ANALYSIS OF REFLECTION AND TRANSMISSION COEFFICIENT OF ELECTROMAGNETIC WAVE FOR SEARCH AND RESCUE OPERATIONS USING ULTRA WIDEBAND RADARS

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ABSTRACT

Radar capable to detect and perform diagnostics of a state of the human being buried under obstacles and in conditions of bad visibility especially during disaster management could be used for the manifold applications. Ultra-wideband (UWB) radar plays an important role in search and rescue at disaster relief sites. Identifying vital signs like movement and heartbeat and locating buried survivors are two important research contents in this field.

UWB radar along with the suitable target detection process would effectively help in vital sign detection and location of trapped victims during search and rescue operations in disaster management sites.

Index Terms: UWB Radar, Electromagnetic Wave, Transmission Coefficient, Reflection Coefficient

I. INTRODUCTION

Ultra-wideband (UWB) radar plays an important role in search and rescue operations at disaster relief sites. Since, it is hard to identify a human's vital signs (body movement and heartbeat) from the radar returns in complex environments [1] due to the low signal-to-noise ration of the vital sigh in radar signals [2], complex algorithms and hardware's has been designed for the signal processing at the receivers end. Another approach that is proposed in this paper is the analysis of the debris under which the human is buried. As electromagnetic waves propagate from one homogeneous medium to another, they experience a change of the wave impedance at the interference [3]. The impedance mismatch generally leads to the reflection, absorption and transmission of Electromagnetic waves. It is therefore necessary to study the reflection and transmission coefficient of different materials to understand its behavior towards electromagnetic wave.

II. UWB RADAR

Ultra-wideband (UWB) radar operates by using a very narrow or short duration pulses that result in very large or wideband transmission bandwidth. UWB technology holds great promise for a lot of new applications that will significantly benefit government, public safety, businesses, and consumers. The recent FCC ruling for UWB increased the interest for investigating this technology for imaging systems (e.g., through wall imaging (TWI), ground penetrating radars (GPRs), surveillance systems, and medical imaging devices), vehicular radar systems, and communications and measurement systems [4].

The primary advantages of UWB for short-range radar detection and imaging include extremely fine range resolution, high power efficiency, low interference, and ability to detect moving or stationary targets at complex environment.

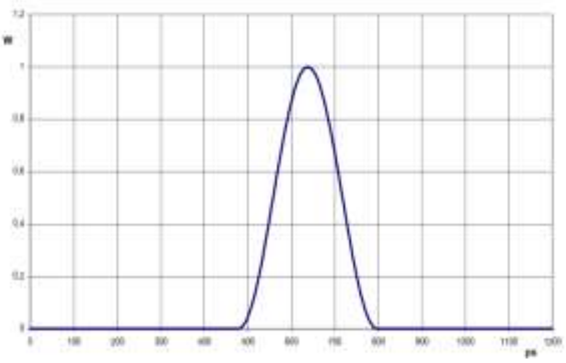

Fig. 1: A UWB Pulse in Time Domain [5]

Principle of operation of UWB radar is based on the comparison of echoes from short duration pulse transmissions to detect small changes over time resulting from target motion. In the simplest sense, the impulse response of successive echoes from a room containing a moving target would be identical, except at the point in time associated with the signal returning from the position of the moving target. Thus, computing successive pulses would produce an output that corresponded only to the moving objects presence and range.

According to FCC rules, through-wall systems must be operated below 960 MHz or in the frequency band 1.99-10.6 GHz. Higher operating frequencies permit the use of smaller antenna, but these frequencies do not easily penetrate walls and boundaries. Low frequencies, on the other hand, are able to penetrate walls but require larger antennas with wider beam widths.

III. ELECTROMAGNETIC WAVE PROPAGATION

Before starting the system design, the characteristics of microwave through wall propagation should be known. The MATLAB model focuses on the signal attenuation, phase change, frequency and polarization selections. During many previous through wall projects the designer did not realize the problems of microwave propagation through the wall [6]. The composition and thickness of the wall, its dielectric constant, and angle of incidence are few of the factors that affect a signal propagating through the wall. The propagating signal slows down, encounters refraction, and is attenuated when it passes through the wall. Non-line of sight propagation happens due to refraction, and waves slowing down will cause a lateral bias in target location. The phase change caused by propagation delay will also introduce information loss in both target range detection and Doppler detection. We will analyze the through wall propagation based on EM modeling of transmission and reflection coefficient.

For a multi-layer wall structure, the developed platform has been used to simulate the through-wall dispersion, attenuation and delay. A plane wave at an incident angle of θ° is used in this experimental setup. Assuming that μ_i, σ_i, ε_i are the permeability, conductivity and permittivity of layer i, and θ_i is the wave propagation angle at layer i, these parameters are used to calculate the reflection coefficient and transmission coefficient through the N layers wall interfaces.

In the equations that follow we are determining the transmission and reflection coefficients based on the assumptions we have taken earlier [7].

$$A_i = [e^{\Psi_i}/2][A_{I+1}(1+ Y_{I+1}) + B_{i+1}(1 - Y_{i+1})] \quad \text{(Eq. 1.1)}$$

$$B_i = [e^{-\Psi_i}/2][A_{I+1}(1 - Y_{I+1}) + B_{i+1}(1 + Y_{i+1})] \quad \text{(Eq. 1.2)}$$

$$A_{N+1} = 1,\ B_{N+1} = 0 \quad \text{(Eq. 1.3)}$$

$$\Gamma_{\perp} = B_0/A_0\ , T_{\perp} = 1/A_0 \quad \text{(Eq. 1.4)}$$

Where:

$$Y_{i+1} = [\cos\theta_{i+1}/\cos\theta_i]\sqrt{\varepsilon_{i+1} - j\sigma_{i+1}/w/\varepsilon_i - j\sigma_{i+1}/w} \quad \text{(Eq. 1.5)}$$

$$\Psi_i = d_i\gamma_i\cos\theta_i \quad \text{(Eq. 1.6)}$$

$$\gamma_i = \pm\sqrt{jw\mu_i(\sigma_i + jw\varepsilon_i)} \quad \text{(Eq. 1.7)}$$

Assuming ε^* and d are the complex permittivity and thickness of the wall, θ_0 is the angle of incidence while θ_1 is the angle of refraction in the wall media, we have $k_0 sin\theta_0 = k_1 sin\theta_1$ according to Snell's law. Then the reflection coefficient and transmission coefficient are given by:

$$\Gamma_{\perp} = \left[\Gamma_{0w}\left(1 - e^{-j2k_1\cos\theta_1 d}\right)\right]/\left[1 - \Gamma_{0w}^2 e^{-2jk_1\cos\theta_1 d}\right] \quad \text{(Eq. 1.8)}$$

$$T_{\perp} = \left[(1 - \Gamma_{0w}^2)e^{-jk_1\cos\theta_1 d}\right]/\left[1 - \Gamma_{0w}^2 e^{-j2k_1\cos\theta_1 d}\right] \quad \text{(Eq. 1.9)}$$

$$k_1 = w\sqrt{\mu\varepsilon^*} \quad \text{(Eq. 1.10)}$$

$$\Gamma_{0w} = \left[\sqrt{\varepsilon_0}\cos\theta_0 - \sqrt{\varepsilon^*}\cos\theta_1\right]/\left[\sqrt{\varepsilon_0}\cos\theta_0 + \sqrt{\varepsilon^*}\cos\theta_1\right] \quad \text{(Eq. 1.11)}$$

The transmission coefficient given by (1-9) is a frequency dependent complex number. Its magnitude demonstrates the through wall attenuation while its phase indicates the through wall time delay.

IV. EXPERIMENTAL DESIGN SETUP

In this MATLAB simulation platform, the walls are assumed to be homogeneous with known properties. In real time conditions the walls could be heterogeneous without known geometrical and electrical characteristics. All of these unknowns may obscure the electromagnetic signatures of the targets behind the wall and create ghost targets.

Most walls are composed of concrete, brick, or wood. These materials are lossless to a low frequency microwave. By inserting the dielectric constants from Table 1 into the reflection and transmission coefficient formula given in equations 1.1 and 1.2, we can visualize the signal attenuation.

Material	ε_r	σ_c	Material	ε_r	σ_c
Air	1	0	Dry clay	3	1 – 10
Metal(iron)	1	10e8	Saturated clay	15	1e2 – 1e3
Fresh water	80	1	Rock	4 – 10	
Sea Water	81	4e3	Dry granite	5	1e-3
Dry sand	3	1e-4 – 1	Wet granite	7	1
Saturated Sand	25	1e-3 – 10	Limestone	4 – 8	0.5 – 2
Dry soil	2-6	1e-1 – 1	Wet sandstone	6	
Wet soil	5-15	1e-1 – 10	Dry concrete	6	1
Clays	5-40	2 - 1000	Saturated concrete	12	1e8

Table 1: Dielectric Constant ε_r and Conductivity σ_c of Common Materials [8]

V. SIMULATION, RESULT AND DISCUSSION

The simulation of through wall penetration has been implemented in MATLAB R2014a.

From the dielectric values given in table 1, we have plotted the transmission and reflection coefficient for some common materials namely dry wall (DW), wood (W), brick (B) and concrete (C) for different values of frequencies (1GHz, 3GHz, 5GHz, 7GHz and 10GHz).

Different MATLAB codes have been written to simulate different wall conditions. Figure 2 shows the penetration changes for different wall parameters as we change the operating frequency of the transmitter. We need to understand that as per FCC regulation, the frequency allocated for through wall imaging systems must be below 960 MHz or in the frequency band 1.99-10.6 GHz so in order to minimize the size of the radar as well as keeping a note that as we increase the frequency we reduce the chances of wall penetration, therefore a standard frequency needs to be selected for all further radar designs.

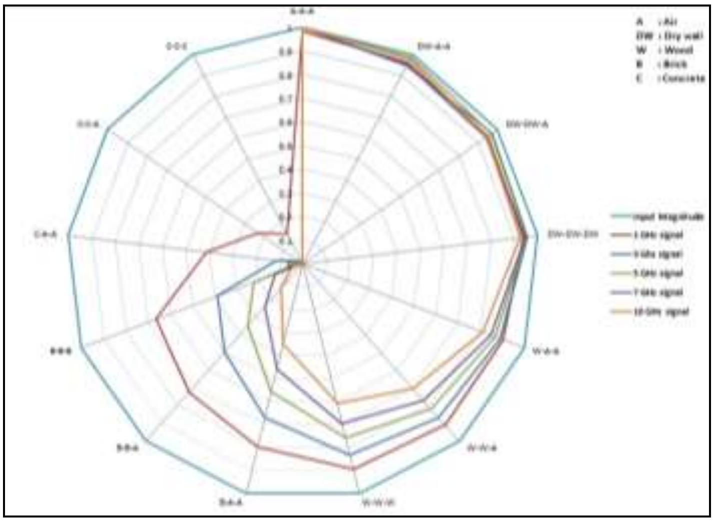

Fig. 2: Signal Amplitude of Electromagnetic Wave for Different Wall Types

Figure 3 shows the power variation for different wall conditions as we increase the operating frequency of the system.

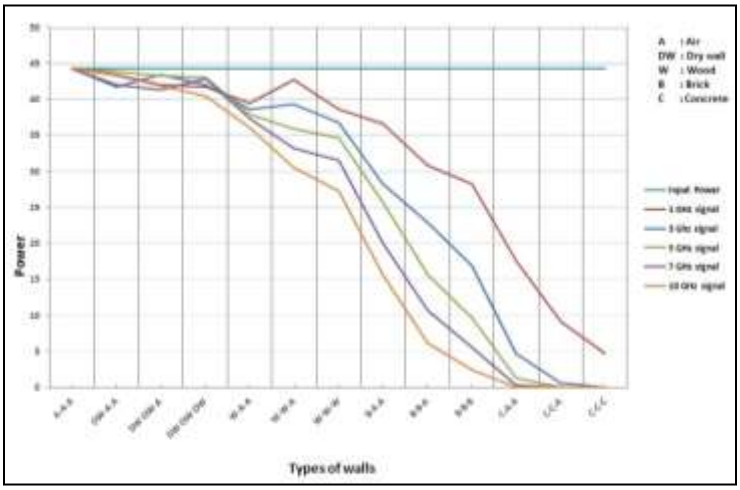

Fig. 3: Signal Power of Electromagnetic Wave for Different Wall Types

VI. CONCLUSION

From this experimental setup we can see that different materials have their own unique characteristics towards electromagnetic waves. If we have a complete data of as to how the electromagnetic wave will change as it penetrates different debris, we can consider this factor as clutter and the computation of the radar return would be simpler. This will not only save us the time and resources used for the processing of the radar returns but the overall cost of making this UWB radar would also reduce many folds.

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