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# A Review on Non-Evasive Groundwater Determination Technique using Electromagnetic Wave Principle

Vrian Jay V. Ylaya[1], Rosemarie C. Arcaya[2]
[1]Master in Industrial Education, Graduate School, Surigao State College of Technology, Surigao City, Philippines 8400
[2]BS Mathematics, College of Arts and Sciences, Surigao State College of Technology, Surigao City, Philippines 8400
Email Address: [1]vrianjayylaya@ssct.edu.ph, [2]rarcaya@ssct.edu.ph

***Abstract***— *Groundwater is essential part in irrigation, and potable water supply to industries, municipalities, and rural homes. Research and innovation for sensors that can target groundwater are increased for the past years. There are evasive and non-evasive methods in locating groundwater hydrology. In the tedious and limited depth evasive sensors, a pair of electrodes are placed in the ground where actual resistivities are determined from the measured currents and potential difference which detect the groundwater. In this paper, a review of non-evasive methods and techniques that is fast and accurate to use utilizing electromagnetic wave (EM) principles and analyze the reflected electromagnetic wave (EM) signals to target the groundwater.*

***Keywords***— *Electromagnetic Wave (EM), Groundwater, Hydrology, Non-evasive Method, Reflected Signal.*

## I. INTRODUCTION

The essential commodity of mankind is water thus the demand drastically increase through time and the largest available source of fresh water lies underground [1]. This fresh water underground or groundwater also provides major roles in our environment such as providing the baseflow that keeps most rivers flowing all year long and maintaining good river water quality by diluting sewage [2]. With this importance of groundwater, researchers, and scientist challenge to investigate and determine groundwater by means of geophysical and hydrogeological methods [3]. If groundwater abstraction exceeds the natural groundwater recharge for extensive the natural groundwater recharge for extensive areas and long times, overexploitation or persistent groundwater depletion occurs [4]. Thus, groundwater management has been implemented in the United States to regulate extreme extraction which address to climate change [5].

Subsurface investigation and determination of groundwater is expensive but alternative methods such as geophysical methods, geologic investigation and reconnaissance, and interpretation of aerial photographs are much cheaper techniques [1]. Geoelectrical method or electrical resistivity method were used in the vast agriculture land of Sistah and Baluchistan Province in the southeast of Iran to monitor and study the condition of groundwater supply [6]. Presence of groundwater were also detected in the geophysical survey at the savannah belt of central Sudan using gravity method [7]. Seismic refraction method were also used in the determination of depth of the water table over unconfined glacial aquifers in New England due to economical aspect than test drilling or aquifer test [8]. Acquired data such as stratigraphy, geologic and air photo data from Remote Sensing and the Geographic Information System (GIS) in the surrounding village of Askeriye, Bugduz, Gelincik, Taskapi and Kayaalti of Burdur City, Turkey were study for groundwater potential [9]. The most ancient method to locate groundwater is called dowsing where the water witch hold a forked stick in both hands and walking over the local area until the butt end is attracted downward to locate the exact coordinate of groundwater as in the case in Zimbabwe [10].

Groundwater conditions at a location are mainly described through the distribution of permeable layers (e.g., sand, gravel, fractured rock) and impermeable layers (e.g., clay, till, solid rock) in the subsurface where each of these layers corresponds by the nature of each electrical conductivity and dielectric constants [8]. The electric permittivity (dielectric constant) and the electric conductivity are petrophysical parameters which determine the reflectivity of layer boundaries and penetration depth which will determine the groundwater in the soil strata [11]. This study aims to review non-evasive methods, design, concept, and technology in determining groundwater utilizing the ground penetrating radar. Antenna parameters, signal processing techniques, ground penetrating radar survey procedures, and software development for human machine interface are not covered with this review. Each of the methods, concepts, design, and technology of ground penetrating radar are explained such as their advantage and disadvantage and briefly summarize as a whole system functions.

## II. THEORITICAL BACKKGROUND

This review relates the basic scientific theory, equations, and concepts that anchor the applications of electromagnetic Principle.

### A. *Electric Permittivity and Conductivity*

Maxwell's equations govern the propagation of electromagnetic waves. They provide a set of differential equations that are related to the electric field, time, space, and material properties.

The specific electric conductivity and the electric permittivity are also important for the propagation of electromagnetic waves. In electrodynamics, a complex



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permittivity is used to describe the properties of various materials:

$$\varepsilon^* = \varepsilon' - i\varepsilon''\left(\frac{As}{Vm}\right)\ with\ i = \sqrt{-1}\ \ (1)$$

$$\varepsilon^* = \frac{\varepsilon^*}{\varepsilon_o} = \varepsilon_r' - i\varepsilon_r''\ \ (2)$$

$$\varepsilon_r'' = \frac{\sigma}{\omega\varepsilon_o}\ (3)$$

The loss tangent is the ratio of conduction to displacement currents and defined as

$$\tan\delta = \frac{\varepsilon_r'}{\varepsilon_r''} = \frac{\sigma}{2\pi f\varepsilon_o\varepsilon_r}\ \ (4)$$

In ground penetrating radar, the loss of tangent is equal to the displacement current. In other applications, the loss of tangent is greater than one and has diffusive processes.

*B. Complex Permittivity of Water*

Due to the dipole characteristics of water molecules, this phenomenon is known as Debye relaxation. It occurs when the water's permittivity drops from 80 to 5.8 at low frequencies and goes through a peak of 10GHz.

Since Debye relaxation can be observed in various geological materials at low frequencies, it provides deep penetration.

*C. Electromagnetic Wave Propagation*

The simplest and most important solutions to Maxwell's equations are the harmonic plane waves and the electric field.

$$E_x(z,t) = E_{x0}e^{\gamma Z-\omega t}\frac{V}{m}\ (5)$$

$$H_y(z,t) = H_{y0}e^{\gamma Z-\omega t}\frac{V}{m}\ (6)$$

$$\gamma = \alpha + i\beta\ m^{-1}\ (7)$$

$$\vec{E} = \vec{E_0}e^{i(\beta z-\omega t)}e^{-\alpha z}\ (8)$$

The electric and magnetic fields are also orthogonal to each other. The first exponential function describes the phase variations of the wave, while the second one describes its attenuation constant.

$$\alpha = \frac{\omega}{c_0}\sqrt{\frac{\varepsilon'_r}{2}\left(\sqrt{1+\tan^2\delta} - 1\right)}\ \ (9)$$

and

$$\beta = \frac{\omega}{c_0}\sqrt{\frac{\varepsilon'_r}{2}\left(\sqrt{1+\tan^2\delta} + 1\right)}\ \ (10)$$

The absorption coefficient is computed with the speed of light in vacuum or air. It is important to note that the constants are small if the loss of tangent is less than one.

The propagation velocity of the radar waves is calculated from Equation 10 by

$$v = \frac{2\pi f}{\beta}\frac{m}{ns}\ for\ f\ in\ GHz\ (11)$$

which collapses to

$$v \approx \frac{c_0}{\sqrt{\varepsilon}}\ \ (12)$$

The wavelength of low-loss materials is calculated from the relation velocity of the materials with loss of tangent.

$$\lambda = \frac{c_0}{f\sqrt{\varepsilon}}\ \ (13)$$

If the materials don't have water, the absorption would plateau. However, with the Debye relaxation, the absorption gets raised to a level of over a hundred megahertz. The Debye relaxation increases the absorption significantly, which means that the high frequencies of the electromagnetic waves are attenuated.

*D. Reflection and refraction of plane waves*

The electromagnetic wave produced by an incident is reflected in one media equation and refracted into another media equation 1 and 2. The directions of incidents, refraction, and reflection are all in one plane.

$$\frac{\sin\theta_1}{\sin\theta_r} = n_{21} = \sqrt{\frac{\varepsilon_2}{\varepsilon_1} = \frac{v_1}{v_2}}\ \ (14)$$

Refraction occurs when the velocity exceeds the sub-surface's critical angle. It causes the refracted wave to propagate along the surface.

The reflection or reflectivity of electromagnetic waves is computed by taking the incident unit amplitude and dividing it by the plane waves' reflection coefficient.

$$r = \frac{v_2 - v_1}{v_2 + v_1} = \frac{\sqrt{\varepsilon_1} - \sqrt{\varepsilon_2}}{\sqrt{\varepsilon_1} + \sqrt{\varepsilon_2}}\ (15)$$

and the refracted (transmitted) part time t by

$$t = \frac{2v_2}{v_2 + v_1} = \frac{2\sqrt{\varepsilon_1}}{\sqrt{\varepsilon_1} + \sqrt{\varepsilon_2}} = 1 + r\ \ (16)$$

The simple relation between the coefficient of refraction and the ideal dielectrics is only applicable to ideal dielectrics. If conductive materials are involved, the resulting reflection may become complex.

*E. Basic Concept*

The concept of ground penetrating radar is based on the principle of electromagnetic reflection. It uses high-frequency electromagnetic waves to acquire subsurface information. It can detect changes in the properties of the subsurface due to the presence of various factors such as rock material, water content, and conductivity as shown in Figure 1 [12].

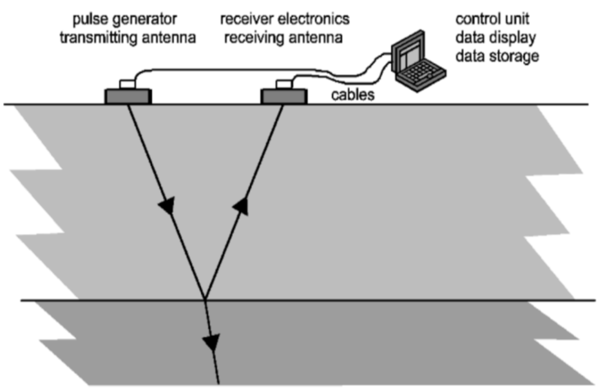


Fig. 1. Ground penetrating radar measurement [12]



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Usually, data is collected using an antenna placed on the ground or in boreholes. The antenna sends signals that reflect from the boundary and propagate in the subsurface. The readings are then recorded in a record that is calculated using the arrival times of the signals [13].

## III. Techniques

The examination of the technique for determining non-invasive groundwater using the principle of electromagnetic waves consists of three techniques. Time, frequency, and random signal based on all existing technology and research publish in which the researcher fully grasp the history until now of techniques.

### A. *Time Domain Ground Penetrating Radar*

This radar can be operated from 100 to 1000 MHz and can detect depth and precision. It is equipped with various components such as an antenna, a gain amplifier, a timing and synchronization controller, and a personal computer as shown in Figure 2 [14].

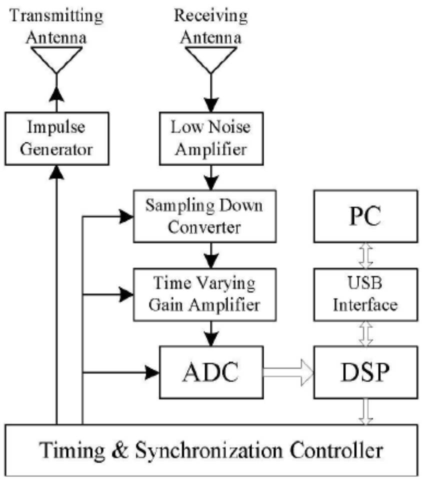


Fig. 2. Block Diagram of the Ground Penetrating Radar [14]

The issue of Figure 2's low signal sampling rate and slow survey speed can be solved by having two channels with a high-speed data acquisition unit as shown in Figure 3 [15].

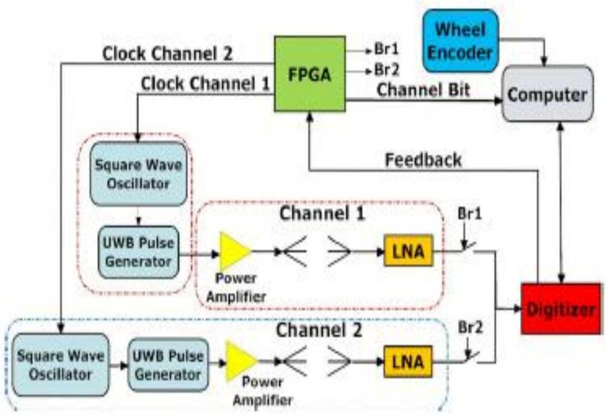


Fig. 3. Ultra-wideband high speed ground penetrating radar [15]

The portability of the impulse penetrating Figure 3 is an issue due to its design. This prototype was developed to address this issue by incorporating a handheld ground penetrating radar.

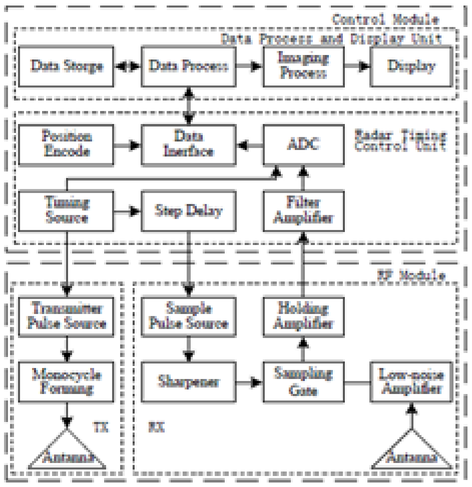


Fig. 4. Schematic Design of the handheld ground penetrating radar (Dai, et al., 2010)

The receiver operates from the sampling circuit and can receive and transmit the signal [16].

### B. *Frequency Domain Ground Penetrating Radar*

The transmitter can generate a low-frequency chirp signal using a DDS receiver. This procedure generates a high-quality analog output with a nominal amplitude. The entire system is controlled through a parallel port of a computer. A second transmitter/receiver unit was then built to handle the data collection. The system is controlled through a parallel port of a laptop computer. A second transmitter/receiver unit was then built to handle the data collection [17].

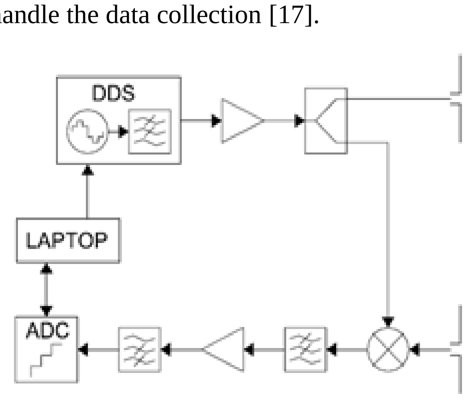


Fig. 5. Block diagram of Frequency Modulated Continuous Wave (FMCW) Ground penetrating radar [17]

Although the disadvantage of using a Stepped Frequency continuous wave is the settling time required for the phase lock loop, it can be used to improve the dynamic range of the ground penetrating radar. This method can be achieved through the use of a range gating technique [18].

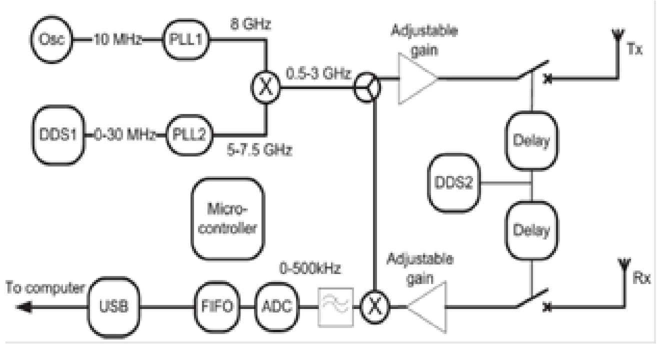


Fig. 6. Schematic diagram of Stepped Frequency Continuous Wave Ground Penetrating Radar [19]

Orthogonal frequency division multiplexing is a technique that combines the stability of a multipath channel with the uniformity of step frequency and amplitude. The Inverse Discrete Fourier transform generates the orthogonal frequencies using a set of sinusoids. This technique can be used to control the radiated spectrum efficiently [20].

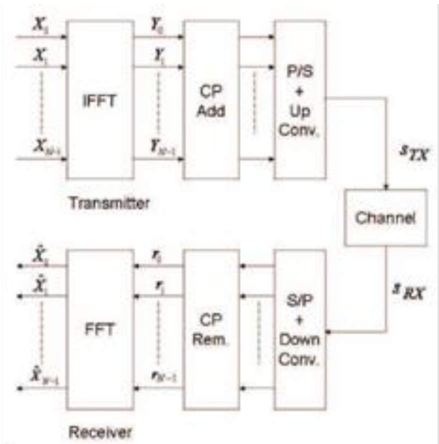


Fig. 7. Block Diagram if a basic OFDM system [20]

When the OFDM signal is received, it will be sent to the receiver along with the location of the objects in its path. The delayed version of the signal will contain the information about the objects in its path [20].

*C. Random Signal Ground Penetrating Radar*

A frequency domain radar is often applied if the duration of a measurement cycle is not critical. For example, sliding correlation processing and random noise excitation require long measurement cycles. However, periodic pseudo-random binary codes can achieve the shortest measurement cycles and high correlation gain, making them ideal for real-time measurement [21].

A GOLAY sequence code was used to limit the penetration of a pseudo random ground penetrating radar. This technique consists of various components such as an optical module, a power amplifier, and an antenna [23]. The controller generates a pseudo random coded signal, which is fed to the receiving antenna and the transmitter. The echo signal is then received by the receiver [24].

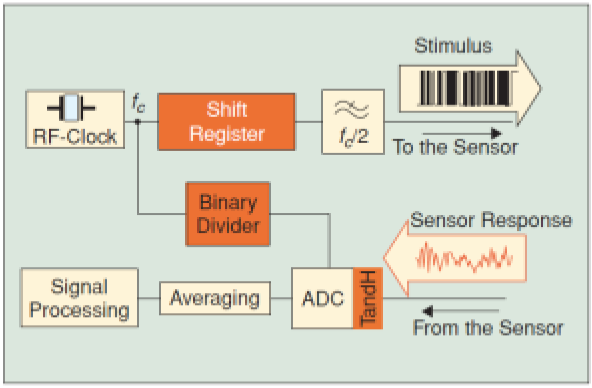


Fig. 8. Block Diagram of a Pseudo Random Noise Ground Penetrating Radar [22]

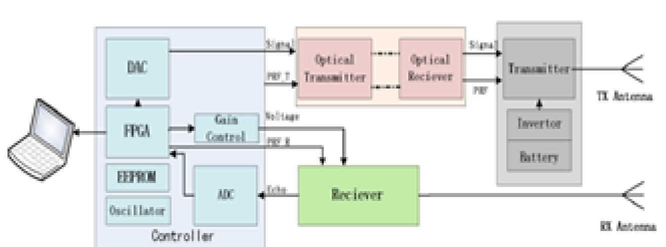


Fig. 9. Block Diagram of Pseudo Random Coded Ground Penetrating Radar [24]

A ground-penetrating radar system that uses a sequence of codes has achieved a sounding depth of more than 130 meters [25].

## IV. Conclusion

Time domain impulse ground penetrating radar systems has been proven and tested for the past decade for groundwater determination and it is now commercially available, but the performance of the system is severely limited by the receiver, where the sampling down-converter exhibits a poor figure and very expensive to implement. Frequency Modulated Continuous Wave (FMCW) and Stepped Frequency Continuous Wave (SFCW) were advocated in ground penetrating radar due to cheaper implementation, wide dynamic range, lower noise figure, higher mean power that can be radiated, more control on spectral contents, and wider range of antenna can be used. But the penetration of the technique is still a challenge for researchers and scientist for deep penetration and reliability to detect groundwater. Promising technique such Orthogonal Frequency Division Multiplexing offers robustness to multipath channel, easy equalization and frequency diversity compared to FMCW and SFCW although this OFDM system has never been used as signaling to ground penetrating radar. Since pseudo-noise UWB radar is spread over a large bandwidth, it can reduce the interference from standard narrowband radio systems. This system is commonly used for deep penetration.

## V. Other Recommendations

This summary of techniques is gathered from articles that are published in internet such as Google Scholar, Science Direct, and IEEE Explore. Device that are available in the market which implemented in the same technique are not included in this review because of the plethora in the market. If these existing devices are added it will tract the maturity of the technology which will be greatly improved the review.

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