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# A Broadband Transmission Line at mm-Wave Frequency (DC-60GHz) Using Metamaterial Spoof Surface Plasmons

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## Abstract

Transmission lines are the basic foundation of any microwave to millimeter-wave integrated circuits. Many efforts have been made to fulfill the demand of the increasingly higher bandwidth and high capacity wireless communication system. This paper reports the design, analysis, and characterization of a broadband and miniaturized transmission line based on the spoof surface plasmonic metamaterial, which operates from DC-60 GHz frequency band. An RT/duroid5880 microwave laminate having a dielectric constant of *2.2* and a height of *254* micrometers has been used to design and fabricate this proposed structure. The size of the whole structure is *20*mm *X 13*mm. Spoof surface plasmon supports highly confined surface modes at the metal-dielectric interface, which offers miniaturized and low-loss RF components with lower cross-talk and mutual coupling as compared to existing conventional planar technology e.g. microstrip. The designed spoof plasmonic structure supports broadband and higher data rates for signal propagation and will pave a path for the development of the next-generation wireless communication system.

## 1. Introduction

Due to the huge demand for higher bandwidth and higher data rates for the upcoming next-generation wireless system e.g. 5G and beyond, it's stringent requirement to develop high bandwidth and propagation of higher data rates RF front end. To meet this demand, circuits and components operating at mm-wave frequency are offering a huge amount of bandwidth; hence, extensive research is going on to explore and develop mm-wave circuits, components, and transmission lines. Transmission lines play an important role in connecting the components in the highly-dense integrated circuits. However, conventional planar transmission lines based on microstrip offers higher cross-talk and mutual coupling with the adjacent transmission lines [1], which degrades the signal integrity and creates signal distortions, which is not desirable. In this direction, it was shown that spoof plasmonic metamaterial-based transmission lines had offered lower cross-talk and mutual coupling [2] as compared to the existing microstrip and thus maintained the signal integrity in the dense environment [3].

Natural Surface plasmon polaritons are the specific EM surface modes found at the visible and near-infrared frequency at the interface of two material having opposite sign of the permittivity. Metals show the negative real part of permittivity at optical frequency and thus support the propagation of SPP. SPPs offers higher EM confinement and localization and provide miniaturization and sub-wavelength propagation [4, 5]. At a lower frequency regime, metals do not show negative permittivity and shows the property of perfect conductor and hence do not support such highly confined mode. To obtain the highly confined mode at THz and millimeter-wave frequencies, corrugated metallic grooves and holes are used, which offers similar characteristics, and their propagation characteristics like dispersion and cut-off frequency can be altered by changing the structural parameter of the unit cell [6]. Thus the development of the low loss and miniaturized integrated circuits can be obtained.

Various researches have been reported at THz and microwave frequency like transmission lines [7-9], filters [10-13], and antennas [14-15]. However, there are less researches have been done at mm-wave frequencies.

In this paper, a broadband transmission line operating from DC-60GHz has been developed using spoof surface plasmonic metamaterial. Full-wave simulation of the designed structure has been performed and its results are analyzed. Fabricated prototype has been developed and its characterization is performed using N5247A VNA.

## 2. Design and Analysis of Metamaterial Spoof Plasmon Based Transmission Line

To develop the spoof surface plasmonic metamaterial (SSPM) based transmission line, an SSPM unit cell has been designed by corrugating the metallic surface, as illustrated in Fig. 1. CST microwave studio Eigenmode solver has been used to derive the Eigen solutions. The dispersion relation is numerically calculated and depicted in Fig 1 (b) using the substrate with a dielectric constant of *2.2* and height *0.254* mm. Copper metal with a thickness of *18* micrometers and conductivity *5.8X10^7* S/m has been used as a conductor. The dimensions of the unit cell are as follows: $w_1=150$, $w_2=250$, $a=187.5$, $h=475$ (all are in µm).

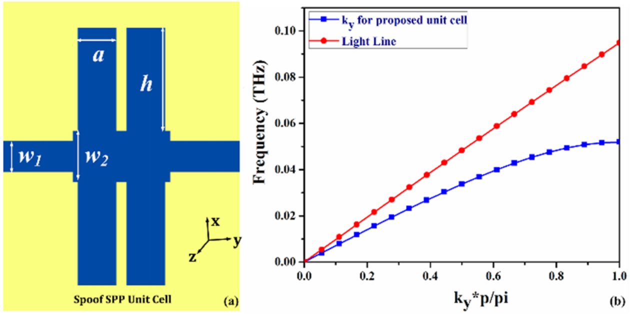



**Figure 1.** (a) Metamaterial spoof plasmonic unit cell, (b) dispersion curve.

Fig. 1 (b) depicts the dispersion curve for the SSPM ($k_y$) and light line ($k_0$), and it can be observed that propagation wave vector $k_y$ becomes much larger than $k_0$ as frequency increases. Thus there is a mismatch between these two wave vectors $k_y$ and $k_0$. To feed the SSPM based transmission line, a conversion between these two is needed, which is done by gradually changing the height of the grooves from $h_1=62.5$ - $h_8=500$ µm ($h_n$, $n=1$-$8$) with an equal step $h_n$. Thus in this way, a gradual conversion between the two modes takes place. Now we have used this conversion to develop back to back to design SSPM based transmission line.

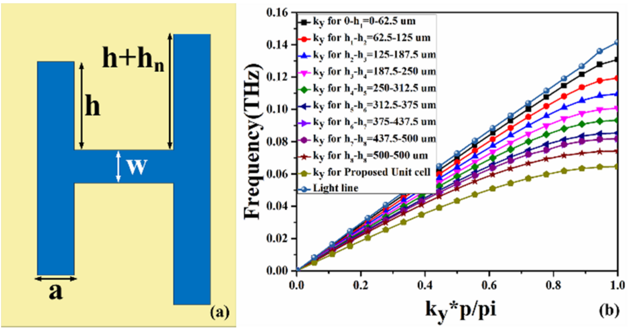
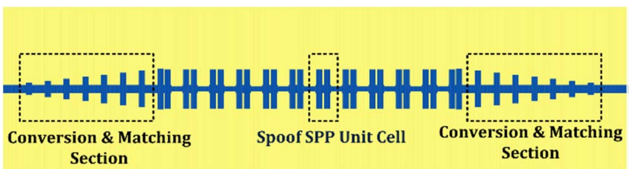
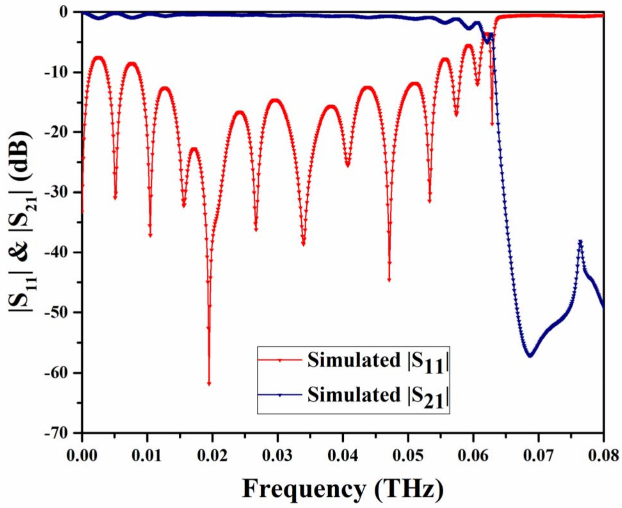



**Figure 2.** (a) Conversion and matching using gradient grooves, (b) dispersion curve.

Fig. 3 (a) shows the schematic of the proposed design of the broadband transmission line operating from DC-60GHz of frequency band. The structural parameters of the designed structure are the same as mentioned above. The full-wave simulation is performed, and its S-parameter results are recorded and shown in Fig. 3 (b). The magnitude of the reflection $|S_{11}|$ and transmission coefficient $|S_{21}|$ are below -10 dB and 5dB respectively in the whole operating frequency band, which shows that a very good transmission efficiency is obtained.




(a)

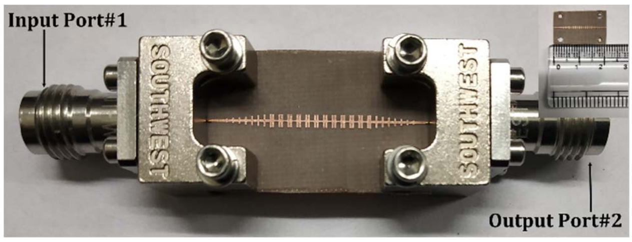



(b)

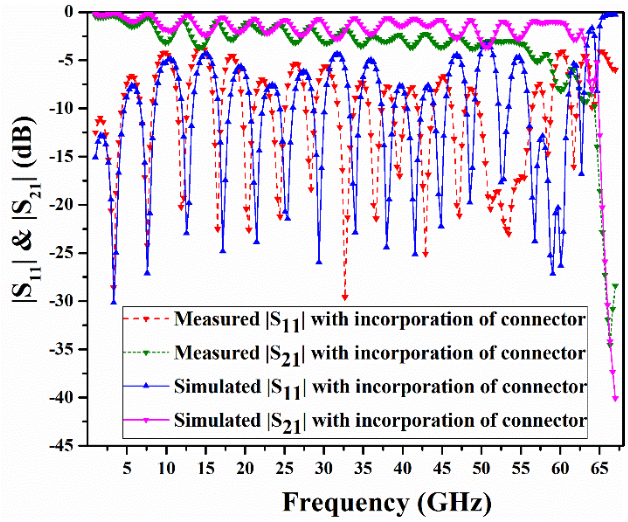
**Figure 3.** (a) Schematic of the proposed transmission line structure, (b) Magnitude of the simulated reflection $|S_{11}|$ and transmission coefficient $|S_{21}|$.

## 3. Experimental Results

For the validation of the proposed approach, a fabricated prototype is developed, as per the design shown in Fig. 3 (a) and depicted here in Fig. 4 (a).




(a)




(b)

**Figure 4.** (a) Fabricated prototype of the proposed transmission line structure, (b) Magnitude of the simulated and measured reflection $|S_{11}|$ and transmission coefficient $|S_{21}|$. [inset: size of the developed transmission line].

The size of the fabricated prototype is *20* mm X *13* mm, in which the transition part is about *11* mm long. The size of the spoof SPP based transmission line is *8.8* mm, which is very much miniaturized. The fabricated prototype is developed on RT/Duroid 5880 and characterized using Vector Network analyzer N5247A with end-launch connectors at both of its ports. The measured results are shown in Fig. 4 (b), which is somewhat not matched with the previous simulated results as shown in Fig. 3 (b). To investigate this, the full-wave simulation is performed again by creating holes in the substrate for all four screws and compared with the obtained measured results. The end-launch connector needs a hole in the substrate to fit it, so after creating the hole, its boundary condition changes and we obtained the results as shown in Fig. 4 (b) that was not accounted for in the initial design. Further, extra losses are due to use of RO5880 substrate at these high frequencies in which conductor loss dominates.

## 4. Conclusions

In this paper, a broadband spoof surface plasmonic metamaterial (SSPM) based transmission line is designed and fabricated. An SSPM unit cell is designed and analyzed which is used to develop the proposed transmission line. The proposed transmission line operates in a broadband which covers the frequency range from DC-60 GHz, which supports the signal propagation with high data rates and bandwidth. This designed transmission line has been fabricated and characterized. The developed transmission line can be used in the development of highly dense RF circuits where a lower crosstalk and mutual coupling is required.

## 5. References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