28 GHz Scattering by Brick and Limestone Walls

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Introduction

As part of a project to develop rapidly deployable high data rate communications systems for disaster response, we are concerned with the characteristics of non-line-of-sight (NLOS) 28 GHz (US LMDS band) radio paths that reach their intended receiver via scattering and reflection from building walls. These “bounce paths” are frequently observed in coverage measurements when signals appear in shadowed areas that cannot be reached by line-of-sight (LOS) propagation[1-7]. While commercial operators would obviously avoid paths that depend on reflection from structures that they do not own and whose existence may be temporary, paths of opportunity may be vital in disaster and military situations where even the temporary establishment of a radio link may save lives.

Even though “bounce” paths are observed to deliver useful signal levels, many researchers think they are too dispersive to support high data rates. Building surfaces are quite rough at LMDS wavelengths, and this roughness should lead to diffuse reflection and a continuum of multipath components rather than the familiar specular reflection and discrete multipath components common to cellular telephone frequencies. To explore these issues, we are making time domain scattering measurements made using 7-nansoecond (measured between the –10 dB points) pulses of 28 GHz RF carrier generated by a novel Sampling Swept Time Delay Short Pulse (SSTDSP) sounder [8]. In this paper, we present data on the reflection coefficients of the walls and some observations on the pulse width expansion that results from diffuse scattering by the walls’ rough surfaces.

Equipment and Measurement Procedure

The SSTDSP sounder [8] operates in a bistatic mode with separate transmitter and receiver. The transmitter generates a fast pulse that is band limited to the desired bandwidth (approximately 250 MHz.). The resulting spectrum is up converted to 28 GHz and transmitted through a horn antenna. The receiver takes the scattered 28 GHz signal, down converts it, and feeds the down converted signal to a high-speed sampler. The sampler operates as a sliding correlator in the time domain. The sampler output is stored over a period of time and then displayed. Figure 1a shows the transmitted waveform in the time domain and Figure 1b shows its envelope, on which our measurements are based.

Figure 2 illustrates the geometry of the measurement setup. The transmitting antenna TX and receiving antenna RX are at distances d1 and d2 from the specular reflection point on the wall. The receiving antenna receives an LOS pulse that follows the path dLOS and then a scattered pulse from the wall. The specular component of the reflected signal arrives first, followed by diffuse components scattered by surface irregularities at points successively farther away from the reflection point.

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Typical results appear in Figure 3, showing the effects of diffuse scatter from brick and limestone walls. The antenna pattern makes the peak of the LOS signal appear smaller than the peak of the scattered waveform, and this effect is removed in later data processing. The signal scattered from the brick wall is slightly stretched in time by diffuse scatter from points lying at successively greater distances from the specular point. This effect is much more pronounced for the limestone wall, whose surface variations are comparable to a wavelength at the 28 GHz operating frequency. We are interested in the peak amplitude of the scattered signal for the information it contains about the specular reflection coefficient of the wall and in the pulse elongation (analogous to delay spread for specular multipath components) that the diffuse scattering introduces.

Reflection Coefficient Measurements

We can estimate the reflection coefficient for each incident angle set-up by using the following equation.

$$|\Gamma| = \frac{V_s}{V_{LOS}} \sqrt{g(q_{TX}) \cdot g(q_{RX})} \cdot \frac{(d_1 + d_2)}{d_{LOS}} \qquad (1)$$

where V_s is the maximum absolute voltage value of the specular reflection pulse and V_{LOS} is the maximum absolute voltage value of the LOS pulse. Quantities d_1, d_2 and d_{los} represent the distances from the transmitter and receiver to the wall and LOS distance for each measurement set-up. The ratio antenna gains are g ($_{TX}$) and g ($_{RX}$) for the transmitter and receiver and depend on the geometry of the setup. The reflection coefficient so calculated can be represented as the product of a Fresnel reflection coefficient and a scattering loss factor that includes the effects of surface roughness. Reliable values for either of these quantities are not available at 28 GHz for brick or limestone.

$$\Gamma_{rough} = \Gamma_{Fresnel} \cdot r_s \qquad (2)$$

Figure 4 presents the results of our reflection coefficient measurements for vertical (perpendicular to the plane of incidence) polarization. The results, including the scatter, are similar to those reported by Landron, et. al., [3] who measured the same walls at 4 GHz and to those reported by Kim, et. al., [5] for cement walls at 28 GHz. See Table 1 for a detailed comparison. We would expect our results to be smaller than either of these at small incidence angles (near normal incidence) because our walls are rougher than cement and our frequency is significantly higher than 4 GHz. At large incidence angles the incident field grazes the tops of the surface irregularities and the effects of the roughness are less important.

Pulse Spreading Effects

As Figure 3 illustrates, 28 GHz signals scattered by building walls indicate significant diffuse scattering from locations at some distance from the specular reflection point. While, as expected, the diffuse scattering effects are much larger for the rough limestone walls than the smoother brick walls, at this time dependences on incidence angle, distance to transmitter and receiver, cannot be quantified reliably. We are continuing to investigate them.

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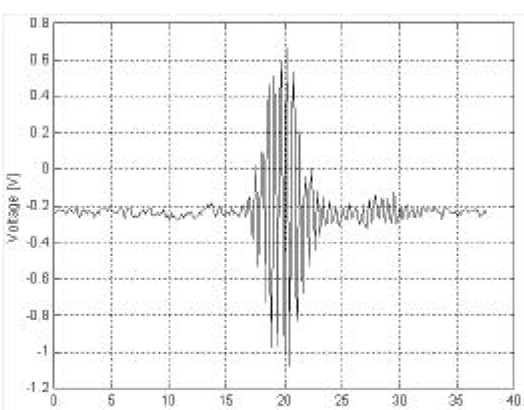

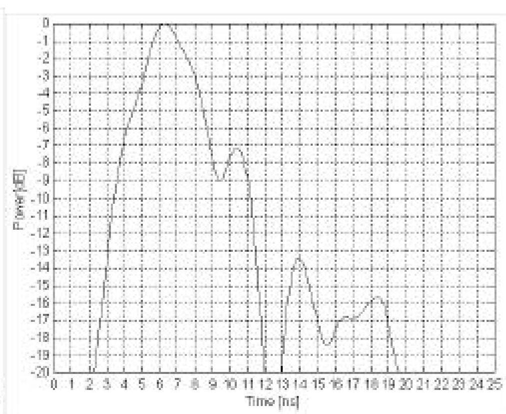

Figure 1a. Sounder waveform in time domain. Figure 1b. Waveform envelope.

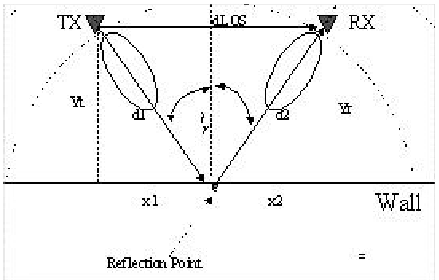

Figure 2. Measurement setup.

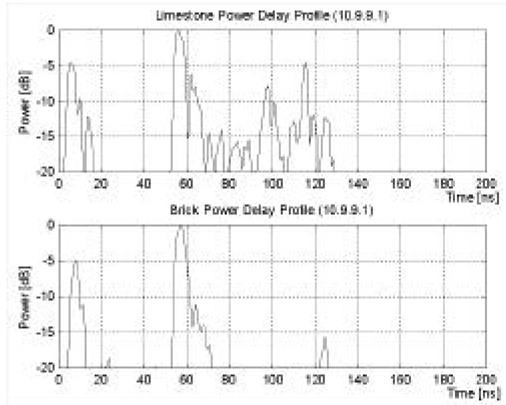

Figure 4. Power delay profiles for scattering by limestone and brick walls. The first waveform is the LOS signal and the second is the scattered signal.

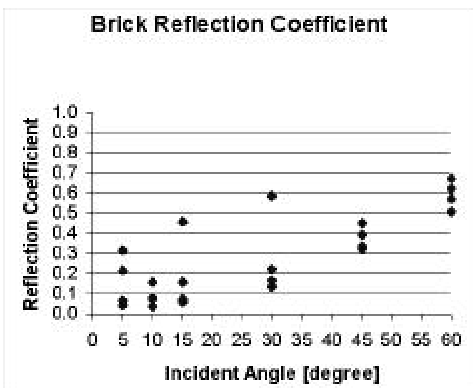

Figure 4a. Measured reflection coefficients for brick walls (vertical polarization).

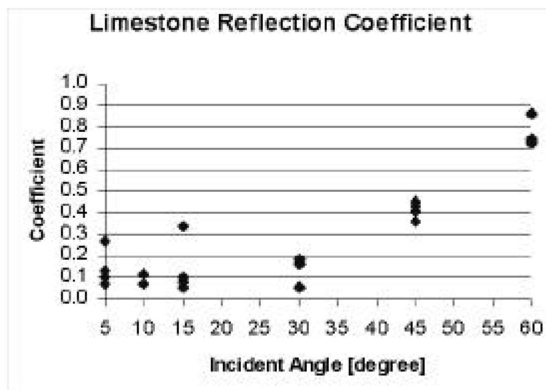

Figure 4b. Measured reflection coeffs. for limestone walls (vertical pol.)

Table 1. Comparison of reflection coefficients.

Wall	Incident angle	Present study (28 GHz)	Landron et. al. (4 GHz)	Kim et.al.(28GHz)
Limestone	0		~0.1 to 0.5	
	5	~ 0.1		
	10	~ 0.1		
	15	~ 0.1	~ 0.1 to 0.3	
	30	~ 0.2	~0.2 to 0.6	
	45	~ 0.4	~ 0.15 to 0.35	
	60	~ 0.7	~0.1 to 0.25	
Brick	0		~0.35	
	5	~ 0.1		
	10	~ 0.1		
	15	~0.1	~ 0.4	
	30	~ 0.2	~0.35	
	45	~ 0.4	~0.35	
	60	~ 0.6	~0.75	
Cement	5			~ 0.1
	10			~ 0.1
	15			~ 0.08
	30			~ 0.15
	45			~ 0.17
	60			~ 0.35
	70			~ 0.5