unlock immense potential in drug delivery, remote patient monitoring and emergency medical response, compared to traditional methods. Current implementations rely on Radio Frequency (RF)-based approaches to enable IBC. However, the use of RF-based wireless communications warrant numerous drawbacks in the form of: (i) limited tissue penetration, (ii) increased risk of tissue heating, and (iii) increased security risks due to signal propagation outside of the body. To avoid the aforementioned drawbacks, extensive work has been done to model the human body as a communication channel using Galvanic Coupling (GC) [1]. However, effectively demonstrating these technologies in a robust platform that allows repeatable experiments remains a challenge. In this paper, we develop and publicly release the design for a Galvanic Coupling Intra-Body Communication (GC-IBC) experimental setup (as seen in figure 1) based on off-the-shelf software defined radio (USRP) platforms.

In GC, a pair of electrodes are used to directly couple weak electric current on and into the human body (0.5 mA). Existing works have theoretically modeled the channel characteristics of the human body [2], enabling the first step towards exploring the feasibility of various communication schemes and protocols that are difficult to perform on the human body directly. As a result, the work presented in this paper demonstrates the creation and use of a uni-directional communication link through synthetic human tissue using the GC concept. In summary, the features of the GC-IBC experimental testbed include: (i) the ability to modify modulation schemes for various communication scenarios, (ii) real-time transmission of physiological data sets and images, (iii) measurement of BER from real-time data transmissions, and (iv) the comparison of the BER with other published works that invoke concepts from wireless communication theory.

II. HUMAN BODY CHANNEL MODELING

Initial efforts towards understanding the behavior of the human body under the influence of GC, led to the development of an adaptable 2-port circuit model [2], where homogeneous tissue layers and the transition boundaries between them, are represented as a complex impedance network. This model allows for the modification of tissue dimension, center frequency, and electrode dimension, and other parameters, in order to compute the channel gain and estimate the channel capacity.

The results from this research constitute the foundation for applying an empirical channel modeling method, known as Stored Channel Impulse Response, on a slab of porcine tissue (dielectric properties similar to human tissue). In this method, a correlative channel sounder in the form of a single-carrier,
BPSK modulated Pseudorandom Noise Sequence, is used to measure and capture the channel impulse response. Alternative ways of viewing channel behavior are also examined by way of the channel frequency response, noise, and capacity estimations. Observations from both works show that the behavior of the channel resembles characteristics of an Additive White Gaussian Noise (AWGN) Channel [3]. The developed testbed is suitable to validate such empirical results, as we shall show in a later section of the paper.

III. GC-IBC TESTBED ARCHITECTURE AND EXPERIMENTAL SETUP

In order to facilitate the creation of the GC-IBC testbed, the USRP N210 by Ettus Research™is used as the SDR platform to emulate a single implanted sensor. It controls all aspects of communication, including, but not limited to bit generation, automatic gain control, preamble insertion and raised cosine filtering. As referenced by the GC-IBC testbed block diagram in figure 2, both USRPs each represent a side of the communication link, and are connected to laptops that run MATLAB®. We use the MathWorks® USRP Hardware Driver (UHD) interface, so that data can be transmitted and collected directly from/within the MATLAB environment. Within the USRP, low frequency daughter boards, the LFTX and LFRX, are used for the transmitter and receiver, respectively. The daughter boards have an operational frequency range from DC to 30 MHz, well within the permissible frequency band used for GC-based communication (100 kHz to 1 MHz). However, the LFTX and LFRX have almost no internal gain. Thus, external amplifiers (provided by MiniCircuits®) are used to provide adequate amplification levels to account for the lossy nature of the channel. Integrated with the Tx is the ZFL-500+, a SMA connector based Power Amplifier (PA) that has a maximum power output of 9 dBm. Similarly, the Rx side of the link employs the use of a Low Noise Amplifier (LNA), the ZFL-1000LN+, which has a noise figure of 2.9 dB. The human body equivalent channel, takes the form of a custom synthetic tissue plate model (20 cm x 20 cm), provided by SynDaver Labs™. The tissue layer thicknesses for skin, fat and muscle are 0.1 cm, 0.5 cm and 25 cm, respectively. The synthetic tissue is composed of salt, water and fiber and is constructed to account for the dielectric properties of actual human tissue to a good approximation. Bridging the connection between the channel and USRP, balun circuits (Schaffner IT239) are used to isolate the common ground return paths of the transmitter and receiver. In order to inject electrical current into the tissue, electrodes provided by TENSPros are used in this study. The electrode separation for both sides of the link is set to a distance of 5 cm, and the distance of the communication link can be varied up to the length of the tissue, but is fixed at 10 cm for comparison purposes.

We present a MATLAB-based GUI, that allows the user to select the physiological data/image for transmission through the channel. Based on the type of physiological information that is chosen for transmission, specific modulation schemes are selected for the link (based on application dependent data rate requirements). The GUI at the Rx displays the BER rate and compares the real-time BER measurement to results from previous channel sounding experiments. An instructional video of the entire system operation is available here [4].

IV. RESULTS AND CONCLUSIONS

Results (figure 3) are presented in terms of BER for DBPSK modulation. Three distinct transmit power levels are used versus the traditional Signal-to-Noise Ratio method of BER assessment, which is more advantageous when monitoring the transmit power levels used in IBC links (considering tissue exposure limits). The reasonable level of agreement between results obtained from previous stored channel response experiments and real-time channel assessment validates the merit of the GC-IBC testbed for the development of future systems.

ACKNOWLEDGMENTS

This material is based on the work supported by the U.S. National Science Foundation under Grant No. CNS-1453384 and the Draper Lab Fellowship Program

REFERENCES