Ground **P**enetrating **R**adar

General Knowledge Document

WM

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Volume 1

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1.0 How it works

When the transmitted signal enters the ground, it contacts objects or subsurface strata with different electrical conductivities and dielectric constants. Part of the ground penetrating radar waves reflect off of the object or interface; while the rest of the waves pass through to the next interface.

For each reflected wave, the radar signal changes polarity twice. These polarity changes produce three bands on the radar profile for each interface contacted by the radar wave.

Ground penetrating radar waves can reach depths up to 100 feet (30 meters) in low conductivity materials such as dry sand or granite. Clays, shale, and other high conductivity materials, may attenuate or absorb GPR signals, greatly decreasing the depth of penetration to 3 feet (1 meter) or less.

The depth of penetration is also determined by the GPR antenna used. Antennas with low frequencies of from 25 to 200 MHz obtain subsurface reflections from deeper depths (about 30 to 100 feet or more), but have low resolution. These low frequency antennas are used for investigating the geology of a site, such as for locating sinkholes or fractures, and to locate large, deep buried objects.

Automatic Target Recognition (ATR) algorithms have the ability to perform both inter-sensor and intra-sensor data fusion.

1.9 Quickies

- What are some of the "hidden problems" associated with Ground Penetrating Radar?

Terrain electrical conductivity of the site plays an important role in determining the depth of penetration of the radar pulse.

- What type of signal does GPR systems typically use?

Electro-magnetic. Electromagnetic waves are discussed later on.

- How does the frequency relate to **attenuation** of the **electromagnetic waves**?

Attenuation increases as frequency increases. If we reduce frequency, however, we notice that two things occur: (a) we lose resolution, and (b) if the frequency is too low, electromagnetic fields no longer travel as waves but diffuse which is the realm of inductive EM or eddy current measurements.

- Resolution is controlled by wavelength of the propagating electromagnetic wave in the ground. Resolution increases with increasing frequency (shorter wavelength).

- GPR signals decay exponentially in soil and rock.

2.0 General Radar Information

Radar is an electromagnetic means of detecting, locating, and study objects. The word radar was coined from the phrase Radio Detection and Ranging. Radar is a remote sensing technique, that is, one capable of gathering information about objects at remote distances from the sensing device.

Radar has two distinguishing characteristics:

1. It employs electromagnetic waves that fall in the microwave region of the electromagnetic spectrum, with wavelengths in the range from about 1mm to 1m.
2. It is an active technique, in the sense that it emits radiation and then observes objects by means of the radiation they reflect. The passive methods depend on a natural source of radiation such as thermal emission.

3.0 Hilbert Transform

The Hilbert Transformer is a system having the frequency response: Magnitude=1, phase = 90 degrees, for all frequencies. This means that any sinusoid passing through by a Hilbert transformer will be unaffected in amplitude, but changed in phase by one-quarter of a cycle. Used in communication systems for modulation. Can be analog or digital. [4]

$$\mathcal{H}[f(x)] = \frac{1}{\pi}\int_{-\infty}^{\infty}\frac{f(x)\,dx}{x-y}$$

The *Fourier transform*, which has occupied so much of our attention thus far, is particularly useful for evaluating the frequency content of an energy signal or, in a limiting sense, that of a power signal. As such, it provides the mathematical basis for analyzing and designing frequency-selective filters for the separation of signals on the basis of their frequency contents. Another method of separating signals is based on *phase selectivity*, which use phase shifts between the pertinent signals to achieve the desired separation. The simplest phase shift is that of 180 degrees, which is merely a polarity reversal in the case of a sinusoidal signal. Shifting the phase angles of all components of a given signal by 180 degrees requires the use of an ideal transformer. Another phase shift of interest is that of ±90 degrees, the resulting function of time is known as the Hilbert transform of the signal. [3]

To be specific, consider a signal g(t) with Fourier transform G(f). The Hilbert transform of g(t), which we shall denote by $\hat{g}(t)$, is defined by

$$\hat{g}(t) = \frac{1}{p}\int_{-\infty}^{\infty}\frac{g(t)}{t-t}dt$$

- What is the "**envelope**" that is discussed in signal processing literature?

Envelope of a (complex-valued) signal is defined as the square root of (x^2 + y^2), where x and y are real and imaginary part respectively. The envelope only contains magnitude information of the signal, not the phase.

- What are some applications of GPR technology?

Detection of Anti-personnel mines. (UXO – Unexploded O)

3.1 In Matlab

The Hilbert function in Matlab returns a complex helical sequence, sometimes called the analytical signal, from a real data sequence. The analytic signal has a real part, which is the original data, and an imaginary part, which contains the ***Hilbert Transform***.

help hilbert

HILBERT: Discrete-time analytic signal via Hilbert transform.
X = HILBERT(Xr) computes the so-called discrete-time analytic signal

X = Xr + i*Xi such that Xi is the Hilbert transform of real vector Xr.

If the input Xr is complex, then only the real part is used: Xr=real(Xr).

If Xr is a matrix, then HILBERT operates along the columns of Xr.

HILBERT(Xr,N) computes the N-point Hilbert transform. Xr is padded with zeros if it has less than N points, and truncated if it has more.

For a discrete-time analytic signal X, the last half of fft(X) is zero, and the first (DC) and center (Nyquist) elements of fft(X) are purely real.

Example:
Xr = [1 2 3 4];
X = **hilbert**(Xr)
produces X=[1+1i 2-1i 3-1i 4+1i] such that Xi=imag(X)=[1 -1 -1 1] is the Hilbert transform of Xr, and Xr=real(X)=[1 2 3 4]. Note that the last half of fft(X)=[10 -4+4i -2 0] is zero (in this example, the last half is just the last element). Also note that the DC and Nyquist elements of fft(X) (10 and -2) are purely real.

See also FFT, IFFT.

3.9 Quickies

- The *ideal Hilbert Transform* is non-causal, i.e**.** **<u>does not</u>** have a value of zero for all negative numbered samples.

- What is the effect of changing the phase of a signal by 90 degrees?

  It is easiest to visualize it in a sine/cosine sense…in that if you apply the Hilbert transform to a sine wave, the wave is phase-shifted to be a cosine wave.

- What are some uses of the Hilbert transform?

One use is in the process of envelope detection.

4.0 The Cauchy Principal Value

What is the Cauchy principal value?

5.0 Electromagnetic Theory

Electromagnetic theory is the branch of electrical engineering (or physics) that deals with the analysis and application of electric and magnetic fields. In electromagnetics, electric circuit analysis is applied at low frequencies. EM theory is based on Maxwell's equations.

EM is regarded as one of the more difficult disciplines in electrical engineering. One reason is that EM phenomena are rather abstract. But if one enjoys working with mathematics and can visualize the invisible, one should consider being a specialist in EM, since few electrical engineers specialize in this area. Electrical engineers who specialize in this area are needed in Microwave industries, radio/TV broadcasting stations, electromagnetic research laboratories, and several communication industries. [6]

In radar, EM waves are emitted by the antenna.

Electromagnetic waves are governed by Maxwell Equations

Approximation to radio wave velocity in terms of dielectric

Dielectric in terms of porosity:

Limit of resolution

The limit of resolution is defined mathematically as:

$$\frac{l}{4} = \frac{V}{4f} = \frac{c}{4fe_r}$$

where λ is wavelength, f is frequency, V- radio wave frequency, ε_r relative permittivity, and c=0.3 m/ns.

An example of this is: a GPR survey with 100 mhz antenna over wet sand where the radar velocity is around 55 mm/ns. Resolution limit is therefore:

$$\frac{0.055x10^9 m/s}{4x100x10^6 Hz} = 0.1375$$

6.0 Antennae

6.1 Fractal Antennae

6.1.1 Sierpenski Multi-band Antenna

Sierpenski gasket is the sierpenski triangle

7.0 Signal Analysis

8.0 Glossary

Beamforming:

Bistatic: a radar having transmitter and receiver located at different sites.

Borehole: Applications developed can be Tunnel Detection, Minerals, Hole-to-hole Radar Tomography, Density and Water Content Logging.

Calculation of apparent conductivity from layered Earth:

Depth of Investigation:

DB/m: decibels/meter, common unit for attenuation.

Dielectric: Having little or no conductivity. Nonconducting. Substances include glass, rubber, or wood. The dielectric constant of a material/substance determines the speed of the radar signal – thus knowing the depth is affected by the dielectric constant.

Dyadic: dyadic data refers to a domain with two finite sets of objects in which observations are made for dyads, i.e., pairs with one element from either set.

Electromagnetic radiation. Energy transfer in the form of electromagnetic waves or particles that propagate through space at the speed of light.

EM Skin depth and depth of penetration:

Envelope Detector: An envelope is the amplitude of a waveform. An envelope detector is necessary, because it allows us to recover a signal by “ignoring” noise or allow us to trace a signal to only include the envelope. It is typically used in AM radio to detect the modulation of the signal.

Faraday's Law of Induction:

Induction: the process by which an object having electrical or magnetic properties produces similar properties in a nearby object, without direct contact.

Induction Number:

Matched Filter: A receiver filter having a frequency response, which is "matched" of the transmitted pulse (complex conjugated) in order to optimize the signal-to-noise ratio. For unmodulated pulse, it can be approximated by a bandpass filter of bandwidth=1/T, where T is the pulse width. When a matched filter is used in the receive, the S/N is proportional only to the pulse energy (P x T) and not to the peak power P.

Monostatic: a radar having both transmitter and receiver located at the same sites (and, generally, sharing the same antenna). The large majority of radars currently in use are Monostatic.

Non-Coherent detector: a detector that does not require that the receiver's carrier signal be in phase with the transmitter's carrier signal.

Phased Array: An antenna which can be electronically steered by changing the electrical length (phase delay) of the feed path of the different radiating elements. Steering can be on one axis only (each radiator "line" is fed with different phase) or two axes, with individual phase control of each element.

Radar Range Equation: Mathematical expression balancing the various uses of EM signal to estimate maximum range of a radar system or signal amplitude of a specific target.

Range Gate: receive "window" opened by tracking radar around the expected range of the target. Range gate position is normally controlled by a closed loop system which keep the range gate around the target.

Magnetic Flux: the total number of magnetic lines of force passing through a specified area, generally expressed in maxwells or webers. The result of dividing the magnetomotive force by the reluctance.

Radiowave reflection Coefficient

Superheterodyne receivers: used in radar systems must have good stability and extreme sensitivity.

Synthetic Aperture Radar: SAR refers to the situation where the radar is moving and the target is stationary.

Target: The *target* is the object you are trying to acquire from sending a signal.

TDEM time constant:

Ultra Wide-band: refers to electromagnetic signal waveforms that have instantaneous fractional bandwidths greater than 0.25 with respect to a center frequency. UWB signals usually occur as either short duration impulse signals and as nonsinusoidal (e.g., square, triangular, chirped) waveforms.

Unity:

UXO: Unexploded Ordinance. Various research projects discuss methods of target (UXO) detection.

Dielectric Values

Material Dielectric Constant

Air 1
Asphalt 5
Coal 4.5
Concrete 12.5
Dry Clay 4
Dry Bauxite 25
Dry Concrete 5.5
Dry Granite 5
Dry Limestone 5.5
Dry Loamy/Clayey Soils 2.5
Dry Mineral/Sandy Soils 6
Dry Salt 6
Dry Sand & Gravel 5.5
Dry Sands 4
Frozen Sand & Gravel 5
Frozen Soil/Permafrost 6
Ice 4 Wet
Organic Soils (saturated) 64
Peats (saturated) 61.5
Potash Ore 5.5
Sea Water 81
Saturated Sands 25
Snow Firn 1.5
Syenite Porphyry 6
Tills 11
Travertine 8
Volcanic Ash 13
Water 81

Wet Basalt 8.5 Wet Clay 27 Wet Granite 6.5
Wet Limestone 8
Wet Sands 15
Wet Sandstone 6
Wet Sandy Soils 23.5

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