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# Near Field Magnetic Induction Based Wireless Communication

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**ABSTRACT:** Newer technology is being developed every day and the NFMIC (Near field Magnetic Induction Communication) is to cater to underground and underwater medium. The main advantage of using this technology rather than the classical technique of Electromagnetic (EM) communication is that this provides a constant channel path in the delivering medium. The major difference between the wireless underground sensor networks (WUSNs) and the terrestrial wireless sensor networks is the signal propagation medium. Wireless communication is a challenging for the underground environment, since the propagation medium is no longer air but water, soil and rock. The well-established wireless signal propagation techniques using EM waves do not work well in this environment due to three problems: high path loss, large antenna size and dynamic channel condition. Detailed analysis on the path loss of the Magnetic Induction (MI) system in underground soil medium is provided in this paper. Based on the channel analysis, the MI technique for communication is developed in order to reduce the high path loss of the traditional EM wave system. The MI communication system is designed and simulated for 2 MHz and 9 MHz signals using Agilent Advanced Design Systems software by varying the transmission range. The MI communication system is experimentally tested for 2 MHz signals. The results disclose that the transmission range of the MI system is dramatically increased. This technique of NFMIC creates constant channel condition which can accomplish the communication with small size coils.

**KEYWORDS:** Magnetic Induction Communication, Path loss, Underwater Communication, Wireless Underground sensor networks.

## I.INTRODUCTION

Two thirds of the earth surface is covered by water. For the past thousands of years, humans have never stopped exploring the ocean. Ocean exploitation has played an important role with increasing demand of underwater wireless information transmission. Also, in recent years, with the ever-increasing global climate change and resource depletion, there has been a growing interest in the research of ocean exploration system. The propagation medium is no longer air but water, soil and rock, where the well-established wireless propagation techniques for terrestrial wireless sensor networks do not work well. The interest towards wireless communication has increased for underground, space and underwater links due to another factor as well – i.e it's capability of providing high data rates with low power and mass requirement. The present technology of acoustic waves for underwater communication has comparatively lower performance as it is limited by low bandwidth and high transmission losses. [1]

The current available underwater acoustic communication can support data rate up to tens of kbps for long distances (ranging in kms) and up to hundreds of kbps for short distances (few meters). Electromagnetic (EM) wave propagation, in the radio frequency (RF) range, is not a good option for underwater wireless communication except for very short distances and attenuation of RF waves increases with the increase in frequency and EM waves are heavily attenuated by sea water. If the sensors of WUSNs are buried in the shallow depth, sensor can communicate with the aboveground data sinks directly using EM waves. This is because the underground path is short in this case. Hence the impacts of the additional path loss and the dynamic channel caused by the soil medium are much smaller. However, many WUSN applications, such as underground structure monitoring, require the sensors buried deep underground, where only underground-to-underground channel is available. Magnetic induction (MI) is a promising alternative physical layer technique for WUSNs in deep burial depth. It can address the problems on the dynamic channel condition and the large antenna size of the EM waves techniques. Specifically, the underground medium such as soil and water cause little variation in the attenuation rate of magnetic fields from that of air, since the magnetic permeability of each of these materials are similar. This fact guarantees that the MI channel conditions remain constant for a certain path in different times. Moreover, in the MI communication, the transmission and reception are accomplished with the use of a small size coil of wire. In addition, since the radiation resistance of coil is much smaller than electric dipole, very small portion of energy is radiated to the far field by the coil. Hence, the multi-path fading is not an issue for MI communication. However, MI is generally unfavorable for terrestrial wireless communication. As the transmission distance increases, magnetic field strength falls off much faster than the EM waves in terrestrial environments. In underground environments, although it is known that the soil absorption causes high signal attenuation in the EM wave systems but does not affect the MI systems, it is not clear whether the total path loss of the MI system is lower than the EM wave system or not. Additionally, since the MI communication involves reactance coils as antenna, the system bandwidth needs to be analyzed [2].

A very promising low-cost, robust and efficient method is the magneto-inductive wireless communication. Unlike acoustic channel, MI channel does not have high latency and it mitigates the challenges of dynamical conditions and high power consumptions by using simple, low cost and low power coils. The channel conditions depend on the permeability of the communication medium and a uniform channel is created in air, seawater and most types of soil and rock due to almost the same permeability. The MI transmitter and receiver are modeled as the primary coil and secondary coil of a transformer. Multiple factors are considered in the analysis, including the soil properties, coil size, the number of turns in the coil loop, coil resistance, operating frequency. The analysis shows that the ordinary MI systems have larger transmission range but lower bandwidth than the EM wave systems. However, neither the ordinary MI system nor the EM wave system is able to provide enough communication range for WUSNs applications [3], [4].

Magnetic induction (MI) is a promising alternative physical layer technique for WUSNs in deep burial depth. It can address the problems on the dynamic channel condition and the large antenna size of the EM wave techniques. The underground medium such as soil and water cause slight variation in the attenuation rate of magnetic fields from that of air, since the magnetic permeability’s of each of these materials are similar. This fact guarantees that the MI channel conditions remain constant for a certain path in different times. Moreover,in the MI communication, the transmission and reception are accomplished with the use of a small size coil of wire. In addition, since the radiation resistance of coil is much smaller than electric dipole, very small portion of energy is radiated to the far field by the coil. Hence, the multi-path fading is not an issue for MI communication. However, MI is generally unfavorable for terrestrial wireless communication. As the transmission distance increases, magnetic field strength falls off much faster than the EM waves in terrestrial environments. In EM waves as the distance increases it is inversely proportional the distance, whereas for MI communication it is inversely proportional to the cube of the distance. Thus it is not suitable for terrestrial communication [5].

## II.MAGNETIC INDUCTION COMMUNICATION

### 2.1 System Modelling:

. Suppose the signal in the transmitter coil is a sinusoidal current, this current can induce another sinusoidal current in the receiver and accomplish the communication. The NFMIC link budget uses the age old principle of a transformer and hence there will be a primary which is referred to a transmitter and a secondary which is referred to a receiver. The block diagram below shows how an RLC circuit acts as an antenna for communication.

The block diagram shown in Fig.1 is for a point to point communication which is suitable for short distances and can be achieved with a simple RLC series network. Therefore, the MI transmitter and receiver can be modeled as the primary coil and the secondary coil of a transformer, respectively, as shown in the second row in Fig.1, where M is the mutual induction of the transmitter coil and receiver coil; Us is the voltage of the transmitter’s battery; $L_t$ and $L_r$are the self-inductions; $R_t$and $R_r$ are the resistances of the coil; $a_t$ and $a_r$ are the radius of the transmitter and receiver coils; r is the communication range between the receiver and transmitter; Zt and Zr  are the total impedence of the transmitter and receiver; Um is the total voltage(signal) transferred from transmitter to receiver.

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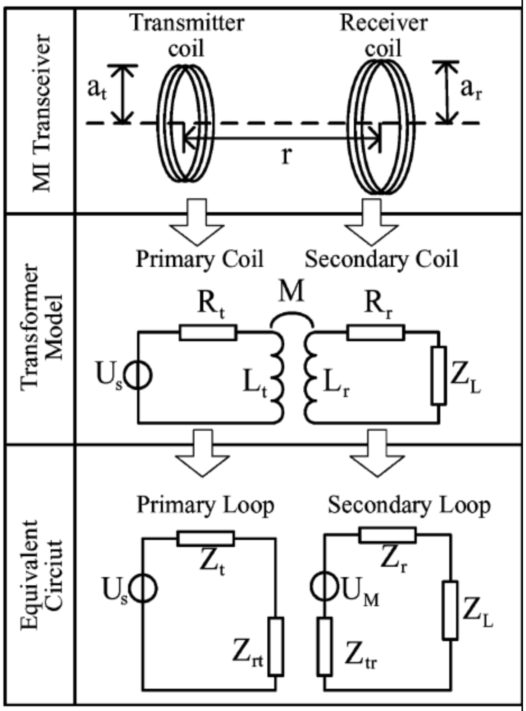


Fig. 1 MI communication channel model

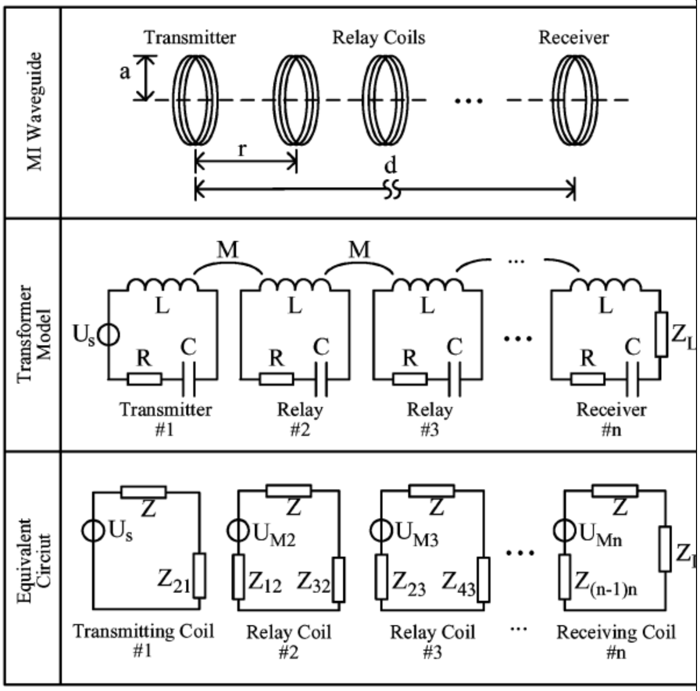


Fig.2 MI waveguide communication channel model.

According to the transmission line principle, the reflections take place unless the line is terminated by its matched impedance. In the equivalent circuit shown in Fig. 1, to maximize the receiving end power, the load impedance is designed to be equal to the complex conjugate of the output impedance of the secondary loop.

M is the mutual inductance between the coils, which has been derived using stokes theorem [6]. Where, $N_t$and $N_r$ are the number of turns of the transmitter coil and receiving coil, respectively;µ is the permeability of the transmission medium and it has to be kept in mind that we are dealing in underwater and underground media and has to be multiplied with the permeability constants respectively.

$$M = \frac{N_r \oint_{lr} A \, . dl_r}{dI} \cong \mu\pi \, N_t N_r \frac{a_t^2 \, a_r^2}{2r^3} \quad (1)$$

In the Fig. 2 it can be seen that to increase the distance of transmission, relay coils can be used. These relay coils act a “hop” that is, the signal can hop on to the relay 1 then hop to relay 2 and so on. The main advantage of this procedure is that the transmission distance is increased without using much power and considerable signal loss, this can be reduced by using an appropriate frequency and a waveguide technique.

**2.2 Path Loss:**

For wireless communication using EM waves, since the radiation power is the major consumption of the EM wave transmitter, the transmitting power ($P_t$) of the EM wave system is a constant and not influenced by the position of the receiver, i.e. for EM waves, $P_r$ is a function of distance r. Hence the path loss is measured by the ratio of the power received to the radiation power. The path loss $L_{EM}$ of the EM wave propagation in soil medium is given by [3]

$$L_{EM}(r) = -10\lg \frac{P_r(r)}{P_t} = 6.4 + 20\lg r + 20\lg\beta + 8.69\alpha r \qquad (2)$$

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Where the transmission distance is given in meters; the attenuation constant is in 1/m and the phase shifting constant is in radian/m. The values depend on the dielectric properties of soil, and is derived using the Peplinski principle [7].
Unlike the EM wave transmitter, the radiation power of the MI communication system can be neglected since the radiation resistance is very small. The induced power consumed at the MI receiver is the major power consumption, since the MI communication is achieved by coupling in the non-propagating near field. The transmitting power of the MI system consists of the induced power consumed at the MI receiver and the power consumed in the coil resistance. If the coil resistance is small, the ratio of the received power to the transmitting power will be close to 1 since the receiving power and transmission power decrease simultaneously as the transmission distance increases. The path loss $L_{MI}$ of the MI communication system can be simplified as

$$L_{MI}(r) = -10\lg\frac{P_r(r)}{P_t} \cong -10\lg\frac{N_r a_t^3 a_r^3}{4N_t r^6}$$

$$= 6.02 + 60\lg r + 10\lg\frac{N_t}{N_r a_t^3 a_r^3} \quad (3)$$

We compare (2) with (3) to evaluate the path loss of EM and MI wave systems in underground situations. In (2), there are two terms in the path loss that are determined by the distance, where the term (20lgr) is due to the space spread and the term (8.69αr) is due to the material absorption. The transmission medium has major influence in the path loss since it determines the propagation constants α and β. In (3), only one term (60lgr) is determined by the distance r, which is due to the spread of magnetic field. The transmission medium has no obvious effect on the MI path loss since we assume that the permeability of the medium is a constant.

## III.SIMULATION AND EXPERIMENTAL RESULTS

**Case1 (MI wave guide communication):**The software used for simulation is Advanced Design Systems by Agilent Networks. The operating frequency is set to 9MHz with two pair of relay coils, transmitter and receiver as shown in Fig. 3.The specification of the wire is 26AWG.It has to be noted that the simulation graphs peaks at 9 MHz, as this was set as the resonance frequency while performing the calculations. The peaks in both the graphs shown in Fig. 4(a) and 4(b) indicate that 85% of the signal is being transferred and also there is no noise. The concept of resonance – maximum transfer of signal and time varying magnetic field there is no loss of signal.

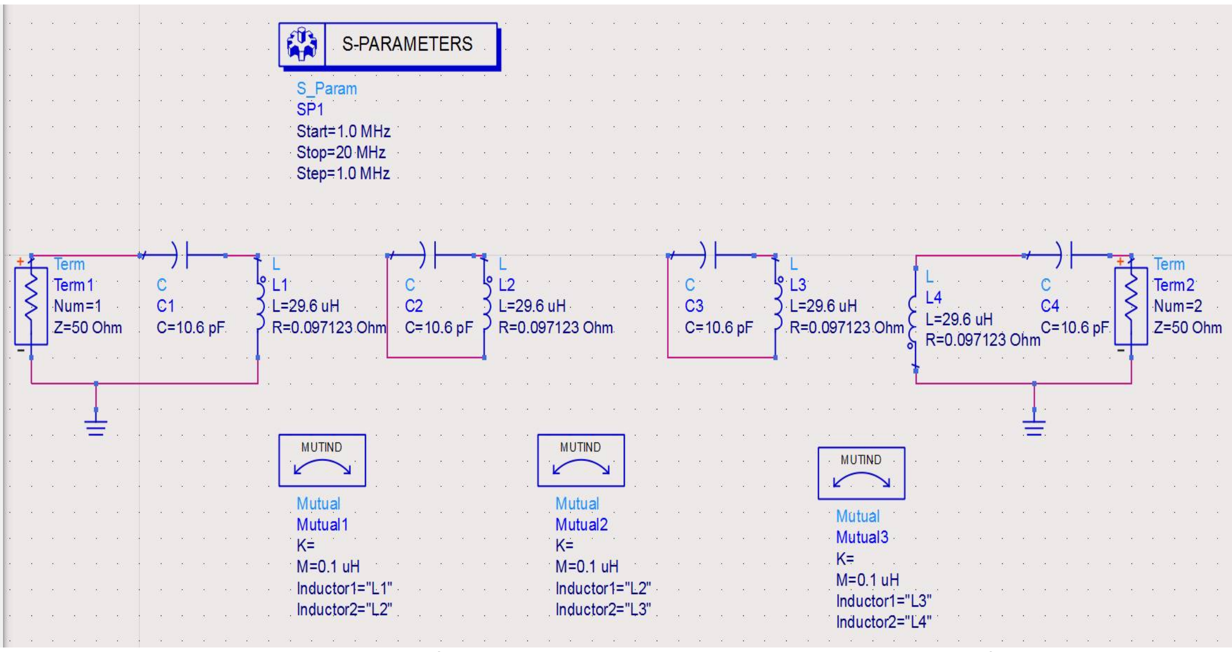


*Fig. 3Equivalent Circuit of MI waveguide communication system – simulated for 9MHz*

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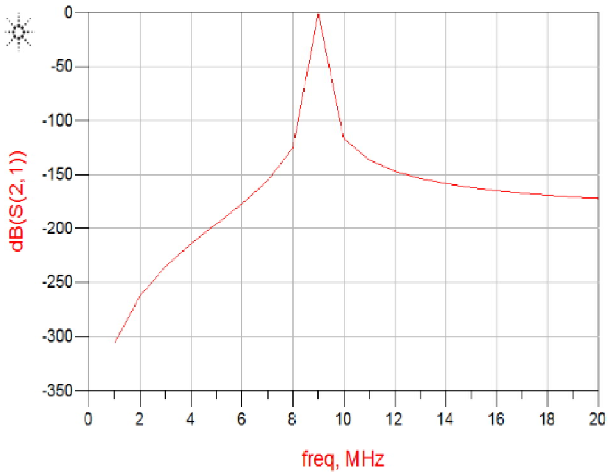


*Fig. 4(a) path loss v/s frequency at 9 MHz*

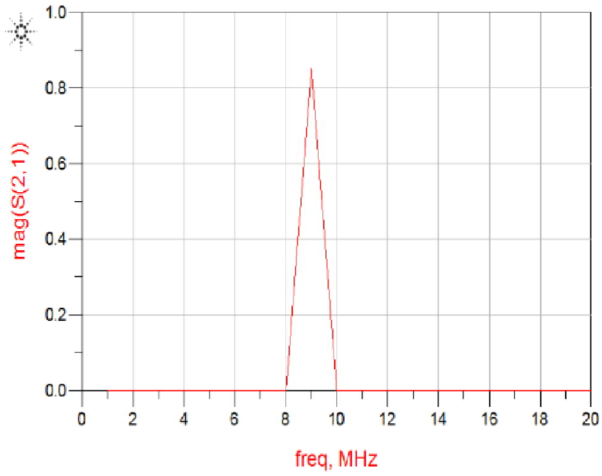


*Fig. 4(b) efficiency v/s frequency at 9MHz*

**Case2 (MI communication):** The operating frequency is set to 2MHz with transmitter and receiver as shown in Fig. 5.The simulation analysis of the transmission range distance and the amount of signal being transferred is studied. The resonant frequency was set to 2MHz. It can be seenfrom the Fig. 6(b), 7(b), 8(b) and 9(b)that the efficiency of the transmitted signal reduces as the distance between transmitter and receiver increases from 0.25m to 1m. It is observed that as the frequency reduced from 9MHz to 2MHz the efficiency of the system reduces.

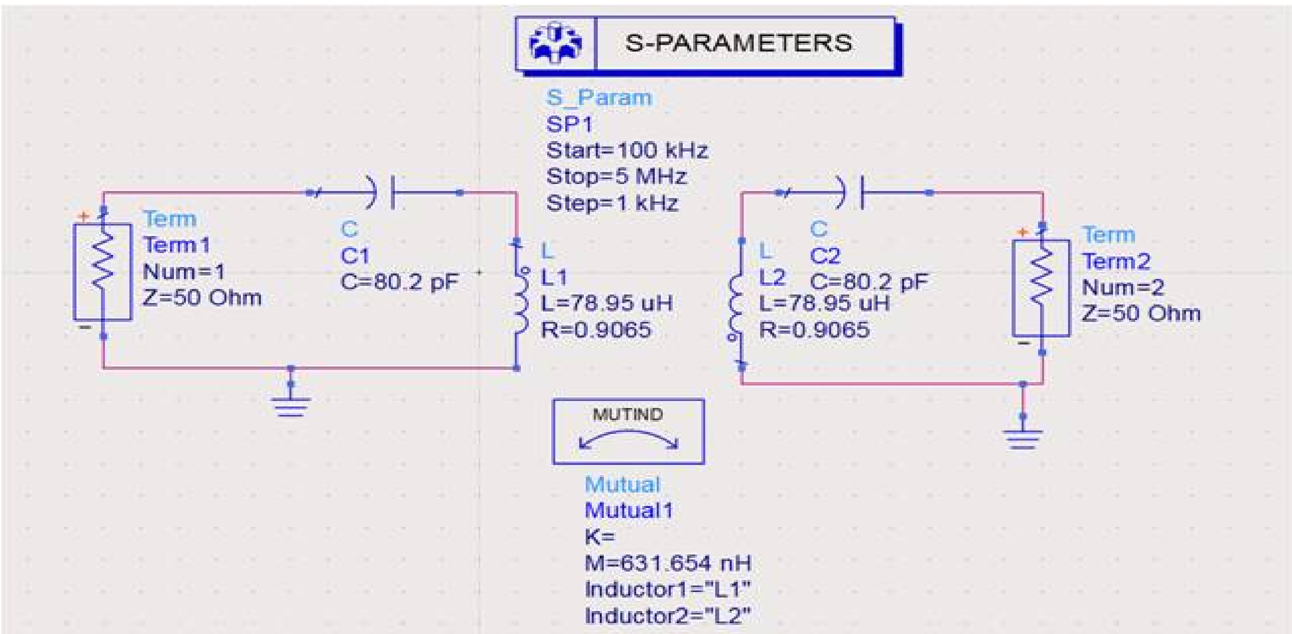


*Fig. 5 Equivalent Circuit of MI communication system- simulated for 2MHz*

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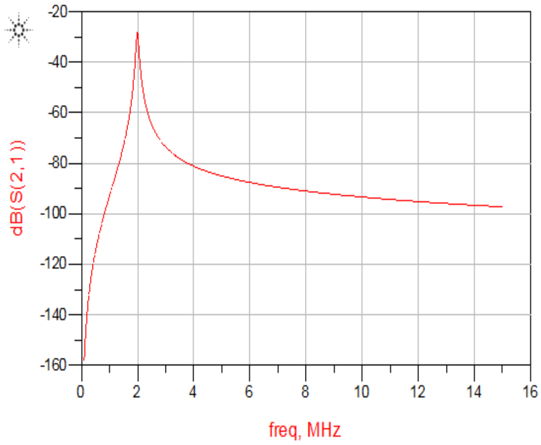


*Fig. 6(a) path loss v/s frequency for 2MHz and 1m*

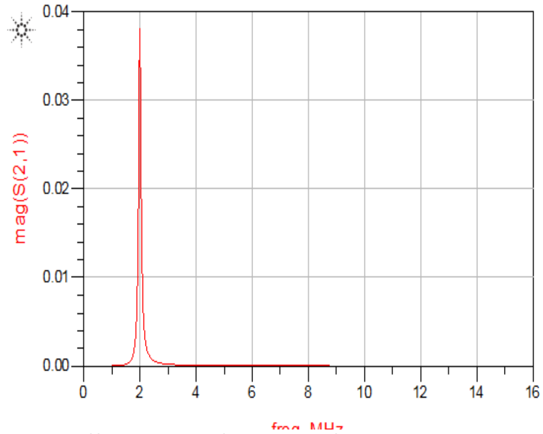


*Fig. 6(b) efficiency v/s frequency for 2MHz and 1m*

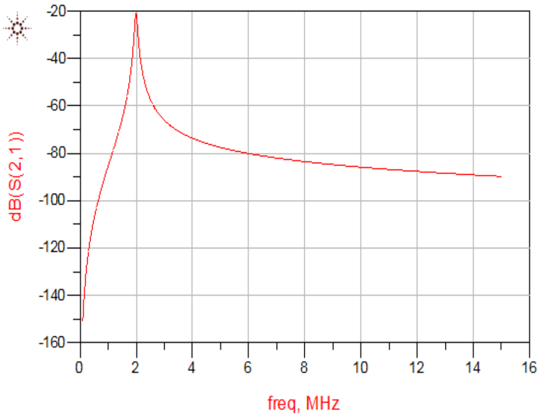


*Fig. 7(a) path loss v/s frequency for 2MHz and 0.75m*

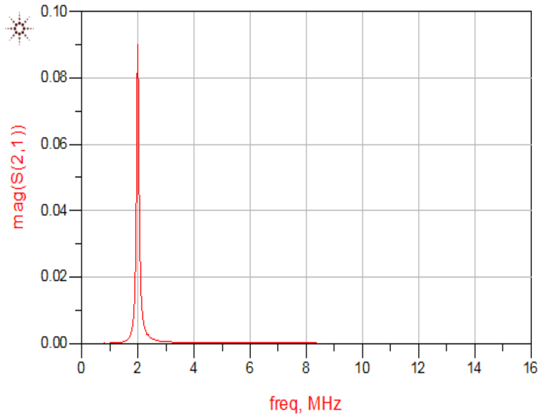


*Fig. 7(b) efficiency v/s frequency for 2MHz and 0.75m*

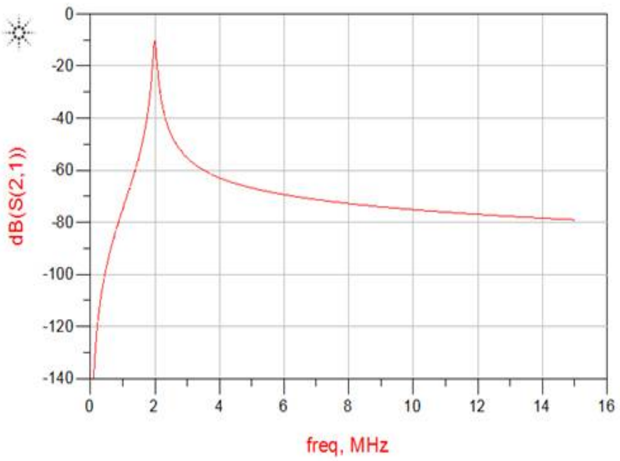


*Fig. 8(a) path loss v/s frequency for 2MHz and 0.5m*

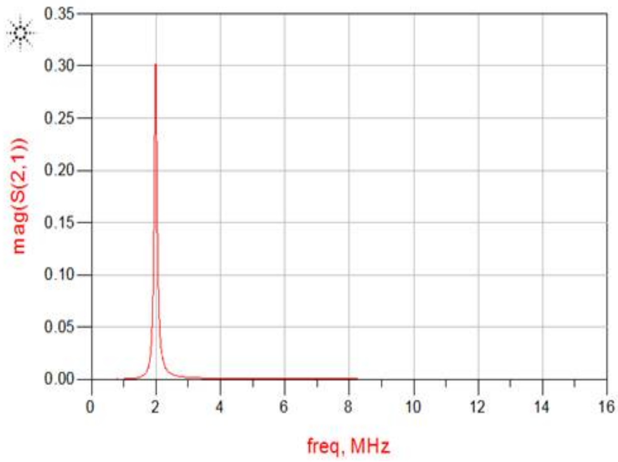


*Fig. 8(b) efficiency v/s frequency for 2MHz and 0.5m*

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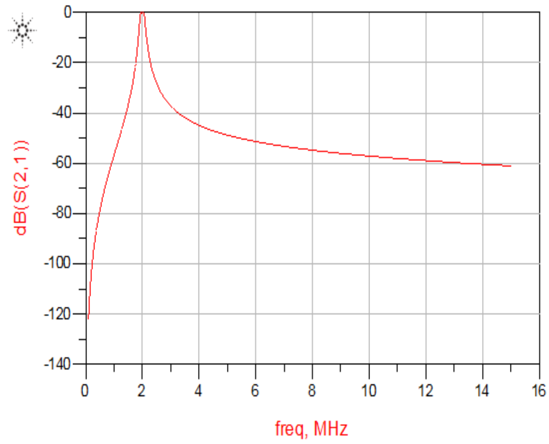


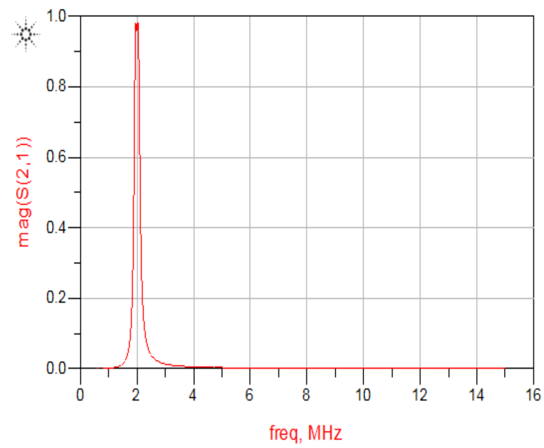


*Fig. 9(a) path loss v/s frequency for 2MHz and 0.25m*   *Fig. 9(b) efficiency v/s frequency for 2MHz and 0.25m*

## IV.CONCLUSION

The transmission range of MI communications can be extended by adopting the MI waveguide technique. The parameters of the coil antenna, including thesize,number of turns, as well as the lumpedand the distributed impedance, have significant influence on theMI communications. Therefore, to maximize the MI communication distance as well as the bandwidth, the optimal coil antenna parameters need to be designed by jointly considering the trade-off between the induced current and the absorption due to skin depth, the trade-off between the MI path loss and the antenna size, as well as the networking mechanisms are of excessive importance, which rely on an accurate energy consumption model of the whole system. The MI technique has constant channel condition because its path loss only depends on the permeability of the propagation medium, which remains the same if the medium isair, water and most kinds of soil and rock. However, the material absorption is the major part of the path loss of EM wave system, which may change a lot in different soil conditions. The MI waveguide technique can greatly reduce the path loss, which is attributed to the relay coils deployed between the transceivers. The relay distance is also larger than the maximum transmission range of the EM wave system. The transmission range of the MI waveguide system has increased dramatically compared with that of EM waves.

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