Channel Capacity of Magnetic Communication in a General Medium Incorporating Full-Wave Analysis and High-Frequency Effects

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***Abstract*— Magnetic communication systems are most often analyzed assuming magnetoquasistatic (MQS) conditions, which neglect full-field terms and high-frequency (HF) effects in the transmitting and receiving coils. Such approximations may lead to nonoptimal designs in terms of operating frequency, size, and coil orientation. This paper presents an optimal design approach for maximizing the channel capacity, using both MQS analysis and full-wave (FW) analysis while incorporating HF effects, such as skin and proximity effects, radiation losses, and the self-resonance of coils. For a given medium and required transmission distance, the optimal operating frequency is such, for which the receiver is located in the radiative near field (NF) and not in the reactive NF. The optimal power allocation and the resulting channel capacity were obtained using a "water-filling" algorithm. The HF effects reduced the signal-to-noise ratio and limited the operating frequency and the coil size. This is especially true for short-distance transmission through low-loss media, where the optimal signal frequency is relatively high. In addition, FW analysis significantly improved potential data rates compared to the typical MQS approach. This improvement was achieved due to a higher operating frequency and sometimes a change of mutual orientation from coaxial to parallel. Electromagnetic simulations validated the primary effects presented here.**

***Index Terms*— Channel capacity, computational electromagnetics (CEMs), electromagnetic induction, electromagnetic radiation, near-field (NF) communication, wireless communication, wireless power transfer.**

relatively low, coil transducers are much smaller compared to larger RF antennas [4]. Moreover, low frequencies are less prone to multipath [10], [25], and the path loss has less time and location dependence [9]. MC systems often use a single transmitter–receiver pair [7], [11], [13]. Long-distance transmission, however, may require the deployment of passive relay coils arranged as a magnetic waveguide [2], [4], [6]–[12], [14]–[23], [26], [27].

As in any wireless communication system, achieving high data rates over a noisy channel is of prime importance [1], [12], [14], [16], [20], [27]–[33]. The channel capacity of MC systems is relatively small, due to the low frequencies involved [13], the rapid decay with distance that results in a low signal-to-noise ratio (SNR), and the narrow bandwidth (BW) dictated by the resonance operation mode [27]. Several methods for improving the capacity were proposed, such as the spread resonance strategy [16], the quality-factor optimization [32], multiple-input single-output (MISO), and multiple-input multiple-output (MIMO) [27].

The prevailing approach in the literature is to analyze MC systems under magnetoquasistatic (MQS) assumption which neglects the far-field terms [1], [2], [4]–[12], [14]–[20], [24], [26], [27], [31], as well as high-frequency (HF) effects