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A New Predictive Hypothesis for Phase Difference Reflection in GHz

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Abstract: Wave phase difference is a fundamental property that characterises the relative behaviour of transmitted signals. It has significant roles in signal wave analysis and in interpreting various propagation phenomena, which are crucial when designing wireless links and various applications in signal processing techniques, optics, as well as acoustics. This study investigated the concept of phase difference significance based on high frequencies (i.e., 1.0, 2.4, 10.0, and 20.0 GHz). Several phase difference models and their shortcomings were reviewed to emphasise the need for greater accuracy and precision in quantifying phase differences. The outcomes revealed that 1 GHz contributed to the lowest phase difference among the other frequencies. The constructive signal may be deployed to provide a better link build-up. Overall, determining the importance of phase difference in GHz and identifying the signal attitude substantially contribute to the advancement of wave analysis, while simultaneously encouraging further exploration in this domain.

Keywords: Phase Difference; Wavelength; Reflection; Frequency; Signal Propagation

1. Introduction

Phase difference refers to the variation between the phase angles of two waves, which can occur when the signal hits the surface and is reflected depending on the properties. Signal reflections on the conducting lines generally display a phase shift from the incident signal. Short circuits (closed line) and open circuits (broken line) are extreme examples of termination, in which a change can occur in the reflected wave in both circumstances. The amplitude, wavelength or phase of the reflection at the surface of the separation of two media may change. However, a change in amplitude or wavelength can illustrate a clear difference between incident and reflected light [1].

The phase difference between waves has a crucial role in interference, diffraction, and wave interactions. It affects the resulting wave patterns, amplitudes, and constructive or destructive interference impacts. Measuring and controlling the phase difference between waves is important in various applications, such as telecommunications, signal processing, optics, and acoustics.

The numeric value of the phase is determined by the subjective choice of the start of each period and the angle interval, which can be influenced by wavelength when frequency is applied. When there is no difference between the phases, the two signals are in phase with each other; otherwise, they are out of phase [2].

When two signals are placed together, they form a constructive interference that increases the signal amplitude and the entire wave, such as that observed in a microphone device that works under the constructive phase phenomenal. However, two waves that cancel each other lead to zero wave; known as destructive interference [3]. In some transmission techniques, including microwave transmission technology, the phase shift device can control the Radio Frequency signal in phased arrays to steer the signal in various directions without moving the antenna.

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The effect of reflector curvature on signal amplitude and phase changes for reflected and transmitted waves between general anisotropic media revealed that, via comparison between numerical and analytical outcomes, using plane-wave reflection coefficient without correction for the interface effect could lead to inaccurate interpretation of AVA/AVO analysis (note: AVO refers to amplitude-versus-offset and AVA represents amplitude-versus angle) [4].

Many scholars have explored phase differences in various aspects. For instance, the principle of phase difference mask resulted in destructive interference and attained better image contrast [5]. In another study, a minor phase difference was measured in a fibre interferometer for pressure sensing [6]. Next, a study on electron-proton deuteron scattering examined the intermediate energies reported in [7] and found that the near-similar sets significantly differed from the initial values and this enhanced the reliability of the final parameter values.

Overall, the phase of a wave is determined by several factors, including the frequency, wavelength, and starting point of the wave. The phase difference between two waves denotes the angular difference between their respective phases at a given point in time or space. It quantifies how much a wave has shifted or delayed relative to the other. As such, this study examined the impact of GHz wavelength on the predictive phase difference, which is substantially significant to wireless engineers when designing links.

The rest of this paper is as follows: Section two explains the model approach and the equations. Section three presents the results. The final section concludes this study.

2. The Model Approach

Physical surfaces are assumed to be rough while roughness influences the dispersion of electromagnetic waves. The degree of roughness of a scattering surface cannot be considered a fundamental characteristic of that surface; instead, it is determined by the properties of the transmitted wave. The frequency of the transmitted wave and the angle of incidence both affect the roughness or the smoothness of a surface look. Ks refers to the relationship between Electromagnetic wavelength and statistical roughness parameters, with k = 2π/λ. The local incidence angle is crucial when assessing surface roughness, especially in the near field where the propagation is rougher than in the far field. Fresnel reflection may be defined as an ideal smooth surface that serves as a function of the transmitted and reflected angles, as well as the scattering dielectric constant. Fresnel reflection coefficient is expressed as follows: $R_{V,H} = \rho_{V,H} e^{j\Psi_{V,H}}$ [8]

$$R_{V,H} = \rho_{V,H} e^{-j\Psi_{V,H}} = \frac{\sin\psi - a_{V,H}\sqrt{\varepsilon - \cos^2\psi}}{\sin\psi + a_{V,H}\sqrt{\varepsilon - \cos^2\psi}} \tag{1}$$

Where $R_{V,H}$ is a plane wave Fresnel reflection coefficient for vertical and horizontal, ψ denotes the grazing angle on the reflecting surface, ε_r and σ are relative permittivity and electrical conductivity, respectively, of the reflecting surface, $a_V = 1/\varepsilon$ indicates vertical polarisation, and $a_H = 1$ signifies horizontal polarisation transmission.

This study examined the interaction of the transmitted EM wave with the surface of different roughness levels based on phase angle, which can change in accordance with wavelengths. Diffuse surfaces are more likely to cause directional scattering than smooth ones. From the electromagnetic standpoint, categorising a surface as smooth or rough is entirely subjective.

Both Rayleigh and Fraunhofer criteria that specify a smooth surface are elaborated in [9]. The phase difference between two rays distributed from distinct points on the surface of an angle-transmitted plane homogenous wave is illustrated in the following:

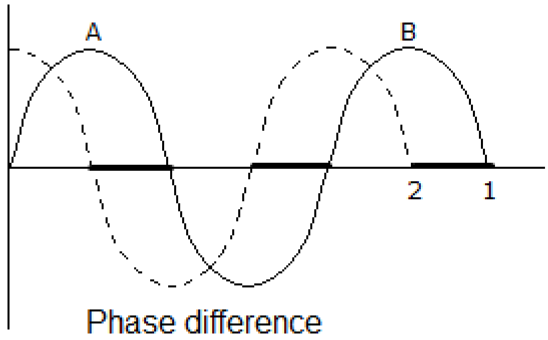

Figure 1. illustrates the phase difference terminology.

Referring to Figure 1, the sine and cosine waves demonstrate the differences in surface waves that reflect the signal behaviour in terms of amplitude and angle. Mathematical-wise, Maxwell's equations are the best way to deal with the wave equation [10]:

$$\nabla^2 E - \mu\varepsilon \frac{\partial^2 E}{\partial t} = 0 \tag{2}$$

Assuming that the propagation is in the X direction, then $\frac{\partial}{\partial t} = j\omega$

$$\frac{\partial^2 Ey}{\partial x^2} = -\ \omega^2 \mu\varepsilon E \tag{3}$$

Hence,

$$Ey\ (x) = A\ e^{-j\ \omega\sqrt{\mu\varepsilon}x}\ + B\ e^{j\ \omega\sqrt{\mu\varepsilon}x} \tag{4}$$

Upon placing time consideration,

$$Ey\ (x,t) = A\ e^{j(\omega t - \beta x)}\ + B\ e^{j(\omega t + \beta x)} \tag{5}$$

Commonly used in the engineering domain, Equation 5 represents wave propagation that is applicable to analyse various wave phenomena, including interference, propagation, and diffraction, which enables the modelling of wave behaviour in varying contexts. Here, Ey(x, t) represents the electric field component in the y-direction as a function of position (x) and time (t).

A and B refer to complex constants that determine the amplitude and phase of the wave, $e^{j(\omega t - \beta x)}$ and $e^{j(\omega t + \beta x)}$ are complex exponential functions that describe the spatial and temporal behaviour of the wave, ω indicates the angular frequency related to frequency (f) by ω = 2πf, and β denotes the wave number related to wavelength (λ) by β = 2π/λ.

The phase shift can be determined by taking the derivative of Equation 5 in light of x, while treating A, B, ω, and t as constants. This results in the following:

$$\mathrm{dEy/dx} = -\mathrm{A}\ \beta\ e^{j(\omega t - \beta x)} + \mathrm{B}\ \beta\ e^{j(\omega t + \beta x)} \tag{6}$$

Referring to Equation 6, the two parts represent the incident and reflected waves, where the phase shift is attainable through the reflected part by considering $e^{j(\omega t - \beta x)} = e^{-j\theta}$. While standard deviation σ describes variability, amplitude A represents magnitude. They are both relevant aspects of each other and to the wave, besides being equal to η. Since the phase difference is concerned with the phase component, the following equation is obtained after applying some trigonometry for simplification of use:

$$\Delta\emptyset = 2\eta\beta e^{-j\theta} \tag{7}$$

Which is

$$= 2\eta\beta\ (cos\theta - sin\theta) \tag{8}$$

The $cos\theta - sin\theta$ calculates the difference between the cos and the sin of angle θ, and multiplying it by $2\eta\beta$ generates the overall phase difference that would quantify the phase difference in terms of the provided parameters.

The model proposed in this study was examined based on a set of high frequencies (1 to 20 GHz) to determine the impact of wavelength on the phase.

3. Results and Discussion

This study assessed 1.0, 2.4, 10.0, and 20.0 GHz (equivalent to 0.29, 0.12, 0.02, and 0.01 wavelengths in meter, respectively) to distinguish the comprehensive phase shift notion that offers significant outcomes by using Matlab simulation software. The results retrieved for each wavelength were combined to determine the impact. The following figures elucidate the concept.

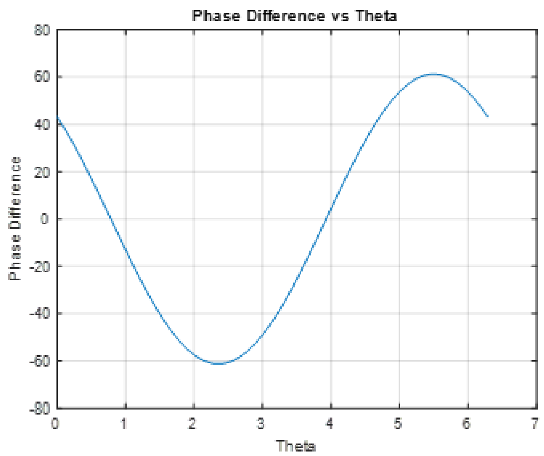

Figure 2. Phase difference at 1.0 GHz.

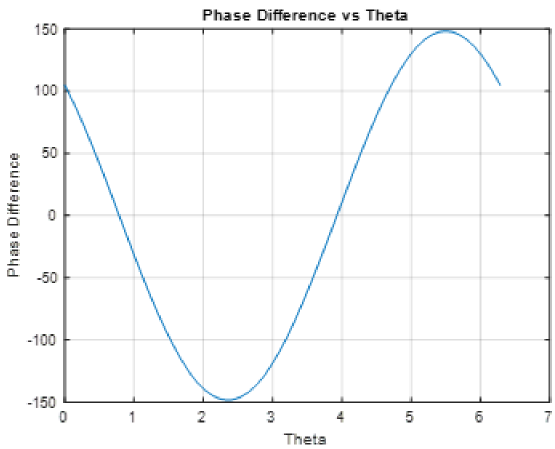

Figure 3. Phase difference at 2.4 GHz.

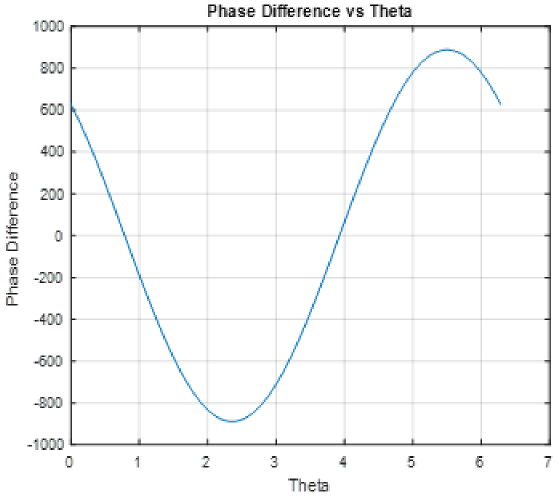

Figure 4. Phase difference at 10.0 GHz.

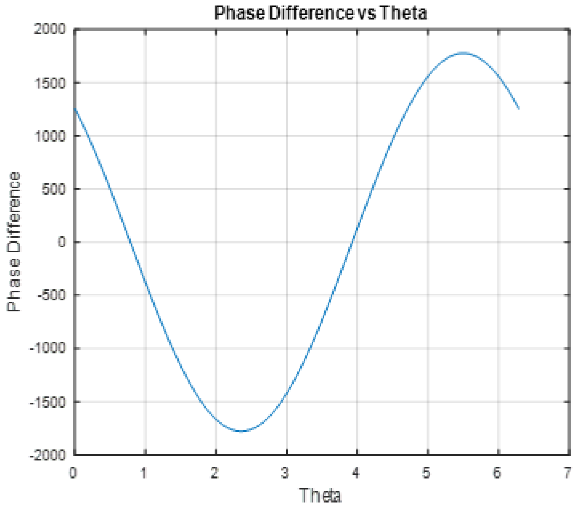

Figure 5. Phase difference at 20.0 GHz.

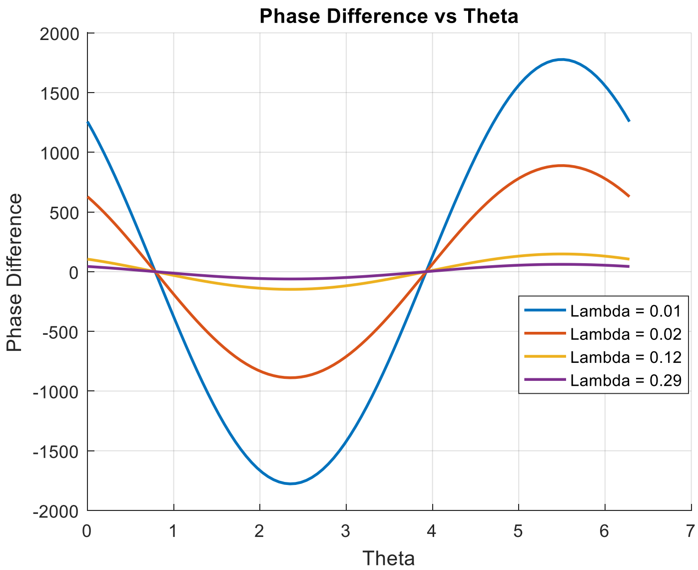

Figure 6. Phase difference at GHz frequency up to 20 GHz.

Since varying wavelengths lead to different phase differences, careful attention should be given while constructing the wireless link to accept such events favourably. As explained earlier, the simulation successfully adapted to the constructive interface after several considerations.

4. Conclusion

The phase difference in GHz is significant due to the technological revolution that suggests occurrences at high frequencies. This study addressed the phase when dealing with a set of GHz frequencies (i.e., 1.0, 2.4, 10.0, and 20.0 GHz equivalent to 0.29, 0.12, 0.02, and 0.01 wavelengths in meter, respectively). The findings revealed that 1 GHz (0.29 m wavelength) recorded the lowest phase shift; signifying that lower frequencies dealt better than higher frequencies in terms of phase difference. The construction interference should be handled in that band to allow for profound advantages when designing wireless links, while otherwise takes place when destructive interference is observed between the waves. Future research endeavours may look into the combination of wave phase difference with intelligent surfaces.

Acknowledgments: University Malaysia Pahang, Malaysia

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