Communication System Design for Magnetic Induction-Based Wireless Body Area Network

Negar Golestani
EE - Electrophysics Department
University of Southern California
Los Angeles, CA 90089 USA
Email: ngolesta@usc.edu

Mahta Moghaddam
EE - Electrophysics Department
University of Southern California
Los Angeles, CA 90089 USA
Email: mahta@usc.edu

***Abstract*—Technological advancement has enabled the realization of wireless sensor networks working around the human body. Wireless Body Area Network (WBAN) is a network of biosensors and computing devices that collect bio signals from the human body for medical or non-medical applications. There are various wireless technologies available for WBANs, among which magnetic induction (MI) is a novel and promising physical layer. For MI communication system design, several parameters should be selected including the operating frequency. Several other key factors affect the system design such as geometry, relative distance and orientation of coils, background medium, etc. In this paper we propose a procedure for MI system design, and optimization for various parameters. Considering the constraints and relative location of coils, the best operating frequency and its corresponding parameters are defined.**

I. INTRODUCTION

Wireless body area network (WBAN) is a short range wireless network of biosensors and processors that works within or around the human body. The WBAN technology has many possible applications in healthcare, human computer interaction, fitness and sports training, education, entertainment, military, etc. Many different communication technologies using electromagnetic (EM) waves have been successfully deployed for WBANs. However, they face several problems such as severe signal attenuation, multi path effect, and interference [1]. Magnetic Induction (MI) is a promising physical layer for WBANs, which can address several problems with EM-wave propagation techniques. We have previously reported on a received voltage model of MI-based WBAN system [2]. Here, we advance our analysis to include the theoretical model and system design, based on an optimization method, for mid-range MI-WBAN. In the proposed model, the relative alignment and positioning of transmitting coil and receiving coil are considered. In this work, we develop an optimization algorithm for frequency adaptation and system design.

This paper is organized as follow: optimization algorithm for MI system design is discussed in Section II. Next, simulation and results are presented in Section III. Conclusions are presented in Section IV.

II. MI-RECEIVED VOLTAGE MODEL

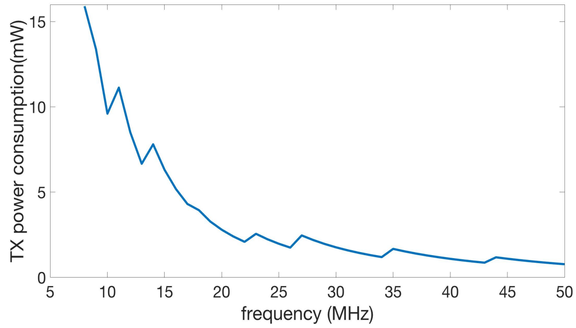
In this section, the optimization algorithm for MI system design is discussed. The MI-received voltage model proposed in [2], and the self inductance, bandwidth and effective resistance model of the coils from [3] [4] are used. We assume that the transmitter (TX) and receiver (RX) coils are identical, air-cored, multilayer circular and have square cross-section. We also assume that the TX coil is electrically small, which means that the circumference of the coil should be smaller than the wavelength ($2\pi a < 0.1\lambda$). The TX coil is centered at the origin with the surface at xy-plane, and the RX coil is centered at RX_{center}. Therefore relative location of coils is determined from location of RX coil. We assume annealed copper wires, so the wire resistivity is $\rho_{wire} = 1.724 \times 10^{-8} (\Omega.m)$, and $isol_{fact}$ = 5% (20% for Litz wires). Moreover, we assume that the system is operating precisely at the selected resonant frequency, and dielectric properties used in model are dielectric properties of background medium, air. So we have:

$$\gamma = j\omega\sqrt{\mu_0\epsilon_0} \tag{1}$$

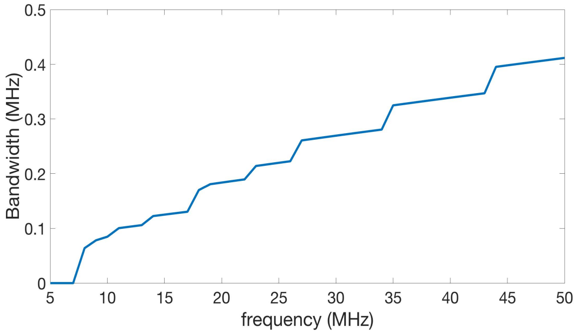
The parameters μ_0 and ϵ_0 are the permeability and permittivity of air, respectively. The parameter γ is the complex propagation constant used in model, and ω is the angular frequency.

For MI communication system design operating in frequency f, the parameters that should be defined are as follow: radius of coils (a), number of turns in the multilayered coils (N), wire diameter (ϕ_{wire}), relative location of MI coils, relative alignment of MI coils which is defined by the rotation about x-axis and y-axis (θ_x, θ_y), and rms value of the sinusoidal current flows through the TX coil (I_{TX}). For a defined geometry (fixed RX_{center}) relative location of the coils is a fixed parameter, and $a, N, \phi_{wire}, \theta_x, \theta_y, I_{TX}$ are variables. In the optimization process, we aim to optimize these variable parameters to minimize TX power. Considering conditions used for model derivation and practical constraints [3], a valid range is defined for each variable parameter; then the best value is investigated among their range.

The additional parameters due to the practical constraints are maximum TX output current in rms (I_{TX}^{max}), maximum DC voltage level of the TX power supply (V_{src}^{max}), minimum RX voltage-level sensitivity (V_c^{min}), minimum allowed resistance for the TX load (R^{min}). It should be noted that for effective resistance (R_{eff}) calculation, we assume that wire diameter is smaller than 4 times the skin depth (δ_{wire}), and as a result



(a) TX power consumption vs. frequency



(b) Bandwidth vs. frequency

Fig. 1. (a) TX power consumption and (b) system bandwidth for $TX_{center} = (0, 0, 0)$ and $RX_{center} = (0, 0, 40cm)$.

resistance due to the proximity effect is neglected [3]. We followed an optimization algorithm similar to [3] to arrive at a set of system parameters.

III. SIMULATION AND RESULTS

Using the optimization algorithm introduced in previous section, simulations are performed for a frequency range and a defined geometry. The input parameters of algorithm require initialization. For example we use $I_{TX}^{max} = 100$mA, $V_{src}^{max} = 1$ V, $V_c^{min} = 100\mu$V, $R^{min} = 5\,\Omega$. Since the coils have to be small, the layers of the MI coil is limited to 10 layer, and the coil radius to 10cm. The wire diameter can take any AWG between 0 and 50. To receive higher voltage at the receiver, 30 degree rotation flexibility about x-axis and y-axis is added to the RX coil alignment.

The received voltage model for MI system around the human body is valid for frequencies below 50 MHz [2]. Moreover, MI system is more efficient as the ratio of radiative part to the inductive part of the signal is small, which is smaller for the lower frequencies. Therefore, the frequency range considered in optimization algorithm is between 1MHz to 50 MHz. Simulations are performed for different RX_{center}, and results of one of them is shown in Fig. 1. As frequency increases, TX power consumption decreases and bandwidth increases. On the other hand, as Fig. 2 shows, the system efficiency, which is defined as the ratio of inductive (MI) part to the radiative (RAD) part of the signal (MI/RAD), decreases as the operating frequency increases. Therefore, for MI system design we should trade off between these parameters. The aim of this trade-off is to choose the optimal operating frequency for any desired application.

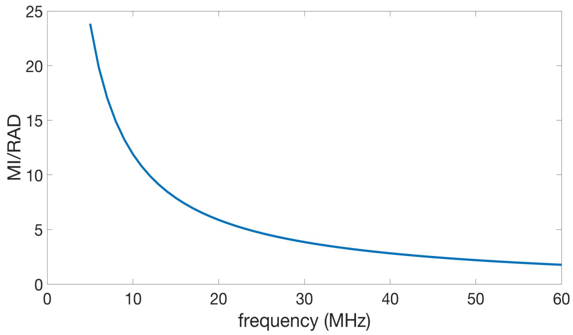


Fig. 2. MI/RAD ratio of generated magnetic field by TX coil

IV. CONCLUSION

In this work, an optimization algorithm for determination of MI system design parameters and best operating frequency for is presented. The practical constrains are considered to define valid ranges for variable parameters, and then the best value is determined to minimize the TX power. According to simulation results, higher frequency result in higher bandwidth, and lower TX power consumption. However, system efficiency (MI/RAD) is higher for lower operating frequencies. The optimum frequency is determined by trading off between system efficiency, TX power consumption, and bandwidth.

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