

# Analysis and Comparison on Roughness at Millimetre Wave

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**Abstract**— This paper described for the propagation characteristics due to the rough surface of an object at millimeter wave. The analysis used the high frequency asymptotic approaches such as the ray tracing mechanism and Kirchhoff approximation. In results, the roughness of the surface at millimetre wave may make the deep fading. Therefore, the accuracy of the surface is so important to estimate the radio propagation characteristics at millimetre wave.

**Keywords**— roughness, millimetre, wave, propagation, kirchhoff

## I. INTRODUCTION

Millimeter wave technology is recognized as having potential for emerging markets, and there is a growing demand for support of 60 GHz systems [1], [2].

Propagation characteristics at millimeter wave are varied by the reflection including scattering according to periodic of the object roughness in indoor or outdoor environment. Because millimetre wave is very short wave length rather than the object roughness degree, the incident wave signal spreads out and reflects randomly around objects. Therefore, propagation characteristic research at millimeter wave is focused with respect to the validity of analysis results for propagation characteristic. When electromagnetic wave strike upon a smooth surface with finite conductivity, part of energy is reflected and part of energy is transmitted. And, their energies are related to the incident wave by reflection coefficient and transmission coefficient given by Snell's law [3]. In the other hand, when the surface is slightly or very rough, the incident wave is scattered into not only the specular direction, but also other directions. With increase of the surface roughness, the specular reflected field decrease, and the incoherent scattered field increases [4]. The most common criterion to describe surface roughness is the Rayleigh criterion [5].

Rayleigh criterion is based on a simplified surface scattering scenario and predicts the basic trends of rough surface scattering. This is a weak point that Rayleigh criterion do not reflect the detail scattering characteristics on various rough surfaces with periodic surface pattern. Therefore, scattering analysis need provide approximation theoretical results.

In this paper, first order Kirchhoff approximation (KA) method for periodic rough surface was theoretically provided [6]. Kirchhoff approximation is used to predict the reflection distribution between specular and diffuse reflection.

As another approach, the ray tracing (RT) and the uniform theory of diffraction (UTD) has been successfully used in prediction of wave propagation models for wireless applications [7].

RT method is the high frequency asymptotic approaches. RT methods have the capability to solve electrically large problems relative fast. Three dimension (3D) ray tracing technique utilizes the uniform asymptotic concepts formulated in terms of UTD.

In this paper, we analyze and compare with two approximation methods in order to verify for the analysis methods of propagation characteristic at millimeter wave.

## II. ROUGHNESS ANALYSIS

One approximation analysis use Kirchhoff Approximation (KA) method and the other is ray tracing (RT) model.

KA method in reference [6] is statistical model proposed by Ishmaru and is called the tangent-plane method.

Also, KA method is numerical method and available to solve the scattering problem for arbitrary geometries such as building structure or obstacles.

We here analyze the performance of the first order KA for a point source in an arbitrary rough medium.

RT in reference [7] is a method for calculating the path of waves or particles. RT based on the geometric optics approximation could be widely used to compute scattering properties of spherical particles.

Measurement of reflected and scattered signals is made for periodic surface at normal incidence as shown in Figure 1.

A transmitter and a receiver are pointed at the test product as shown in Figure 2.

Surface roughness of a medium is made by the root mean square height distribution in relate to wavelength and by the correlation length.

Periodic surface has sine wave pattern with periodic function,  $\xi(x) = h \cos Tx$ . Here,  $h$  depicts the amplitude of cosine function and is related to the depth of roughness.  $kh = 3$ , where,  $k = 2\pi/\lambda$  is wave number dependent on the frequency.  $T$  is  $2\pi/\Lambda$  and  $\Lambda$  means a surface cycle and is defined as multiple times of wavelength,  $\Lambda = 10\lambda$ .

Roughness medium dimension is shown in Figure 1. Product length,  $dx$  is 0.25m, the width,  $dy$  is 0.25m. A relative dielectric constant of test product is  $\epsilon_r = 3.5$  (acetal)

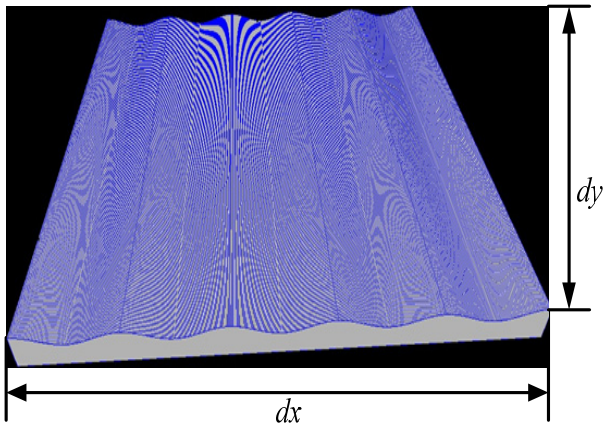


**Figure 1.** Roughness medium with periodic surface

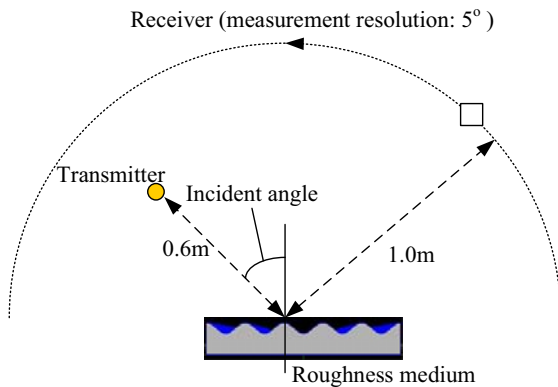


**Figure 2.** Measurement scenario

#### A. Analysis

As shown in Figure 2, transmitter is located with 0.6m radius in front of a roughness medium. And reflected waves received to receiver are measured around an arc with 1.0m radius. The test of both specular and non-specular reflection is performed at 60GHz.

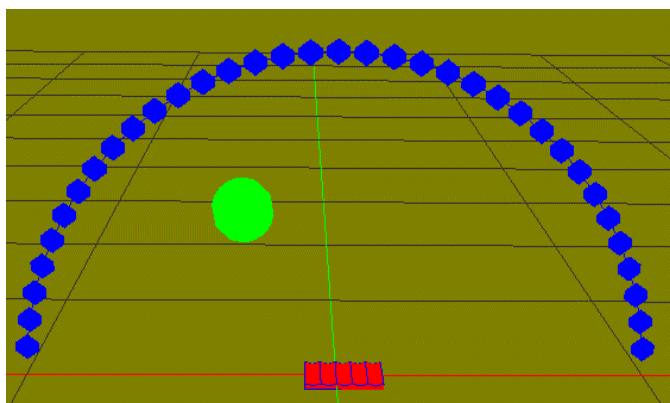


**Figure 3.** Geometrical modelling using ray tracing approximation

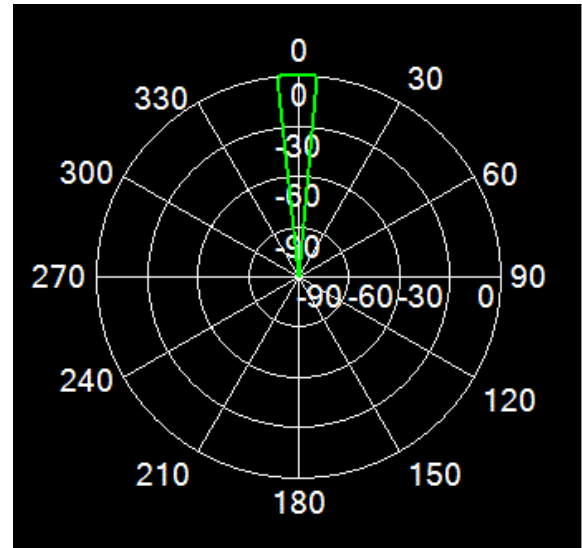


**Figure 4.** Antenna deployment in ray tracing approximation

Physical propagation like received signal strength and pathloss could be provided from the deterministic model such as ray tracing (RT). Deterministic model are physically meaningful, and potentially accurate. RT model uses the theory of geometrical optics to treat reflection and transmission on the plane and diffraction on edges. Reflections are accounted for by applying the Fresnel reflection coefficients, whereas for diffractions the field is multiplied by appropriate diffraction coefficients obtained from the uniform geometrical theory of diffraction. The geometrical modelling of the test for the ray tracing simulation is depicted in Figure 3. This Figure 3 is the same dimensions with roughness medium in Figure 1. For the analysis, we chose an transmitter and receiver antenna with beam width of  $12^\circ$  in azimuth and vertical pattern such as Figure 4. For the analysis, the ray tracing tool was set to analyze the propagation response. In the analysis, the direct, reflected, transmitted and diffracted rays up to three order. Figure 5 shows the scattered rays on roughness medium.

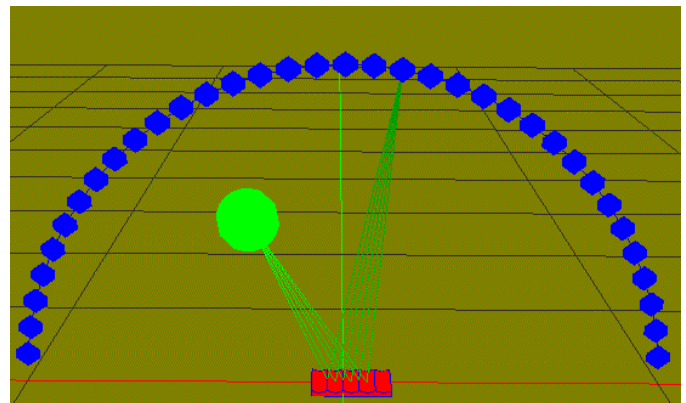


**Figure 5.** Ray path searching in ray tracing approximation

### III. RESULTS

Figure 6 to Figure 9 shows results of scattering characteristic at  $kh=3$ . Figure 6 and Figure 7 are results on Kirchhoff approximation (KA) at the incident angle of  $30^\circ$  or  $40^\circ$ , respectively. Figure 8 and Figure 9 are results on ray tracing (RT) approximation at the incident angle of  $30^\circ$  or  $40^\circ$ , respectively. As results, KA results are reasonable agreement with scattering degree.

### IV. CONCLUSIONS

We compared with Kirchhoff approximation and ray tracing approximation results. Kirchhoff approximation results showed reasonable agreement with ray tracing results to solve periodic rough surface problems. Finally, there is proved that the provided approximation methods are possible to support to extract practical scattering characteristics.

The paper described for the propagation characteristics due to the rough surface of an object at millimeter wave. The analysis used the high frequency asymptotic approaches such as the ray tracing mechanism. In results, the roughness of the surface at millimetre wave may make the deep fading. Therefore, the accuracy of the surface is so important to estimate the radio propagation characteristics at millimetre wave.

### ACKNOWLEDGMENT

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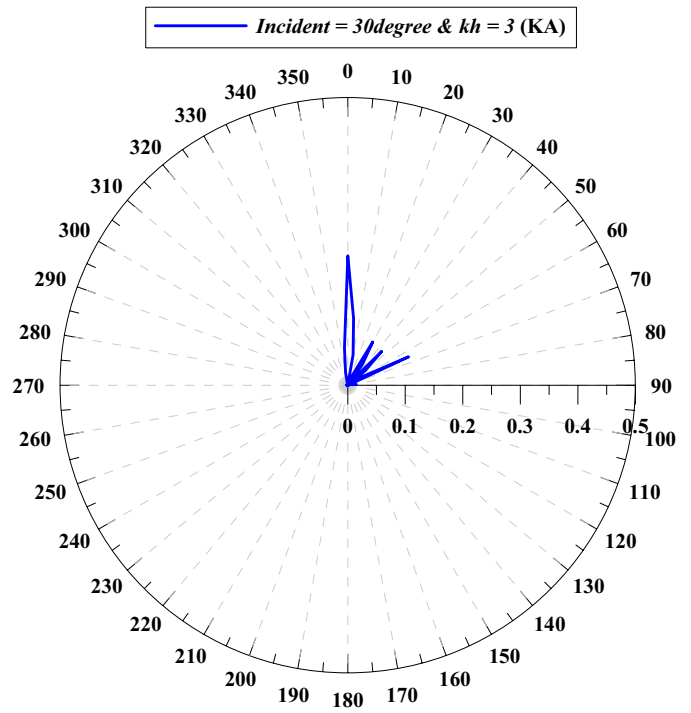


Figure 6. Results on KA approximation at  $30^\circ$  incident angle (polar)

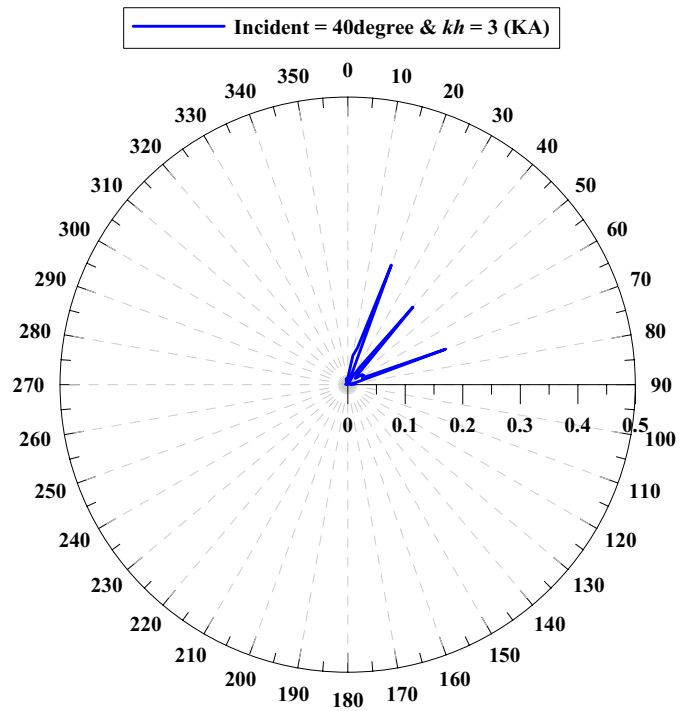


Figure 7. Results on KA approximation at  $40^\circ$  incident angle (polar)

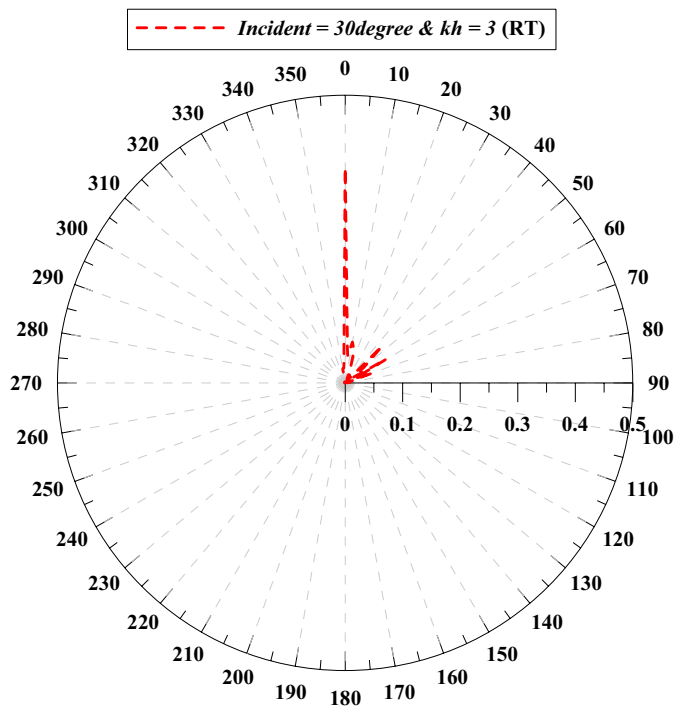


Figure 8. Results on RT approximation at 30° incident angle (polar)

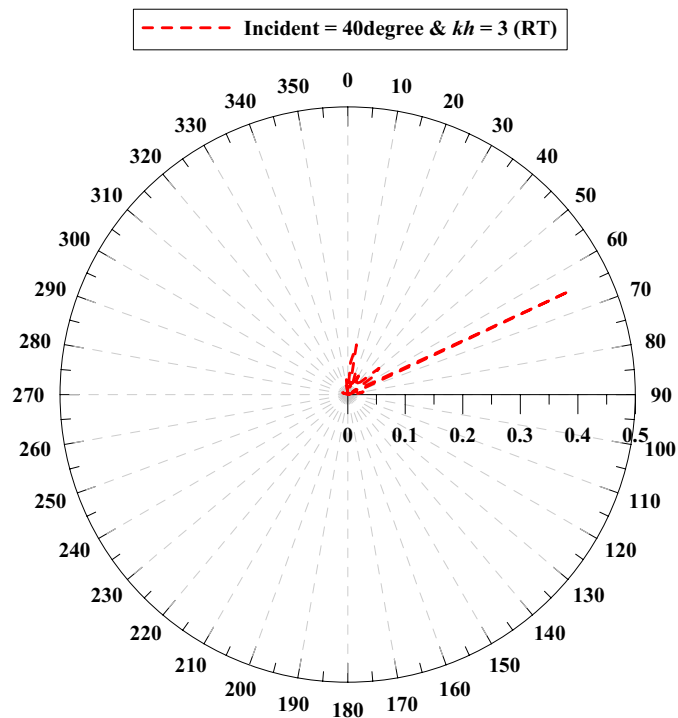


Figure 9. Results on RT approximation at 40° incident angle (polar)