PERFORMANCE OF MAGNETIC INDUCTION METHOD AS CHANNEL MODELING TECHNIQUE IN UNDERWATER COMMUNICATION

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Abstract: **Under water communications draws the attention of researchers of different fields as this has many applications in the areas of sea diver communications and environment monitoring. The challenges that stop achieving a reliable communication in underwater are noise, limited bandwidth and power resources and harsh ambient conditions.**

As acoustic waves severely affected by ambient noise, multipath propagation and fading leads to large propagation delays which made the acoustic channel to be not a reliable one. In this paper Magnetic Induction (MI) method as a channel modelling technique is implemented and its performance measures are studied. MI channel can achieve low path loss and better Signal to Noise Ratio (SNR).

Index Terms - Underwater Channel modelling, MI, SNR, Path Loss

I. INTRODUCTION:

Underwater communication deals with the transmission of a signal between the transmitter and receiver in under water. It is like dealing with the free space communication [1]. The biggest challenge in this communication is dynamic nature of the channel [2]. To deal with these dynamic behaviours, three channel models are proposed in the literature. They are Acoustic, Electromagnetic and Magnetic induction methods. Even though acoustic communication can achieve long distance communication due to reflections in deep water and reflections in shallow water make the communication cumbersome. The low bandwidth and high bit error rate of the acoustic channel also hinders the communication. MI cannot be affected by multipath propagation and fading. Signal can be received at the receiver with low attenuation when compared to electromagnetic signal [3]. Hence, the motivation is to effectively model the channel using MI technique so that it can be used in the application of data transfer in underwater.

In this paper MI communication channel has been modelled and its performance measures are studied with respect to frequency and range. The results give us the operating frequency and range up to which an MI can give reliable communication. The paper is structured as follows. In section 2 we discuss the fundamental properties of MI. In section 3 underwater channel is modelled and performance measures are analysed. In section 4 evaluations are discussed. This paper is concluded in section 5.

II. FUNDAMENTAL PROPERTIES OF MI:

When a time varying current flows through a straight conductor (ex: thin wire), a magnetising force is developed. If the wire wounded into a coil then the magnetic field greatly intensified. This leads to producing a time varying magnetic field developed around it. If the magnetic field itself is varying with time, the flux may be affected by time varying magnetic field. Faraday's law states that changing magnetic flux causes an Electromotive Force (EMF) in the coil itself. If the current in the first coil is varied magnetic flux in the secondary coil also vary with time. The variation of magnetic flux in the secondary coil causes an EMF to be generated in the secondary coil. This phenomenon is due to mutual induction [4]. The figure 2.1 shows the basic structure of MI principle and its equivalent circuit whose details are described in the following sections.

Figure 2.1: Schematic for Magnetic Induction

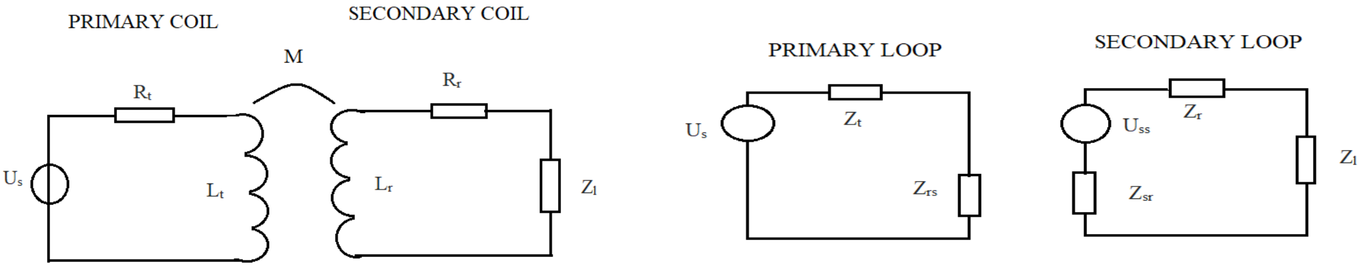


Figure 2.1.(a): Transformer Model

Figure 2.1.(b): Equivalent Circuit

III. CHANNEL MODELLING USING MI TECHNIQUE:

In the fundamentals of MI it is discussed how a signal can be generated and propagated. So, with the help of this technique a setup for a communication channel is possible. The figure 3.1defines the basic function of Magnetic Induction method as transceiver where a_t is radius of the transmitter coil and a_r is radius of the receiver coil and r is the distance between transmitter and receiver. The variations in the parameters are dependent on the operating frequency. The signal generated at the transmitter will transmit through the channel to the receiver through mutual induction principle.

Figure 3.1: MI Transceiver

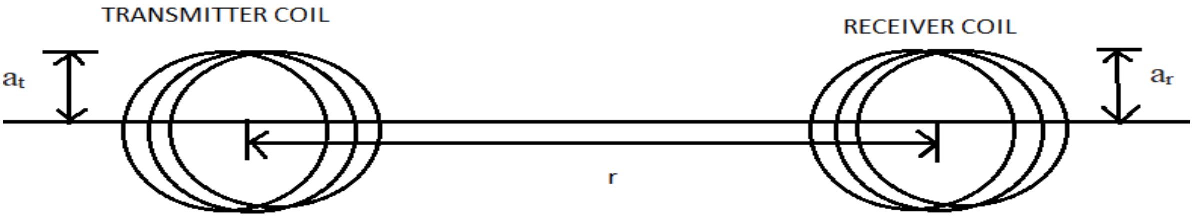
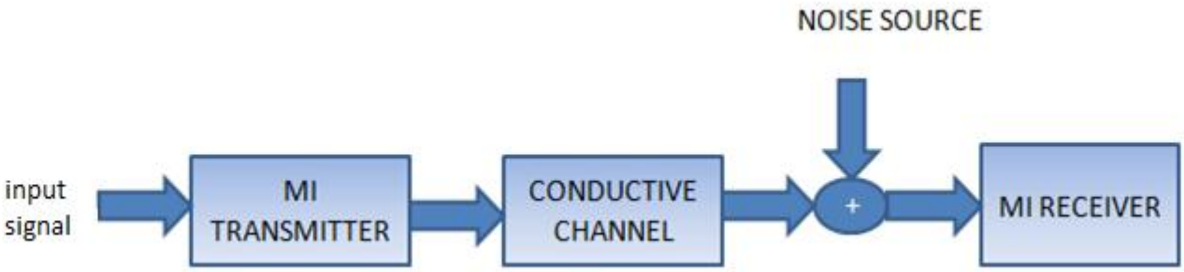


Figure 3.2: Magneto Inductive Channel structure



The block diagram shown in figure 3.2 contains the function of Magnetic Induction channel in detail. The signal generated by MI mechanism will transmit through the channel which is associated by mutual induction. As we know that the noise will be added to the transmitted signal in the channel which degrades the strength of the signal. So at the receiver end, signal will have low power due to the addition of noise in the channel.

In the literature it is found that MI systems in underwater can operate over a very short range. So in this paper, a near field magnetic induction medium is modelled for short range wireless communication which is done by a non propagating magnetic field between devices.

Table 3.1: Parameters table:

Parameter	Value
Operating Frequency (f)	500Hz
Radius of Transmitter Coil (at)	1.5m
Radius of Receiver Coil (ar)	1.5m
No. of turns in Transmitter and Receiver(N)	1000
Electrical resistivity of copper (ρ)	0.01724ohm-mm^2/m
Diameter of copper wire(d)	1.45mm(AWG 15)
Cross-sectional area of copper wire of 1.45mm (A)	1.65mm^2

The parameters considered for analysis in table 3.1 are from the literature [3]. Based on the above parameters coil resistances, impedances, load impedance are calculated. After that performance measures are studied. Operating frequency also influences the performance measure which is given by

$$\omega = 2\Pi f \qquad (3.1)$$

where ω is angular frequency of a transmitting signal

Skin depth is another most important factor which influences the performance measures, which is given by

$$\alpha = \sqrt{\pi f \mu \sigma} \qquad (3.2)$$

where α represents attenuation which is inverse of skin depth and μ represents permeability and σ represents electrical conductivity of the transmitting medium.

The coil resistances and the inductances based on the parameters are given by

$$Rt=(N * 2\Pi * at * \rho)/A \tag{3.3}$$

$$Rr=(N * 2\Pi * ar * \rho)/A \tag{3.4}$$

$$Lt=(\mu * N^2 * a)/l \tag{3.5}$$

$$Lr=(\mu * N^2 * a)/l \tag{3.6}$$

R_t and R_r represent coil resistances at the transmitter and receiver
L_t and L_r represent self inductances at the transmitter and receiver
Where l is the length of the solenoid

Zt is the transmitter impedance

$$Zt = Rt + j(\omega * Lt) \tag{3.7}$$

Zr is the receiver impedance

$$Zr = Rr + j(\omega * Lr) \tag{3.8}$$

$$m = (\mathrm{\mu} * \Pi * \mathrm{N} * \mathrm{N} * \mathrm{at}^2 * \mathrm{ar}^2)\ /(2 * \sqrt{(ar^2 +}\, r^2)\text{^}3) \tag{3.9}$$

where m is the mutual induction between the transmitter and receiver

$$Ztr = j(\omega * m) \tag{3.10}$$

where Ztr represents the impedance between transmitter and receiver which is due to mutual induction

$$Rl=Rr + \frac{(\omega * m)^2 * Rt}{Rt^2 + (\omega * Lt)^2} \tag{3.11}$$

where Rl is the load resistance

$$Xl = \frac{\omega^3 * m^2 * Lt}{Rt^2 + (\omega * Lt)^2} - (\omega * Lr) \tag{3.12}$$

where Xl is the load reactance

$$Zl = Rl + jXl \tag{3.13}$$

where Zl is the load impedance which is the combination of resistance and the reactance.
With the help of above equations an MI system in under water is developed and in the following section performance measures are analysed.

IV. ANALYSIS OF PERFORMANCE MEASURES:

In this paper path loss and signal to noise ratio (SNR) are taken as performance measures and system is analysed.
Transmitted power 'Pt' can be calculated as follows

$$Pt = Re\left(Zt - \left(\frac{(Ztr)^2}{Zl + Zr}\right)\right) * (I)^2 \tag{4.1}$$

4.1. Path loss:

It gives the information of how much the signal is lost during the transmission of the signal. Path loss is given by

$$PLf = (-10) * log\left(\left(Rl * (\omega .* m)\right)^2 / ((Rt * \left((Rl + Rr)^2 + \left(xl + (\omega * Lr)\right)^2\right) \tag{4.1.1}$$

where PLf represents the path loss in fresh water

$$PLr = 8.69 * \alpha * r \tag{4.1.2}$$

where PLr is additional path loss that has occurred due to the attenuation in the medium

$$PLs = PLf + PLr \tag{4.1.3}$$

where PLs is the path loss that has occurred in the sea water

4.2. Signal to Noise Ratio (SNR):

Signal to Noise ratio gives the information of the signal strength when it is transmitted under the influence of noise.
SNR can be calculated as

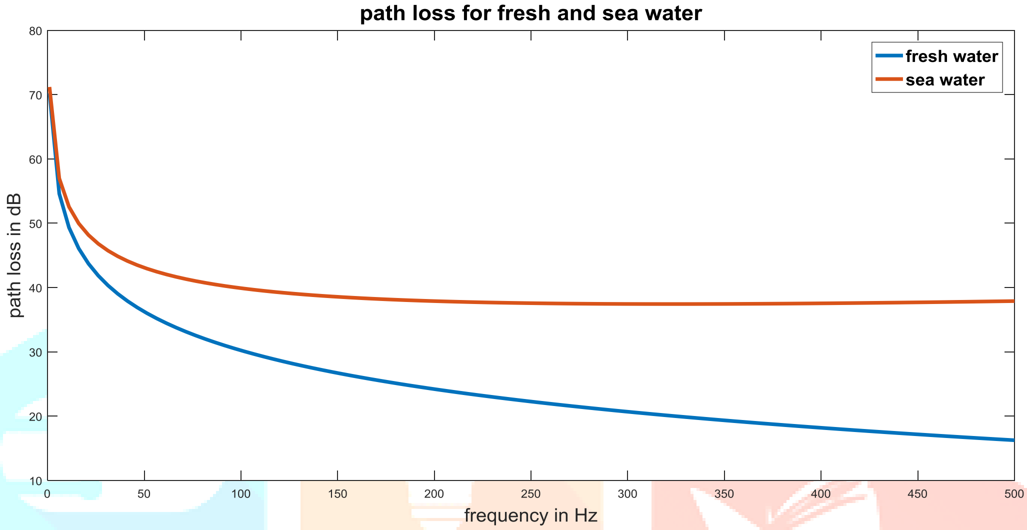
$$SNR = Pt - PL - N \tag{4.2.1}$$

where SNR (fresh water) is the signal to noise ratio in the fresh water, N is noise power and *PL* (fresh water) is the path loss in the transmission medium. All these are calculated in dBm for mathematical simplicity and for easy analysis. It is observed that the two performance measures are influenced by skin depth.

V. RESULTS AND DISCUSSIONS:

In this section performance measures are studied as a function of distance and operating frequency whose relation is observed in the below results.

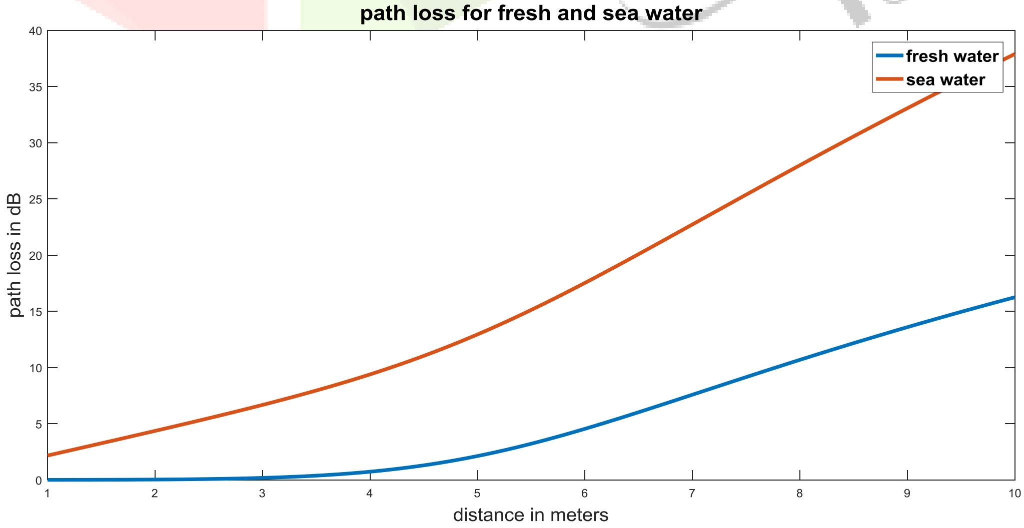
Figure 5.1: Path loss as a function of frequency



This plot is taken under the condition that frequency should be varied linearly from 0 to 500Hz with number of turns and the range kept fixed at 1000 and 5m respectively.

It is observed from the plot that path loss decreases as frequency increases gradually. In sea water due to the path loss which is occurred by the attenuation, total path loss has significant level when it compared to fresh water.

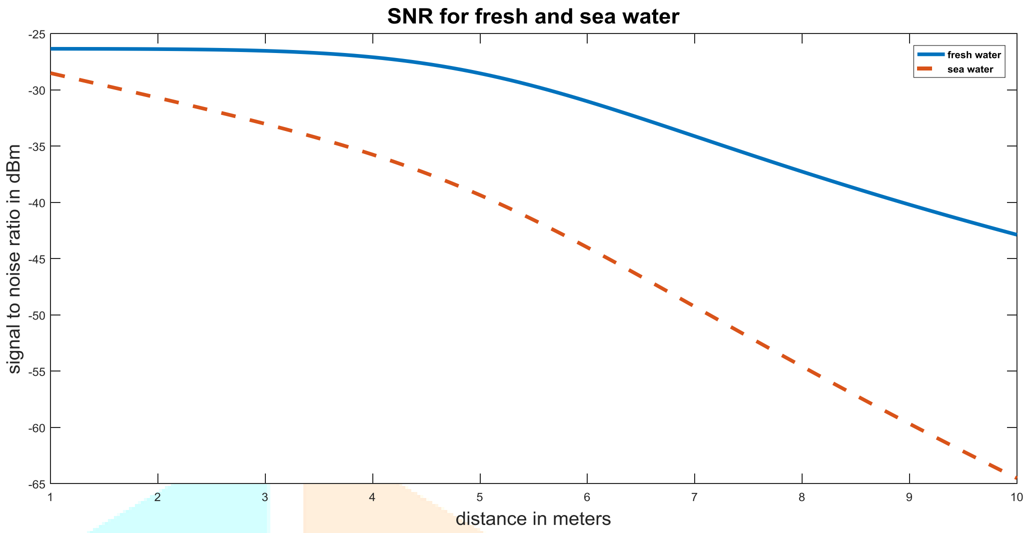
Figure 5.2: Path loss as a function of Distance



In figure 5.2 distance is varied linearly from 1 to 10m with No. of turns and operating frequency kept fixed at 1000 and 500Hz. Radius of the coil at the transmitter and receiver is kept fixed at 1.5m.

It is observed that as the distance between the transmitter and receiver increases the path loss increases due to the attenuation which is directly proportional to the square root of the distance. This factor contributes more path loss in the sea water than in the fresh water.

Figure 5.3: SNR as a function of Distance



In figure 5.3 distance is varied linearly from 1 to 10m with No. of turns and operating frequency kept fixed as above and the following observations are made.

It is observed that SNR is remains same for certain distance but when it crosses the distance then SNR decreases gradually as distance increases. When it comes to the comparison between fresh and sea water SNR is less for sea water when it compares to the fresh water.

Table 5.1: SNR and path loss as a function of operating frequency

Operating Frequency	SNR (in dBm for sea water)	Path Loss in Fresh Water (in dB)	Path Loss in Sea Water (in dB)
20MHz	-2.18*10^3	-1.05*10^-4	2.16*10^3
10MHz	-1.55*10^3	-1.05*10^-4	1.53*10^3
1MHz	-508.73	-1.04*10^-4	483.88
500KHz	-367.00	-1.02*10^-4	342.16
1KHz	-40.78	0.6132	15.91
500Hz	-37.85	2.12	12.94
10Hz	-29.27	2.82	2.95
50Hz	-26.56	0.14	0.21

From the table 5.1 as frequency varies path loss increases as well as SNR also increase. SNR in the sea water is directly influenced by operating frequency and path loss. The sea water is also influenced by the attenuation factor which is dependent on the frequency.

Table 5.2: Path loss and SNR as a function of distance

Range (in m)	SNR (in dBm for sea water)	Path Loss in Fresh Water (in dB)	Path Loss in Sea Water (in dB)
5	-37.85	2.12	12.94
10	-63.01	16.24	37.88
15	-84.24	26.64	59.10
20	-102.51	34.08	77.36
25	-119.11	39.87	93.97
30	-134.67	44.61	109.53
35	-149.50	48.61	124.35
40	-163.79	52.02	138.65
45	-177.68	55.15	152.53
50	-191.24	57.90	166.10

From the table 5.2 as distance varied from 5 to 50m there is a gradually increasing path loss and gradual decreasing of SNR as distance directly influences attenuation factor which causes this.

VI. CONCLUSION:

If MI system is implemented in fresh water and sea water, it gives better performance in fresh water compared to see water. It is also observed that when the operating frequency is varied, path loss increases. Compared to the sea water, fresh water has given low path loss. This is because the skin depth in sea water is more.
When range (distance between the transmitter and receiver) is varied path loss increases gradually which is due to the weakening of the magnetic field. Noise has shown its effect on the amplitude of the time varying signal. When SNR is varied as a function of range it decreases as range increases, it is observed that SNR can be stabilised for limited range. This shows that MI system can be used for low range communication applications. An alternate way to enhance the performance of this MI system for longer distance applications is to use repeaters between the transmitter and receiver.

In this paper, it is assumed that transmitter and receiver are stable, so Doppler effect is not included in the performance analysis. Doppler effect can also be considered by moving either transmitter or receiver as a form of future scope. For improvement of system performance Orthogonal Frequency Division Multiplexing (OFDM) can also be introduced.

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