Full U-Band Rectangular Waveguide-to-Microstrip Transition Using *E*-Plane Probe

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Abstract- **A full U-Band rectangular waveguide-to-microstrip transition using E-plane probe is presented. Simulations show that $|S_{11}|$ is below -20 dB over the frequency band 40 GHz to 60 GHz and $|S_{21}|$ is below -0.27 dB in this band. Simulations have been performed using the 3D electromagnetic full-wave simulator HFSS from ANSYS. For verification, HFSS simulated results are compared with CST Microwave Studio. Good agreements are found over the aforementioned band.**

Index terms- **Low loss, sleeve, U-band, waveguide-to-microstrip transition.**

I. INTRODUCTION

In radar systems, microstrip antennas are recommended where low profile, light weight antenna subsystem [1], [2] is in demand. Often rectangular waveguides are used as interconnect elements due to its low loss characteristics compared to other interconnects at millimeter-wave and submillimeter-wave frequencies. Transitions are essential to transform efficiently electromagnetic energy from waveguide to microstrip or vice versa. It requires coupling between TE_{10} mode of rectangular waveguide to the quasi-*TEM* mode of microstrip line.

In recent years, many transitions have been proposed using a quarter-wavelength impedance transformer along with a high-impedance inductive line [3]. According to impedance match theory, one major drawback of the quarter wave transformer is its narrow bandwidth, to yield a broadband RF matching between the high impedance waveguide, and microstrip line one alternative idea on the transition probe design is the concept of planar monopole antenna [4].

In this paper, a U-band low loss broadband waveguide to microstrip *E*-plane probe using symmetric ground sleeves. Parametric studies are performed to analyze dimensional sensitivity of the proposed structure.

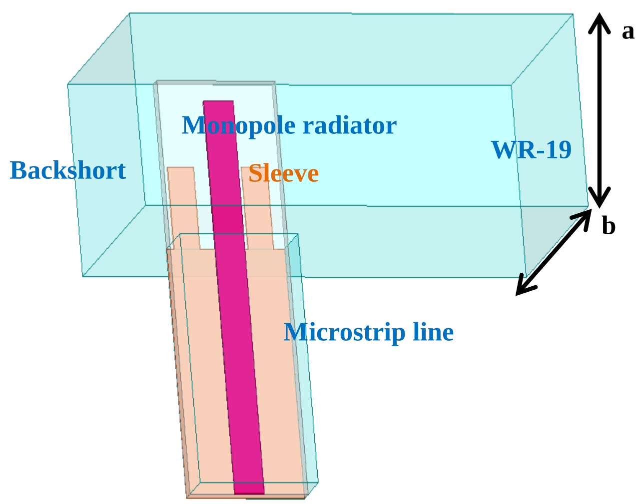


Fig. 1. Perspective view of the proposed transition.

A. Structure

As is illustrated in Fig. 1, the proposed waveguide-to-microstrip transition is made up of an input waveguide, a waveguide backshort, a microstrip line (characteristic impedance of 50 Ω) in a metallic enclosure, ground plane with symmetric sleeves, and a strip probe of length approximately λ/4 (acting as a monopole radiator). The corresponding probe configuration is shown in Fig.2.

For this type of transition, the aperture should be taken as large as possible, to suppress the waveguide modes [5]. Assuming a 1.6-mm wide substrate for this U-Band transition, an aperture size of 1.6 mm × 0.5 mm has been used. The corresponding cutoff frequency of waveguide mode is around 93.7 GHz, which is far beyond the operation frequencies of the U-Band transition.

The design concept of this transition is adapted from the monopole antenna with the ground plane sleeve [6]-[8]. Sleeve can be treated as an extension of ground

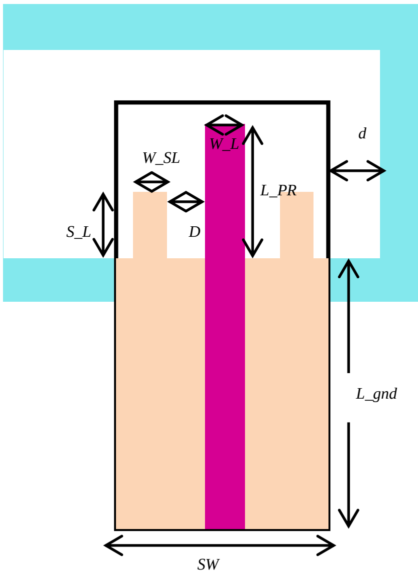


Fig. 2. The configuration of the transition probe.

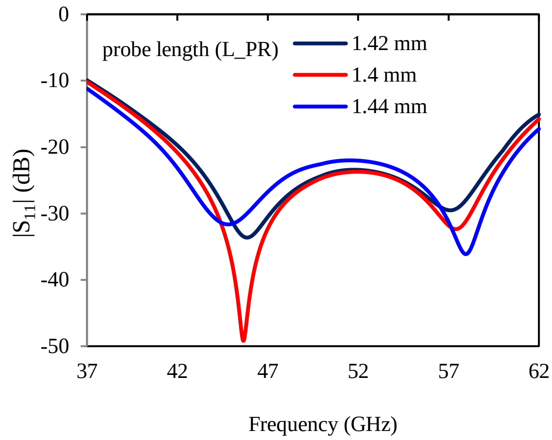
plane inside waveguide [7], and generates an additional resonant mode above the fundamentally generated mode, which helps to attain a wider bandwidth. In [7], it is found the widest bandwidth can be achieved while keeping the length of the sleeve (*S_L*) one third of the monopole probe radiator length (L_PR). So, *S_L* = λ/12 and *L_PR* = λ/4 have been taken as initial value. However, fine tuning is required as the transition probe is enclosed inside metallic enclosure.

Although the input impedance at the microstrip seen at the microstrip port is independent of the probe width, a narrow probe might limit the transition's matching bandwidth and results in excessive inductive loss [5], [9]. To simplify the design, here it is taken as 50 Ω.

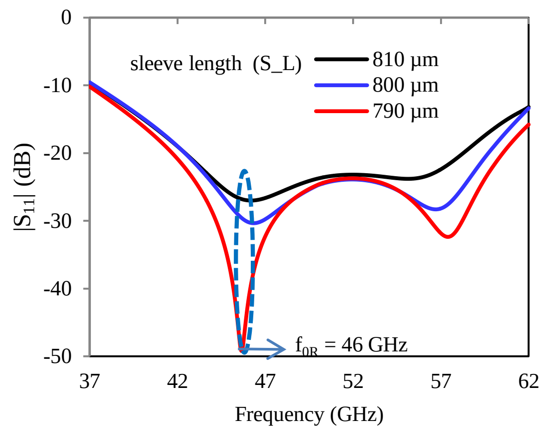
B. Simulations

3-D EM simulator HFSS from ANSYS is used for simulations. The transition probe has been implemented using a WR-19 rectangular waveguide and a 5-mil thick 5880 RT/duroid substrate from Roger having permittivity 2.2 and loss tangent 0.0009. The conducting material is copper of conductivity 5.8×10^7Siemens/m. The broad wall and narrow wall dimensions of the waveguide are a = 4.7752 mm and b = 2.3876 mm, respectively. The width of the 50 Ω microstrip line for the present substrate is ≈ 0.39 mm and the length of the radiator inside waveguide is ≈ 1.37 mm at 40 GHz.

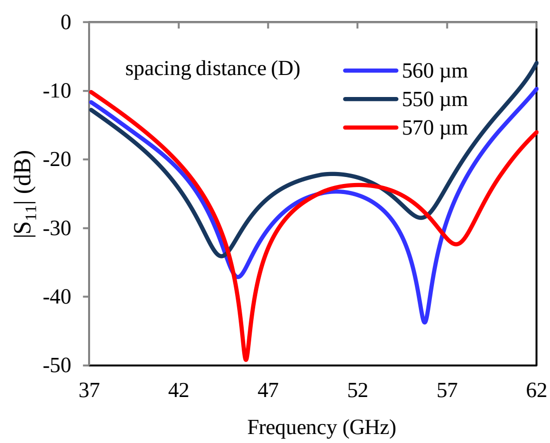
Fig. 3(a), (b) clearly indicate the probe length affects the fundamental resonant frequency (around 46 GHz) but the sleeve length does not have significant effect on fundamental resonant frequency, and it affects second resonant frequency significantly. Distance between



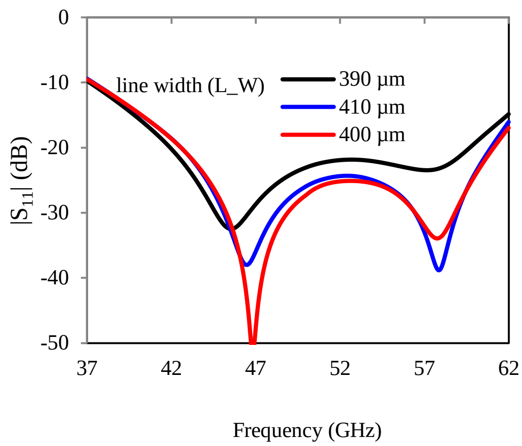
(a)



(b)



(c)



(d)

Fig. 3. Parametric study of the designed transition with variation of (a) probe length (b) sleeve length (c) spacing distance between probe and sleeve (d) probe width which is equal to microstrip line width.

Table I

Optimized dimension of the parameters

Variable	Value in mm
W_L	0.4
L_PR	1.4
S_L	0.79
D	0.57
d	0.16
SW	1.6
L_gnd	4.86
Aperture height	0.509

monopole and sleeve (*D*) kept fixed as 560µm for the above simulations. Simulated results with variation of D are shown in Fig. 3(c). The figure indicates that D has slight effect on both fundamental as well as second resonant frequencies, and can be used to improve the matching. Fig. 3(d) indicates that line width does not have significant effect on resonant frequency but improves the matching around these frequencies.

Surface roughness increases the conductor loss as frequency increases especially when the signal skin depth is comparable or smaller than the conductor roughness [10]. Calculated skin depth at high end of frequency band is 0.27 µm, and the surface roughness for the chosen substrate given in the datasheet is 0.4 µm on the dielectric side. Optimized values of *S*-parameters with the effect of surface roughness are shown in Fig. 4. Final optimized structural parameters are listed in Table I.

Fig. 3 has clear evidence that dimensional variations of ± 10 µm do not have any significant effect on the *S*-parameters in frequency range of interest. Thus, the design can sustain fabrication tolerance ± 10 µm given by Rutherford Appleton Laboratory, UK.

The configuration of the back-to-back transition is shown in Fig. 5. Simulation results with the microstrip line length variation 2λ and 4λ, λ @ 50 GHz are shown

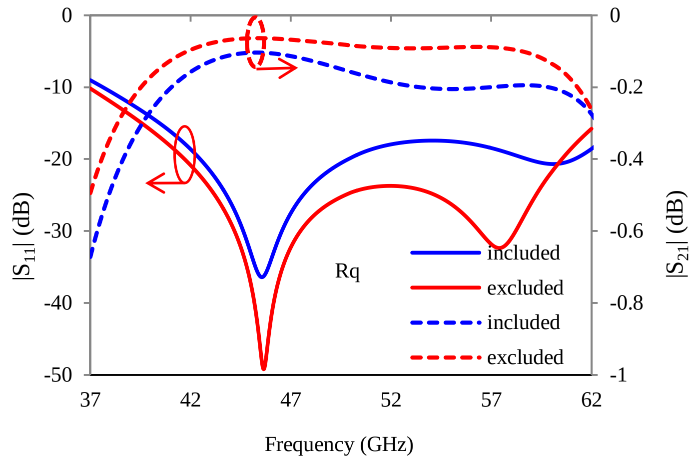


Fig. 4. Optimized *S*-parameters of the designed transition with and without surface roughness.

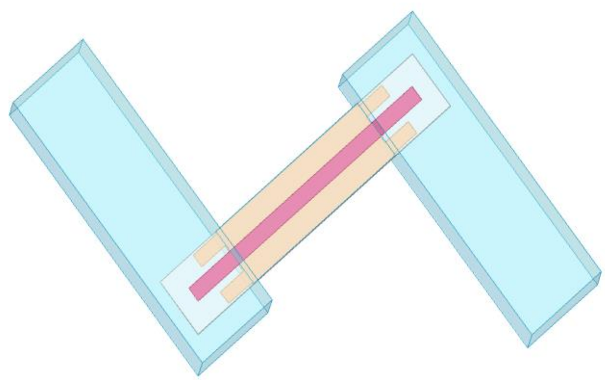
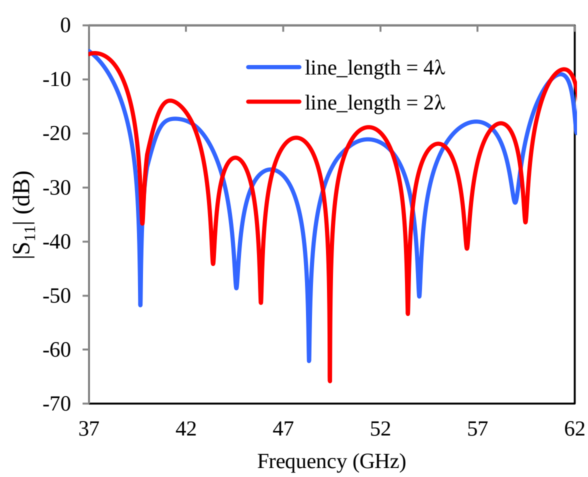


Fig. 5. A back-to-back transition



(a)

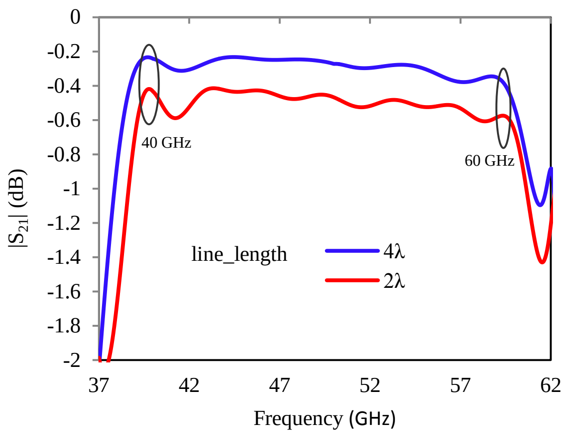


Fig. 6. Simulation (a) $|S_{11}|$ and (b) $|S_{21}|$ of the back-to-back transition configuration.

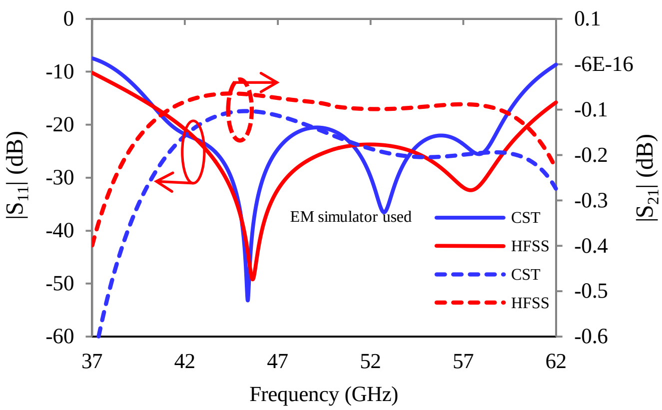


Fig. 7. *S*-parameters obtained from two different EM simulators.

in Fig. 6. It indicates a good transition design over the desired frequency range i.e. 40-60 GHz.

It is appropriate to verify the simulation accuracy and reliability by comparing the results obtained from another simulator. Fig. 7 shows that *S*-parameters obtained from HFSS are in a good agreement with that obtained from CST Microwave Studio.

III. CONCLUSION

A U-band low-loss waveguide to microstrip probe transition has been designed. The design is simulated in two different 3-D EM simulators, and results are found to be in a good agreement. Parametric studies have been performed to obtain the dimensional sensitivity of the structure. It is seen that the design can sustain fabrication tolerance ± 10 µm which is within the limit given by Rutherford Appleton Laboratory, UK.

The transition could be utilized in millimeter wave communication systems in U-band, which has a promising future in astrophysics, or atmospheric sounding and remote sensing. In addition, the improved design approach proposed in this paper also could be used to design excellent probe transition at other frequency band.

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