Measurement and evaluation of Scattering parameters for Surface wave communication-based waveguide at millimetre range frequency band

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Abstract. The surface wave communication-based waveguide (SWW) can replace copper traces to cater millimeter wave frequency bands with loss losses [1], the efficiency of the proposed waveguide has been analyzed considering various factors like surface impedance, dispersion, power flow and attenuation. We have been focused on scattering parameters and Voltage standing wave ratio (VSWR) in this article which are also the fundamental factors to analyze the signal loss, at the frequency range 50 GHz to 150 GHz, we have compared the theoretical entities of these parameters with the simulated results. The entire analysis and comparison prove that the optimum scattering parameters and VSWR were achieved with the proposed SWW as per the expectations than existing copper traces, we have considered copper as the conductor, Teflon as the dielectric material keeping the thickness of the conductor and dielectric at 0.2mm, the entire simulation performed using CST Studio suite.

1 Introduction

The surface wave communication-based wave guide (SWW) performs well at the millimeter wave frequency band especially between 50 GHz and 150 GHz with low loss signal transmission [2], this article focused to determine the efficacy of the SWW in terms of the scattering parameters and VSWR, these parameters relate the loss quotient of the waveguide. The article determines the scattering parameters and VSWR for the proposed SWW both analytically and through simulation using CST studio suite, we have considered the structure of proposed SWW as stated in [3] with the combination of copper and Teflon, this combination proved to be effective for surface wave communication at millimeter wave frequency bands. Scattering parameters describes the response of the waveguide in terms of the incident wave, we are considering the analysis in terms of wave due to the high frequency state, and the VSWR determines the impedance matching in the SWW, the low level of VSWR indicates the good impedance matching and minimal losses with less reflections.

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The evaluation of the proposed SWW waveguide in terms of scattering parameters and VSWR at the frequency band from 50 GHz to 150 GHz has been included in this article, we have analyzed the relation between the S parameters and VSWR with the power flow and surface impedance at above mentioned frequency ranges. The complete analysis was performed at the specific dimensions, structure and component properties of the proposed SWW, ideally the scattering parameters which defines the signal reflection and the VSWR which measures the impedance matching should be low as per the analysis, the verification of these parameters with empirical and idle conditions is part of this article, we have presented the simulation results in this article. In precisely the entire analysis was made at the optimum surface impedance value of 100 Ω, at this stage the proposed waveguide behaves well in propagating the surface waves with low amount of attenuation loss [3]. The surface impedance at the millimeter frequencies is purely inductive and should be optimum in order to maintain the signal propagation, the surface impedance decides the power flow and the field confinement which eventually relates the signal attenuation, the corresponding relations discussed below.

$$X_s = 2\pi f \mu_0 \left[\frac{\varepsilon - 1}{\varepsilon} |T_d| + 0.5\Delta\right] \qquad (1)$$

This article provides the holistic approach in measuring the scattering parameters and VSWR in the form of literature survey in chapter II, followed by evaluation of relations between the S parameters and VSWR in terms of losses regards to the proposed SWW in chapter III, chapter IV focus on the measurement of these parameters bases on SWW specification with corresponding results and discussions followed by conclusion.

2 Literature Survey

The scattering parameters determines the reflection of the wave in response to the incident wave at the particular port should be less enough of 0 dB in the idle conditions with VSWR of less than 2 defined by Songlin Yan *et.al* [4] is the benchmark to set the conditions for our proposed waveguide SWW. The relation between the scattering parameters and the signal loss factor determined in [5] concludes that the impact of these parameters in ascertaining the performance of the proposed SWW. The authors of [6] proposed the impact of scattering parameters in the wave traversal, we have analyzed the outcome of the article to conclude the loss less wave distribution across the SWW. Zhu, Hankai *et.al* [7] defines the frequency relation with the scattering parameters and reflection factors, considering this outcome we have proposed the frequency benchmarks for effective wave propagation across the SWW. The surface current and corresponding frequencies also impacts the efficacy of the wave propagation across the proposed channel, the authors [8] provide the relation between those entities of surface current and frequency [9], we have considered all these factors concluded in the above articles to maintain the efficacy of the proposed channel for millimeter range frequency bands for low loss communication between the integrated circuits maintaining the optimum levels of scattering parameters and VSWR [10].

3 Evaluation of S-Parameters and VSWR for SWW

The proposed SWW consists of a conductor and dielectric which propagates the waves with the surface wave phenomenon. The effectiveness of the signal propagation across the waveguide relies on low-loss phenomena which maintain various factors like high field confinement at the interface, dispersion and optimum surface impedance. Apart from these factors, the efficiency will be decided based on scattering parameters and VSWR. As stated above, this section primarily focuses on determining the scattering parameters and VSWR.

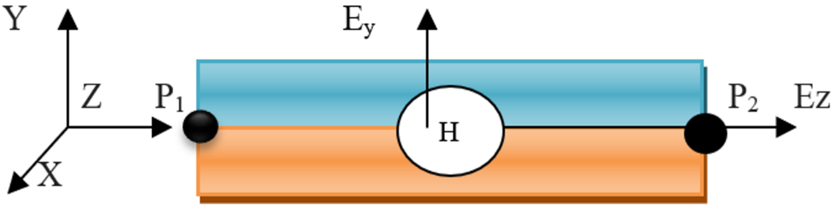

Fig.1. Proposed SWW with TM mode of propagation.

The above picture depicts the SWW considering two ports, P1 and P2. To analyze the scattering parameters in this case, we have considered the incident and reflected wave parameters at port 1 and port 2, and the scattering parameter analysis at port 1 is discussed below.

$$A_1 = \frac{V_1{}^{INCI}}{\sqrt{Z_0}} = \frac{INCIDENT\ VOLTAGE\ WAVE\ (port\ 1)}{\sqrt{Z_0}} \qquad (2)$$

$$B_1 = \frac{V_1{}^{REFL}}{\sqrt{Z_0}} = \frac{REFLECTED\ VOLTAGE\ WAVE\ (port\ 1)}{\sqrt{Z_0}} \qquad (3)$$

The power representation at port 1 is represented as

$$P_1{}^{INCI} = \frac{1}{2}|A_1|^2 = \frac{|V_1{}^{INCI}|^2}{2Z_0} = \frac{|I_1{}^{INCI}|^2}{2} Z_0 \qquad (4)$$

$$P_1{}^{REFL} = \frac{1}{2}|B_1|^2 = \frac{|V_1{}^{REFL}|^2}{2Z_0} = \frac{|I_1{}^{REFL}|^2}{2} Z_0 \qquad (5)$$

The generalized considerations for A_I and B_I for any port is defined as

$$A_I = \frac{V_I + I_I Z_0}{2\sqrt{Z_0}} \qquad (6)$$

$$B_I = \frac{V_I - I_I Z_0}{2\sqrt{Z_0}} \qquad (7)$$

Solving the above equations, we will get voltage and current parameters as shown below.

$$V_I = (A_I + B_I)\sqrt{Z_0} = V_I{}^{INCI} + V_I{}^{REFL} \qquad (8)$$

$$I_I = \frac{1}{\sqrt{Z_0}}(A_I - B_I) = \frac{V_I{}^{REFL}}{Z_0} \qquad (9)$$

To trigger the harmonic excitation

$$v(t) = Re\{Ve^{j\omega t}\} \tag{10}$$

The incoming power at port i is shown below.

$$P_i = \frac{1}{2} Re\{V_i {I^*}_i\} \tag{11}$$

$$P_i = \frac{1}{2}(a_i {a^*}_i - b_i {b^*}_i) \tag{12}$$

The relation between the incident and reflected coefficients is discussed below.

$$B_1 = S_{11}A_1 + S_{12}A_2 \tag{13}$$

$$B_2 = S_{21}A_1 + S_{22}A_2 \tag{14}$$

The representation of the scattering parameters, S_{11} is the input reflection parameter when the output of the waveguide terminated with matched load ($A_2 = 0$), S_{21} measures the transmission coefficient in forward direction (Port 1 to Port 2), S_{12} measured the transmission in reverse direction (Port 2 to Port 1) and S_{22} is the output reflection parameter, based on the above analysis we have been evaluated of these scattering parameters specifically as shown below.

$$S_{11} = \frac{B_1}{A_1} = \frac{V_1 - I_1 Z_0}{V_1 + I_1 Z_0} = \frac{Z_L - Z_0}{Z_L + Z_0} \tag{15}$$

$$S_{11} = \frac{Z}{Z + 2Z_0} \tag{16}$$

Similarly,

$$S_{21} = \frac{B_2}{A_1} = \frac{V_2 - I_2 Z_0}{V_1 + I_1 Z_0} = \frac{2Z_0}{Z + 2Z_0} \tag{17}$$

Considering the symmetric condition $S_{11} = S_{22}$ and $S_{12} = S_{21}$, the outcome is shown below

$$S_{11} + S_{21} = 1 \tag{18}$$

$$S = \begin{pmatrix} \frac{Z}{Z+2Z_0} & \frac{Z+Z_0}{Z+2Z_0} \\ \frac{Z+Z_0}{Z+2Z_0} & \frac{Z}{Z+2Z_0} \end{pmatrix} \tag{19}$$

The insertion loss in this case shown below

$$Insertion\ Loss = -20log|S_{21}| \tag{20}$$

The ideal conditions for transmission of the surface waves defined as

$$S_{11} = S_{22} = 0 \tag{21}$$

$$S_{21} = S_{12} = e^{-\gamma l} \tag{22}$$

$$S_{21} = 0dB \tag{23}$$

Here,

$$\gamma = \alpha + j\beta \tag{24}$$

Were γ is the propagation constant of the proposed SWW, α is the waveguide attenuation and $\beta$is the phase constant, we have considered S_{21}=|1| in the analysis keeping loss less condition, the Voltage standing wave ratio (VSWR) factor is

$$VSWR = \frac{1+|S_{11}|}{1-|S_{11}|} \tag{25}$$

This analysis proves the relation between SWW, the scattering parameters and VSWR, which are related to the transmission losses.

4 Scattering Parameters for SWW

The above analysis on the scattering parameters and VSWR applied on the surface wave communication-based wave guide (SWW), we have considered the impact of surface reactance X_s with the scattering parameters at the frequency range of 20 GHz to 180 GHz with copper as the conductor and Teflon as the dielectric, the reflection coefficient and transmission coefficient were measured at different values of surface reactance specifically at 100 Ω and 150 Ω, the reflection and transmission impact of the SWW depends on the impedance and especially for the proposed channel the surface reactance plays vital role.

$$X_s = 2\pi f \mu_0 \left[\frac{\varepsilon - 1}{\varepsilon} |T_d| + 0.5\Delta\right] \tag{26}$$

From the above equation the scattering parameters impacted by the surface reactance which directly related by the dimension of the proposed waveguide, where T_d is the thickness of the dielectric medium of the proposed waveguide, we have considered 100 Ω and 150 Ω of surface reactance due to the strong field confinement and less dispersion at this range for the proposed waveguide. The measurement of the scattering parameters for the SWW considered at three different values of dielectric thickness 0.2mm, 0.3mm and 0.4mm, we are presenting the justification to consider the right dimensions of the proposed waveguide measuring the scattering parameters, for the ideal waveguide the reflection coefficient should be considerably less in terms of dB and the transmission coefficient should be high enough in terms, the empirical outcomes for the SWW based on the analysis has been projected in the upcoming graphical representation. The reflection coefficient which represents scattering parameters S_{11} has been measured for SWW, the figure 2 represents the reflection coefficient vs frequency at two different surface reactance of the waveguide which are 100 Ω and 150 Ω respectively at 0.2mm of dielectric thickness, the measured values were observed based on the above mathematical evaluation discussed earlier, the reflection coefficient is optimum of around -140 dB at 100 GHz of transmission frequency at 100 Ω of waveguide surface reactance compared to the 150 Ω level, the situation is near to the ideal conditions of the loss less medium, similarly we have analyzed the same scenario at the dielectric thickness of 0.3 mm and 0.4 mm thickness as shown in the figure 3 and figure 4.

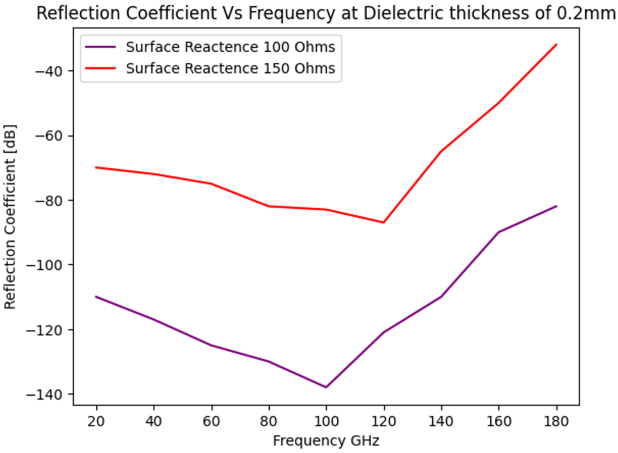

Fig.2. Reflection coefficient at 0.2 mm of dielectric thickness.

The dielectric thickness affects the surface reactance which eventually impacts the scattering parameters at different frequencies as per the above analysis, the similar behavior has been observed, figure measure the reflection coefficient at 0.3 mm of the dielectric material thickness and the performance is degraded in terms of scattering parameter at this level when compared to figure 2, we have observed the reflection coefficient is around -70 dB at 80 GHz of frequency, figure 4 depicts the parameters at 0.4mm of dielectric thickness, and the parameter still degrades at this level of – 25 dB at 60 GHz.

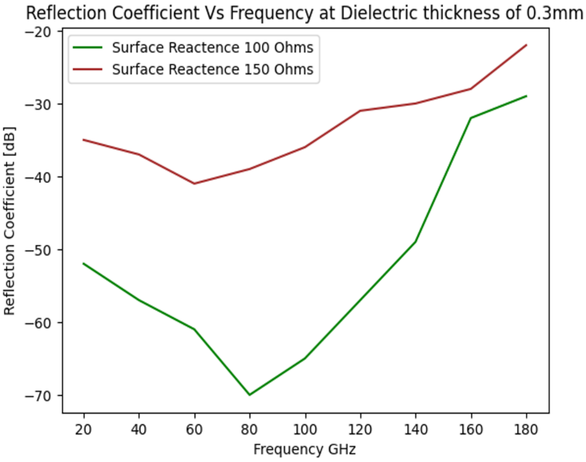

Fig. 3. Reflection coefficient at 0.3 mm of dielectric thickness.

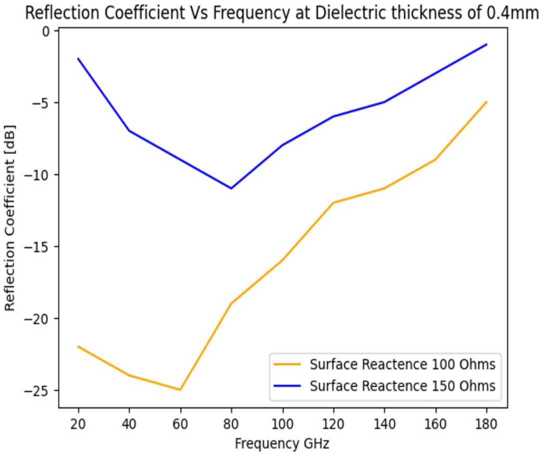

Fig. 4. Reflection coefficient at 0.4 mm of dielectric thickness.

Whenever the dielectric thickness changes, the surface reactance changes drastically making the waveguide vulnerable to losses at millimeter range frequencies, the same has been reflected on our above findings. We also measured the transmission coefficient with the same conditions in order to evaluate the proposed SWW in terms of losses reduction at the mentioned frequency range, as discussed earlier the transmission coefficient should be high enough for the ideal conditions, the similar outcome has been observed at 0.2 mm of dielectric thickness of around -1 dB at 100 GHz as shown in figure 5.

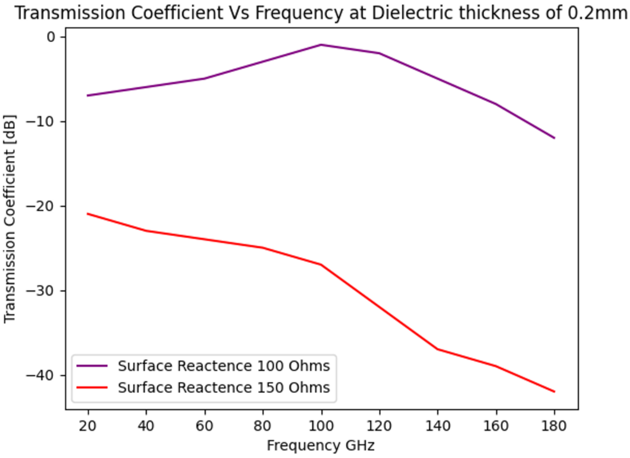

Fig. 5. Transmission coefficient at 0.2 mm of dielectric thickness.

Similarly, we have measured the transmission coefficient at the levels of 0.3 mm and 0.4 mm dielectric thickness as shown in figure 6 and 7.

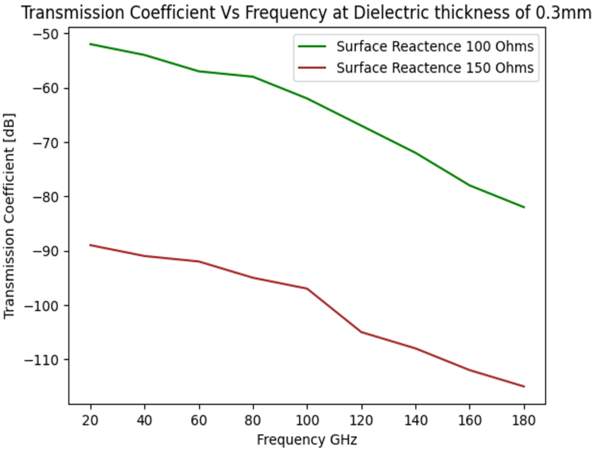

Fig. 6. Transmission coefficient at 0.3 mm of dielectric thickness.

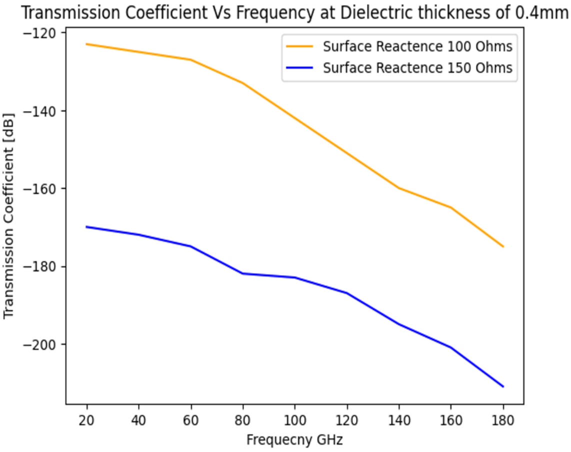

Fig. 7. Transmission coefficient at 0.4 mm of dielectric thickness.

5 Conclusion

The efficiency of the proposed surface wave communication-based waveguide for losses reduction at millimeter wave frequency decided by the optimal value of the scattering parameters in terms of reflection and transmission coefficients. The low loss condition was achieved at a specific surface reactivity value that has an effect on the surface wave field confinement and low dispersion, based on mathematical and empirical evaluation, based on the optimal scattering parameters observed during the evaluation, it can be concluded that the proposed SEE waveguide has less lossy conductors such as copper and Teflon. Precisely, the scattering parameters, which are reflection and transmission coefficient, were optimal at 100 GHz of signal frequency, 100 Ω of waveguide surface reactance and 0.2 mm of dielectric thickness, which are about -140 dB and -1 dB respectively. Based on this observation, it has been concluded the proposed SWW is effective at 100 GHz frequency level with low losses for communication when compared to the conventional copper traces.

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