Exploration of the Rayleigh Roughness in THz medical Imaging

Shijun Sung[1], Neha Bajwa[2], Warren S. Grundfest[1,2,3], Zachary D. Taylor[2,3]

[1]Department of Electrical Engineering, University of California, Los Angeles, Los Angeles, CA, 90025 USA

[2]Department of Bioengineering, University of California, Los Angeles, Los Angeles, CA, 90025 USA

[3]Department of Surgery, University of California, Los Angeles, Los Angeles, CA, 90025 USA

***Abstract*—The effect of rough surface scattering on the contrast observed in THz medical imaging is explored. A Frequency Modulated Continuous Wave (FMCW) THz imaging system operating at a center frequency of 650 GHz with a time averaged bandwidth varied between ~ 0.01% and 1% bandwidth was used to image rough surface targets to explore the effect of rough surface scattering on the contrast observed in THz medical imaging. In addition to the commonly characterized expected power reflected in the specular direction we also ascertained the variance (second moment) of the power and computed the observed signal to clutter ratio (SCR). The results fit well to standard Rayleigh roughness theory and confirm that operating THz imaging systems at moderate incidence angles offer a significant increase in SCR at the minimal cost of spatial resolution.**

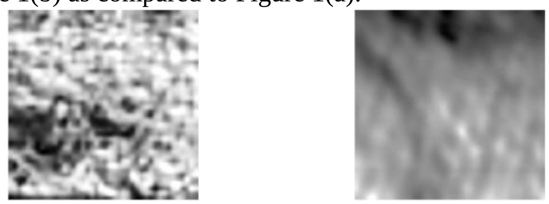
I. INTRODUCTION

The majority of THz medical imaging systems that acquire images in reflection mode display that the acquired signal is mostly sensitive to power reflected by the target in the specular direction. Theory of Rayleigh scatting from random surface are often used to model such behavior. Some Rayleigh roughness factor discussions [1] in the literature report experimental results with focused, broadband THz beams, yet there is a good agreement between experiment and theory which is based on assumptions of plane, single k-vector incidence wave. Another interesting observation in the literature is that the majority of the quantitative fits to experimental data are performed with the mean (first moment) of the Rayleigh roughness random variable [1] and few (if any) treatments discuss the variance (second moment) of the Rayleigh roughness random variable. Acquisition of both the mean and variance of the Rayleigh roughness random variable will allow the computation of a theoretical signal to clutter ratio (SCR) where the mean received power is normalized with respect to the variance of the received power as a function of incidence angle, wavelength, and spot size.

In our work we are pursuing windowless THz imaging where imaging systems comprised primarily of reflective optics are used to acquire non-contact images of the tissue of interest. We have observed in previous results that the SCR of the resulting images is much lower than the SNR and CNR and thus forms the performance limit of the system. We constructed a THz imaging system based on a narrow band amplified multiplier chain and performed imaging of rough targets with varying, characterized surface characteristics. The mean and variance of the signal was ascertained form the resulting image series and trends in SCR were computed and compared to theory.

II. RESULTS

A plot of two rough surface targets are displayed in Figure 1(a) and 1(b). Figure 1(a) was imaged at a 30 degree incidence angle with a 0.7 mm spot size. Figure 1(b) was imaged with a 45 degree incidence angle and 2.2 mm spot size. The increase in SCR as a result of increasing spot size and incidence angle is evident from the reduced overall observable contrast in Figure 1(b) as compared to Figure 1(a).



(a) (b)

Fig. 1: Effect of rough surface scattering on an image. (a) 0.7 mm spot size and 30 deg. incidence angle. (b) 2.2 mm spot size and 45 deg. incidence angle.

The first and second moments of pixel populations were computed and compared to the theory described in equation 1 and equation 2 [2].

$$<\rho> \; = \exp\left[-\frac{1}{2}\left(\frac{4\pi\sigma\cos\theta_1}{\lambda}\right)^2\right] \quad \textbf{(1)}$$

$$D\{\rho\} = \frac{F_3^2}{A^2}\int_0^{\infty}\int_0^{2\pi} e^{i(v_x\tau\cos\varphi+v_y\tau\sin\varphi)}[\chi_2(v_z,-v_z)-\chi(v_z)\chi^*(v_z)]\,\tau\, d\tau\, d\varphi \quad \textbf{(2)}$$

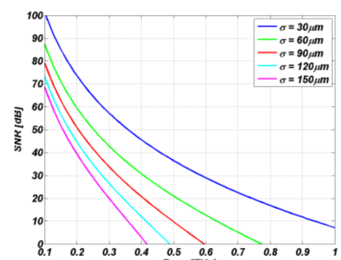


Fig. 2: Signal to clutter ratio as a function of spectrum and surface roughness

The results indicate that (1) the accuracy of the Rayleigh roughness theory extends to higher order moments and (2) the SCR at a surface roughness proportional to human skin may be too small to provide sufficient medical image quality suggesting that different optical designs need to be implemented to achieve non-contact imaging.

III. SUMMARY

Rayleigh roughness factor theory extends to higher order modes and can be used as a tool in the design of THz medical imaging systems.

REFERENCES

[1] R. Piesiewicz, C. Jansen, D. Mittleman, T. Kleine-Ostmann, M. Koch, and T. Kurner, "Scattering Analysis for the Modeling of THz Communication Systems," *Antennas and Propagation, IEEE Transactions on,* vol. 55, pp. 3002-3009, 2007.

[2] P. Beckmann and A. Spizzichino, *The scattering of electromagnetic waves from rough surfaces*. Norwood, MA: Artech House, Inc., 187.