



# Underground Radio Propagation on Frequency Band 97 Mhz – 130 Mhz

S Suherman\*, Ali Hanafiah Rambe, Agustiar Widodo Tanjung

Electrical Engineering Department, Universitas Sumatera Utara, Medan, Indonesia

\*Corresponding author E-mail: suherman@usu.ac.id

## Abstract

Radio communications do not work only in the air and underwater, but also underground. Some applications such as mining and earthquake detection require underground radio devices. This paper reports an assessment of underground radio characteristics for frequency band 97 MHz to 130 MHz. The assessments were performed through an experimental propagation measurement and a mathematical prediction. Both assessments then are compared by using the normalized graph to predict propagation characteristics so that correct link budget for future application can be assisted. The mathematic analysis and measurement results still produce huge errors; achieving 50.33% for frequency 130.762 MHz, 17.58% for 109.818 MHz and 13.38% for 97.335 MHz. Error can be minimized when the ground permittivity is more precise

**Keywords:** Underground radio propagation, Friis radio model, Correction factor

## 1. Introduction

Underground radio propagation experiences dispersion by multi-layer ground, power absorption, and scattering [1], [2]. Complex structure of the ground exerts problem for radio signal to propagate. Deep attenuation occurs that degrade signal significantly. The working frequency should be examined carefully for particularly type of ground path so that the underground radio can work.

A very high frequency is suitable for underground propagation as its signal can penetrate deep underground, and requires low transmitting power. This frequency has been used for mining worker [3], [4]. The VHF signal is good deliver electromagnetic power, but is sensitive to the ground characteristics. Therefore, in order to get maximum results, an assessment of the underground radio system should be performed in area where the radio is applied. In order to understand the underground radio characteristics, this paper describes an example of underground propagation measurement and mathematical modeling, where impact of ground parameters will be presented.

In order to understand the basic concept, the mathematical analysis of the underground signal propagation is outlined in the following sub sections.

### A. Underground signal propagation

Underground signal propagation experiences attenuation, multi-path spreading as each area passing through by the signal has different ground parameters, fading and signal scattering. Beside signal propagates through the ground, some signals may pass through the air, reflect from the air to the ground and pass to the underground. This results two paths of radio signal, direct signal and reflected signal. Direct signal is the main components, but reflected signal sometimes is significant. In order to avoid reflected signal, transmitter antenna should be penetrated in to the ground.

### B. Multi-path fading

When direct signal is the only considered one, the complex structure of the ground produce an ideal wave surface that causes vertical reflection and refraction. It is even worse if the plantation roots and mud with heterogenic characteristics presents in signal path. Then, *multi-path fading* occurs. Multi-path fading in the air is caused by random diffraction of the air. Underground fading behaves similarly where amplitude and phase are time invariant random. The multi-path follows Rayleigh or log-normal distribution probability.

### C. Model for predicting underground propagation

Underground signal propagation requires approximation to model. The original losses calculated by using Friis equation. The received signal is the transmitted signal gained by the transmitter and receiver antennas, but decreases to path loss [5]:

$$P_r(\text{dBm}) = P_t(\text{dBm}) + G_t(\text{dB}) + G_r(\text{dB}) - L_0(\text{dB}) \quad (1)$$

This path loss can be formulized to as Equation 2, where losses increase to distance and frequency [5]:

$$L_0(\text{dB}) = 32,4 + 20 \log(d) + 20 \log(f) \quad (2)$$

Where  $d$  is distance between transmitter and receiver in km,  $f$  is the operating frequency in MHz To propagate underground, correction factor should be added to Friis equation by considering the effect of the ground. The received power level is then determined by:

$$P_r = P_t + G_t + G_r - L_p \quad (3)$$

The corrected path loss  $L_p$  is  $L_0 + L_s$ , where  $L_s$  be the ground propagation.  $L_s$  is calculated by considering propagation difference between air and ground. Some aspects to be considered:

1. Signal speed and wavelength

2. Amplitude
3. Phase speed which causes scattering and distortion.

The path loss increment caused by ground propagation consists of space loss and attenuation loss caused by wavelength differences between air and ground:

$$L_s = L_\alpha + L_\beta \tag{4}$$

$$L_\alpha = 8,69\alpha d \tag{5}$$

$$L_\beta = 154 - 20 \log(f)(\text{Hz}) + 20\log(\beta) \tag{6}$$

The attenuation constant  $\alpha$  (1/m) and phase shift  $\beta$  (radian/m) depends on dielectric parameter which is approximated using Pep-linski [5]:

$$\epsilon = \epsilon' - j \epsilon'' \tag{7}$$

$$\epsilon' = 1.15 \left[ 1 + \frac{\rho_b}{\rho_s} (\epsilon_s^{\alpha'}) + m_v^{\beta'} \epsilon_{fw}^{\alpha'} - mv \right]^{1/\alpha'} \tag{8}$$

$$\epsilon'' = \left[ m_v^{\beta''} \epsilon_{fw}^{\alpha''} \right]^{1/\alpha'} \tag{9}$$

where  $\epsilon_m$  is dielectric constant,  $m_v$  is volumetric water content (VWC),  $\rho_b$  is density,  $\rho_s = 2.66\text{g/cm}^3$  is solid ground parameter,  $\alpha' = 0.65$  is empiric data [5]:

$$\beta' = 1.2748 - 0.519S - 0.152C \tag{10}$$

$$\beta'' = 1.33797 - 0.603S - 0.166C \tag{11}$$

$\alpha$  and  $\beta$  can be expressed by [5]:

$$\alpha = \omega \sqrt{\frac{\mu \epsilon'}{2} \left[ \sqrt{1 + \left(\frac{\epsilon''}{\epsilon'}\right)^2} - 1 \right]} \tag{12}$$

$$\beta = \omega \sqrt{\frac{\mu \epsilon'}{2} \left[ \sqrt{1 + \left(\frac{\epsilon''}{\epsilon'}\right)^2} + 1 \right]} \tag{13}$$

where  $\omega = 2\pi f$ ,  $\mu$  is magnetic permeability and  $\epsilon'$  and  $\epsilon''$  are real and imaginers of permittivity.

#### D. Ground Permeability

Permeability is the characteristics reflecting how easy a material is affected by a magnetic material. This characteristic influence how signal propagate. Most ground permeability is assumed as free space:  $\mu = \mu_0$  and  $\mu_0 = 1$  [6].

#### E. Regression Analysis

Regression analysis is declared as the correlation between two mathematical equations which means each variable relates to other variables. The regressions analysis is used in this paper to describe how close the experimental research and modeling.

## 2. Research Method

In order to measure underground radio propagation characteristics on 97 MHz to 130 MHz, some equipment are employed. A bipolar junction transistor signal generator is assembled using circuit diagram shown in Figure 1 [7].

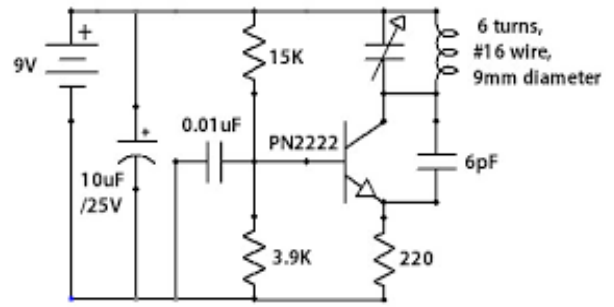


Fig.1: Signal generator

The tuned circuit consists of C1 and L1 is determined to generate sinusoidal signal from 97 MHz to 130 MHz. By voltage divider feeding the Q1, collector current flows through LC. The Q1 amplifies signal within range of the intended frequencies, so that collector current falls to these frequencies. This signal is feed back to basis through emitter, and amplified until at a stable level. Finally the desired frequency signal is fed to a wire antenna.

A rectifier with two-diodes supplies the voltage for the transmitter, providing 6 volt; 7.5 volt and 9 volt. The circuit is shown in Figure 2. A spectrum analyzer is employed to receive the transmitted signal as shown in Figure 3



Fig.2: VHF Signal generator and power supply



Fig.3: Vector network analyzer

The  $1/8 \lambda$  wire monopole antennas are connected to both transistor transmitter and the spectrum[8]. The antennas are buried under the ground following the measurement map as in Figure 4.

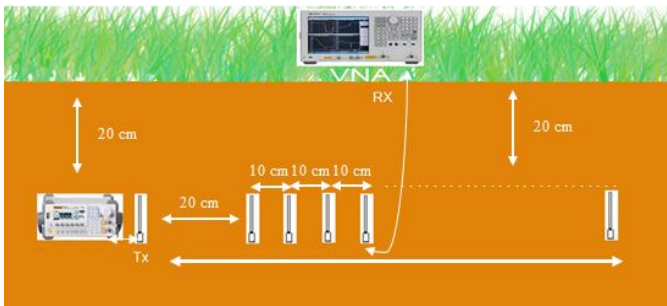


Fig. 4: Measurement plan

Ground appearance is shown in Figure 5 and location is in Medan city as plotted in the map in Figure 6.



Fig. 5: The ground sample

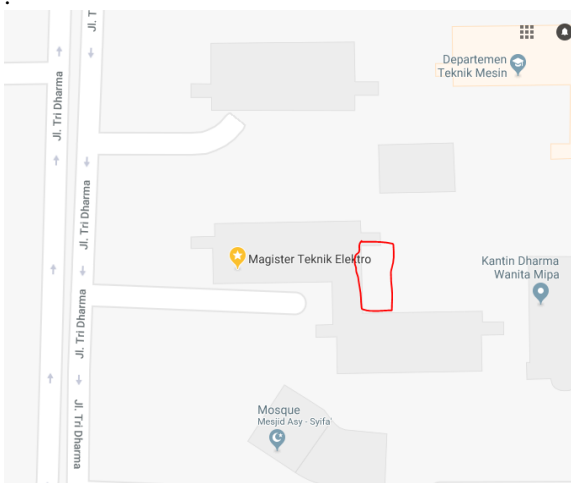


Fig. 6: The measurement location

Permittivity parameters are taken from [9] as described in Table 1 [9].

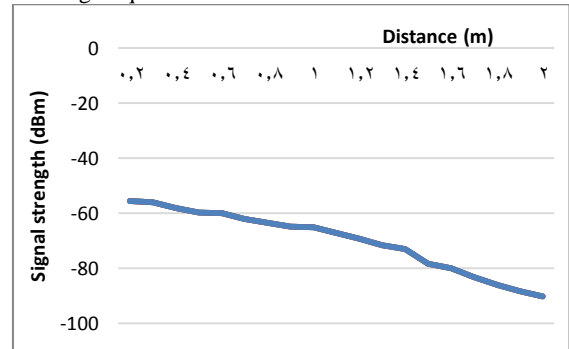
Table.1: Dielectric parameters

Type	$\epsilon'$	$\epsilon''$
Ground with mud and stone	6.53	1.88

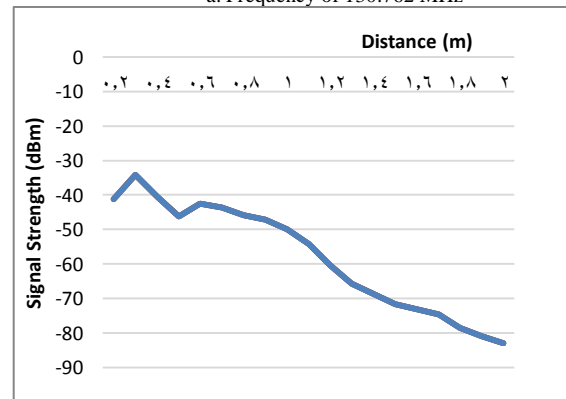
### 3. Measurement and Analysis Results

#### 3.1 Measurement Results

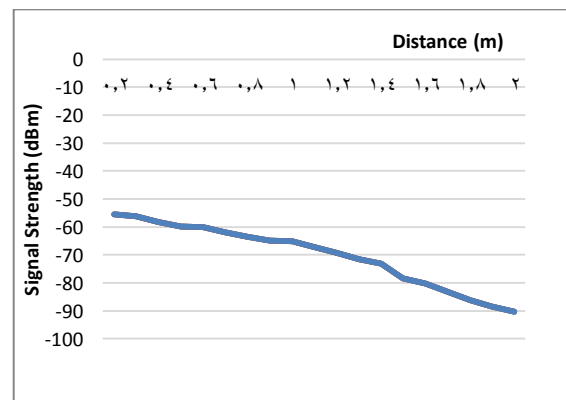
By reading values displayed in receiver, the received signal strength for various distances can be plotted. Figure 7 plotted signal strength received for transmitting frequencies of 130.762 MHz, 109.818 MHz, and 97.335 MHz. These sample frequencies are representing frequencies on band 97 – 130 MHz.



a. Frequency of 130.762 MHz



b. Frequency of 109.818 MHz

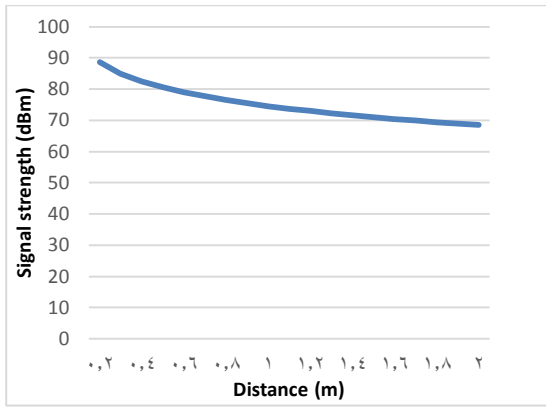


c. Frequency of 97.335 MHz

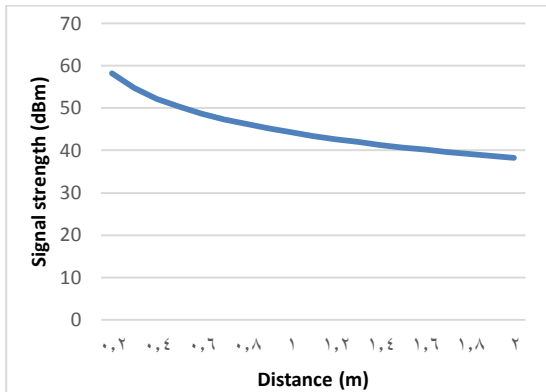
Fig.7: Measurement results

#### 3.2 Modelling Results

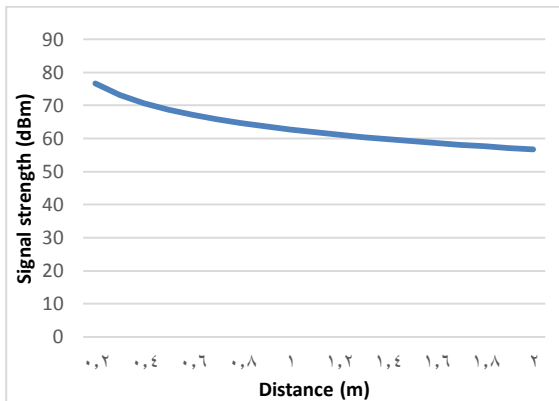
Mathematical analysis on the plotted experiment results received signal level model. As it was difficult to measure actual transmit power, the signal level on model is initially ignored. The focus is on attenuation pattern. The models are plotted in Figure 8.



a. Frequency of 130.762 MHz

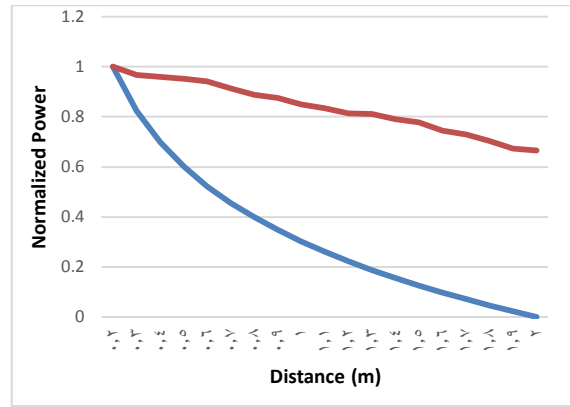


b. Frequency of 109.818 MHz

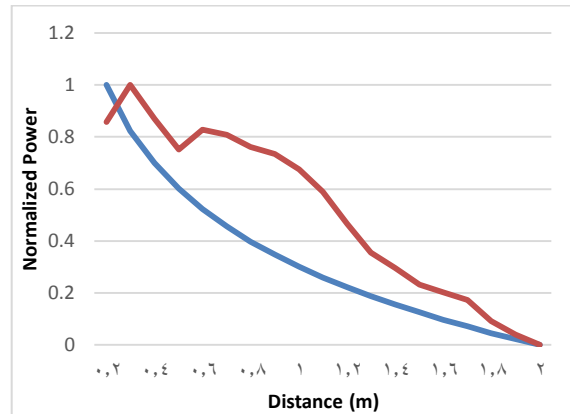


c. Frequency of 97.335 MHz

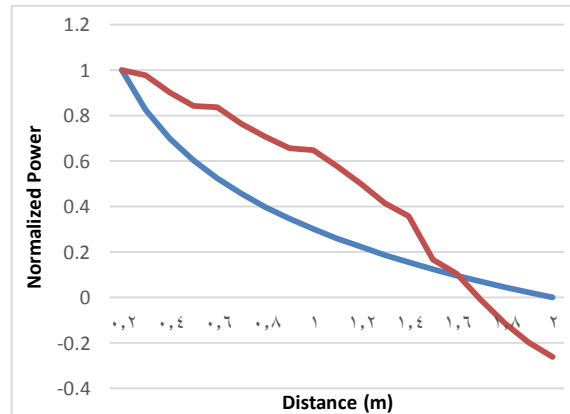
Fig. 8: Modelling results



a. Frequency of 130.762 MHz



b. Frequency of 109.818 MHz

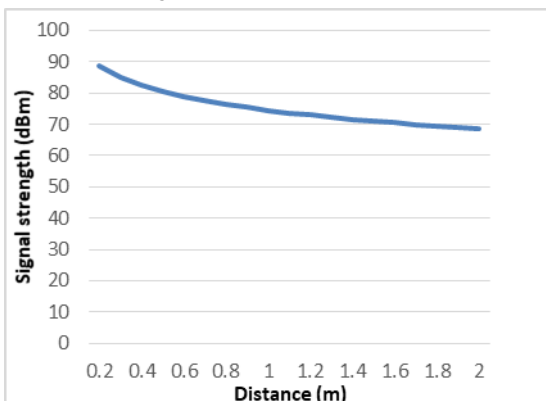


c. Frequency of 97.335 MHz

Fig. 9: Modelling results

### 3.3 Normalized Analysis

In order to get more precise comparison, normalized analysis is performed. Figure 9 shows the normalized comparison. In average, error achieves more than 50% for frequency 130 MHz. Frequency 109.818 MHz gets 17.58% error and 97.335 MHz has 13.38%.



There are significant errors between measurement and analysis patterns. These high errors may be caused by many factors, one of them the permittivity values of the ground which is not accurate. By adjusting one of the permittivity values of  $\epsilon'$ , average error moves lower as shown in Figure 10.

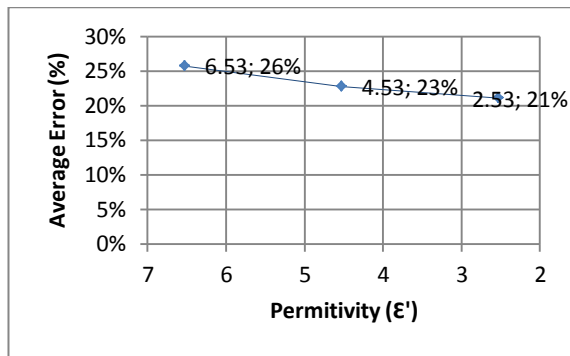


Fig. 10: Error changes as  $\epsilon'$  changes

## 4. Conclusion

This paper has examined underground radio propagation by means of measurement and mathematical analysis. Experiment was conducted from frequency 97 MHz to 130 MHz. The results show that ground attenuates radio signal. The mathematical model employed to predict signal level experience high errors. The highest is 50.33% for frequency 130.762 MHz, decreasing as frequency lowers: 17.58% for 109.818 MHz and 13.38% for 97.335 MHz.

High errors may be caused the non-precise equipment or in accurate ground parameters. It is shown that by changing one ground parameter, error decreases. Better propagation model may be required to obtain better prediction.

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