Frequency selection for ground monitoring using propagation characteristics

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Abstract. Ground monitoring can be used for observing ground structure changes or other specific objectives. Rather than using expensive ground penetration radar, the ground propagation characteristics may be able to describe the structure changes. Ground propagation can be evaluated by using a simple radio transmitter and receiver. This paper employs a vector network analyzer (VNA) to explore ground propagation characteristics. As the available VNA works from 500 MHz to 1 Ghz, the paper proposes how to select suitable frequency for ground monitoring. Tangential comparison between mathematical model and direct measurement is proposed. The result shows that the selected frequency exerts promising propagation characteristic even dough signal diffraction causes irregular signal strength at the receiver.

1. Introduction
Underground monitoring is useful to observe ground structure even though object detection or finding is the most frequent applications [1]. The ground structure was initially conducted by the electromagnetic induction that is able to detect metallic materials presence in the ground [2]. Electromagnetic induction makes use radiated electromagnetic field and senses the remaining field left over on the detected object. Ground penetration radar or GPR [3] is the most popular method for observing underground object by transmitting radio signal into the object and receiving the reflected signal to determine object pattern. Ground penetration radar is like other surface radar but uses higher power as signal penetrates to a more dense material than of the surface radar. Time domain reflectometer (TDR) [4] and capacitance measurement [5] can also be use to explore ground content.

As GPR is intended to explore object shape rather than ground structure changes, GPR is too expensive for ground monitoring [6]. This paper proposes ground monitoring using a separated radio transmitter and receiver. Although the same radio schema has been used for through the earth (TTE) radio, which is for communication purpose [7], this paper focuses the usage for structure monitoring. Some extended radio facilities such as noise cancelation [8] are not discussed. Instead, the study uses the existing vector network analyzer. This paper presents the initial step which is frequency selection techniques based on tangential comparison between mathematical model and measurement results.

2. Research Method
In order to select the best frequency for monitoring ground structure, mathematical model is employed and direct measurement was performed. The approximated mathematical model for underground propagation uses Friis equation as plotted in Equation 1 [9]:

\[ P_r(dBm) = P_t(dBm) + G_r(dB) + G_t(dB) - L_0(dB) \]  

The \( L_0 \) denotes propagation loss which varies to distance (d in km) and frequency (f in MHz).

\[ L_0(dB) = 32.4 + 20 \log(d) + 20 \log(f) \]
Additional factor ($L_p$) is added to correct the Friis equation which is mainly used for surface propagation. The received power is approximated by Equation 3.

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

$L_p$ comprises of space loss $L_s$ and ground loss $L_g$. $L_s$ determines losses based on attenuation constant $\alpha (1/m)$ and phase shift, $\beta (\text{radian/m})$. The corrected loss is expressed in Equation 4 [9], while value $\alpha$ and $\beta$ are given by Equation 5 and 6 [9]. Magnetic permeability $\mu$, and permittivity $\varepsilon$ are selected as in [10].

$$L_s = 8.69\alpha d + 154 - 20 \log(f)(\text{Hz}) + 20\log(\beta)$$ (4)

$$\alpha = \omega \sqrt{\frac{\mu\varepsilon'}{2}} \left[ \sqrt{1 + \left(\frac{\varepsilon'}{\varepsilon''}\right)^2} - 1 \right]$$ (5)

$$\beta = \omega \sqrt{\frac{\mu\varepsilon'}{2}} \sqrt{1 + \left(\frac{\varepsilon'}{\varepsilon''}\right)^2} + 1$$ (6)

Measurement was conducted by using scenario plotted in Figure 1. Depth and distance are adjusted to the limit of the employed VNA (Figure 2). Frequency selection is also based on VNA capability. Object size is a box made of metal sheet with size 20 cm x 20 cm x 20 cm, located at the middle measurement path.

![Figure 1. The measurement scenario](image1)

The proposed frequency selection is by finding the linear trend of mathematical model and the measurement result. Tangential values were extracted from the linear trend. Since negative tangent is expected, only negative tangential values from both mathematical model and results determine the selected frequency.

![Figure 2. VNA for measurement](image2)
3. Modelling and measurement results

Figure 3a shows the loss and the received signal patterns generated by the mathematical model. Loss in lower frequency band increases to distance; while in higher frequencies tend to be flat. By using normalized graph, the received signal is inversely proportional to losses as plotted in Figure 3b.

![Figure 3a](image1.png)  
![Figure 3b](image2.png)  

Figure 3. Propagation loss and received signal generated by mathematical model

Figure 4a shows the sample of measurement results. Amplitudes of received signals vary to working frequency. Frequency band lower than 600 MHz gets the best signal strength followed by band higher than 1 GHz. This variation is influenced by underground scattering. The samples of received signal to distance is shown in Figure 4b. Unlike surface propagation, signal decrease inconsistently to distance.

![Figure 4a](image3.png)  
![Figure 4b](image4.png)  

Figure 4. Received signal level to frequency and distance

The comparison of tangential values between mathematical model and measurement is shown in Figure 5. Tangential value of the model changes from minus to zero, while measured tangential values changes irregularly.

![Figure 5a](image5.png)  
![Figure 5b](image6.png)  

Figure 5. Tangential based selection
Since both tangential values for the selected frequency should be in negative region, frequency of 537.69 MHz is selected as best signal. Figure 6 shows the received signal sample of frequency 537.69 MHz that changes to distance. This frequency will be used for the ground monitoring.

4. Conclusions
This paper has presented frequency selection method for underground monitoring system based on propagation characteristics. The proposed method made use of the tangential value comparison between mathematical model and direct measurement. As VNA used in this experiment has frequency range of 500MHz to 1 GHz, the selected frequency is 537.69 MHz. The selected frequency has decreasing trend of signal strength to distance. Future work will discuss the use of this frequency for underground monitoring.

Acknowledgement
This research has been supported by DRPM DIKTI under the scheme of Penelitian Dasar Unggulan Perguruan Tinggi research grant 2019.

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