A SIMPLE MICROSTRIP TO WAVEGUIDE TRANSITION FOR MM-WAVE 5G BASE STATION ANTENNA

Le Minh Thuy*

Abstract: *A compact patch type microstrip-to-waveguide transition at the mm-wave band is proposed using a planar proximity coupling structure. Small patches are put inside the apertures to enhance the suppression of reflection. The bandwidth of 3% (850MHz) at S11≤ -10 dB is obtained. As a result of the simulation, low transmission loss and high return loss are realized at the design frequency of 28 GHz for mmWave 5G application.*

Keywords: mm-wave; Microstrip-to-waveguide transition; Planar proximity coupling.

1. INTRODUCTION

As communication systems adopt millimeter-wave frequencies, an increasing number of carriers will need to apply to transceiver modules, a waveguide-type antenna [1] that is easily produced and has good-gain characteristics. These devices are expected to apply to high speed and a considerable capacity wireless network such as small cell backhaul. The microstrip antenna is widely used in mmWave 5G base station antenna due to its advantages of low cost and low profile as well as easy to form an array to increase the antenna gain. In the usual configuration, microstrip antennas are placed on the surface of a remote radio unit (RRU) and are connected to the millimeter-wave circuits inside the RRU via waveguides. Therefore, transitions from the waveguide to the microstrip lines are required [2-3]. Different types of microstrip-to-waveguide transitions are presented in the literature. [4-15] which can be categorized into broadband and narrowband. Planar broadband microstrip-to-waveguide transitions have been developed using multi-layers with complex structures [11-15]. To solve the complex structure problems, a planar proximity coupling transition is designed using a patch element to enhance the energy from the rectangular waveguide to the transmission line. The proximity coupling type has been developed more recently. It can be composed of a single dielectric substrate attached to the waveguide end. A rectangular patch element on the lower plane of the dielectric substrate couples with a micro-strip line on the upper plane of the dielectric substrate. It is suitable for mass production. This type of transition is easy to integrate with planar circuits and does not require the short metal block of the waveguide, and can be made of hermetic sealing. Also, the proposed transition has features of low-loss characteristics, but the bandwidth of this structure is still relatively narrow. Planar microstrip-to-waveguide transitions are ussualy used from the industrial point of view even the bandwidth is narrow [7-10].

In this paper, the proposed single layer microstrip-to-wave guide transition allows a simplified design based on standard impedance transformers and easy to be fabricated.

The paper is organized as follows. The design procedure is presented in Section 2 and applied in Section 3 to the design of a one layer transition. Finally, conclusions are drawn in Section 4.

2. PROPOSED MICROSTRIP TO RECTANGULAR WAVEGUIDE TRANSITION

The proposed transition first couples the quasi-TEM mode of the microstrip line to the TE10 mode of a rectangular waveguide. It composes a rectangular waveguide RW-34 with the dominant operating mode of TE10 to substrate integrated waveguide-SIW and a SIW to microstrip line transition. This configuration uses a patch placed at the back of the substrate that operates in TM01 mode to convert from TE10 mode to TEM mode of the microstrip line, at the same time enhancing the coupling on the micro-strip that works according to the principle of proximity coupling patch.

The SIW structure can be regarded as a unique rectangular waveguide with a series of slots on the narrow bilateral walls. If the slots cut the currents, a large amount of radiation may appear. This is the well-established design principle of waveguide slot antenna. However, if the slots are cut along the direction of the current flowing, there is only very little radiation. The TE10-mode surface current flowing pattern of a rectangular waveguide with slots on its narrow bilateral walls. The slots do not cut the surface current on the narrow walls; the TE10 mode can thus be preserved in the structure. The other modes have similar surface currents on the narrow walls. This is why modes can exist in SIW structures. SIW structure can model equivalent to rectangular waveguide (RWG) with the width of a_{RWG}, the width a of the SIW structure can be expressed through the formula (1):

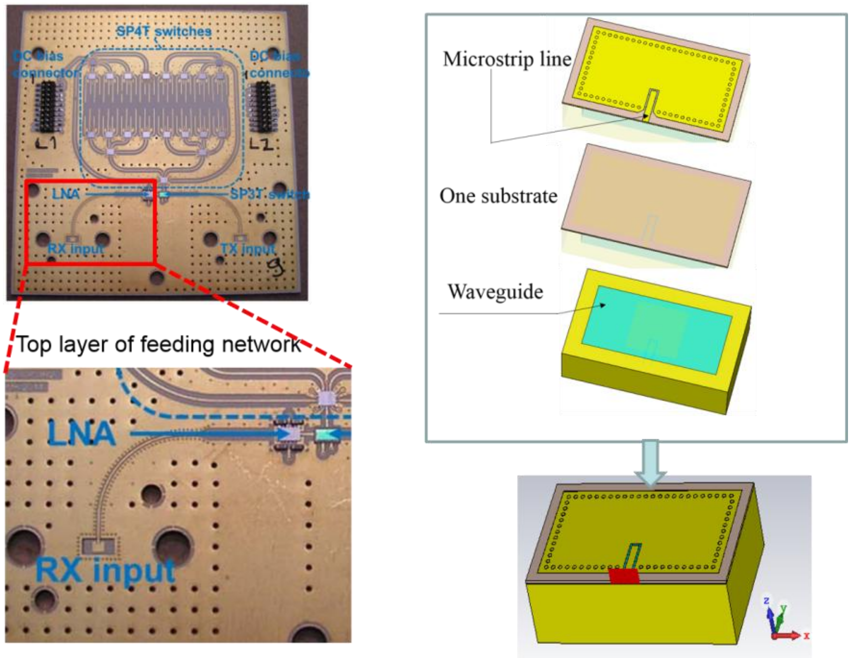
$$a = a_{RWG} - \frac{1.08d^2}{p} + 0.1\frac{d^2}{a_{RWG}}$$
$$a_{RWG} = \frac{c}{2f_c\sqrt{\varepsilon_r}} + 0.1\frac{d^2}{a_{RWG}} \tag{1}$$

Parameters such as hole diameter d, the distance between two adjacent p holes, and width of SIW are determined by equation (2):

$$d < \frac{\lambda_g}{5}$$
$$p \leq 2d$$
$$\lambda_g = \frac{2\pi}{\sqrt{\frac{(2\pi f)^2 \varepsilon_r}{c^2} - \left(\frac{\pi}{a}\right)^2}} \tag{2}$$

The characteristic impedance of SIW is calculated by equation (3):

$$Z_0 = Z_{TE}\frac{\pi^2 h}{8a}$$
$$Z_{TE} = \sqrt{\frac{\mu}{\varepsilon}} \times \frac{\lambda_g}{\lambda} \tag{3}$$



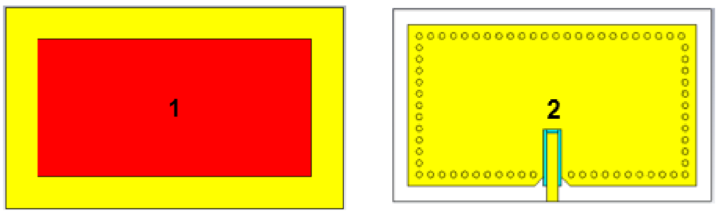
a) b)

Figure 1. *a) The function of microstrip to waveguide transition in a 5G mmWave Basation; b) The initial 1-layer transition structure.*

The configuration of the transition is shown in figure 1. A microstrip line, a probe, and a waveguide short are located on the upper plane of the dielectric substrate of RT 5880 with the dielectric constant of 2.2 and the tangent loss of 0.0009. A rectangular patch element and a surrounding ground are patterned on the lower plane of the dielectric substrate. Via holes surround the aperture of the waveguide on the lower plane of the dielectric substrate to connect the surrounding ground and the waveguide short electrically that is SIW structure.

3. NUMERICAL INVESTIGATE AND SIMULATION RESULT

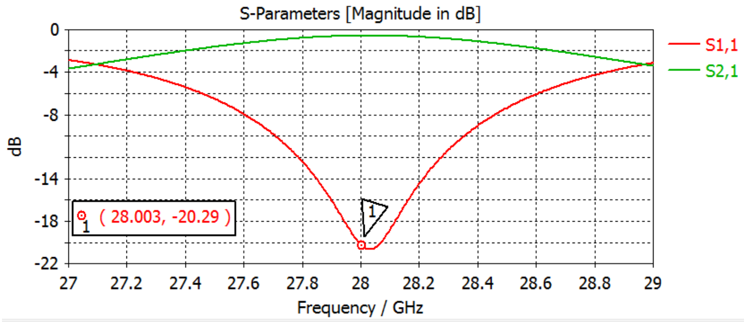
Transition is simulated on CST software with the structure as analyzed in the preceding section, with 2 power supplies at both ends of the structure using RT 5880 substrate. Power supply level 1 (port 1) provides a rectangular waveguide with standard 50 ohm impedance; power supply level 2 (port 2) supplies power to 50 ohm microstrip transmission.



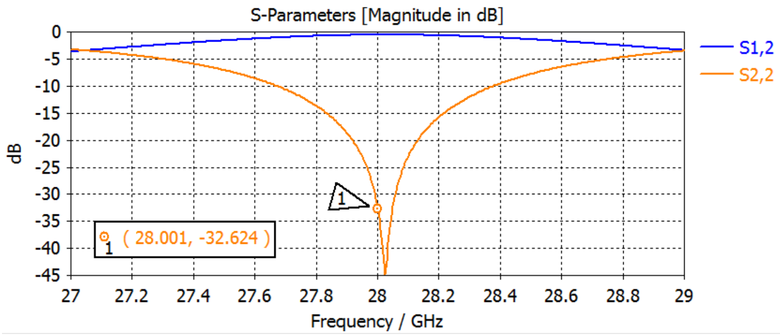
a) b)

Figure 2. *a) Top View b) Bottom View of the initially proposed transition.*

From the above results, the transition works well at 28 GHz with a reflection coefficiency of - 40 dB. However, the bandwidth is narrow, with 360 MHz and 700 MHz at -15 dB and -10 dB, respectively. To improve the bandwidth of the transition, a wideband impedance matching must be implemented using the inserted probe; both the length and the width of the inserted probe are optimized as shown in figure 3:



a)



b)

Figure 3. *Reflection coefficient at port 1 (a) and at port 2 (b).*

The proposed transition works well at 28 GHz with S11= -40 dB; the lowest reflection coefficient is – 55 dB at 27.88 GHz. The low insertion loss of 0.5 dB over operating bandwidth shows that energy from the waveguide is completely transmitted to the micro-strip line; bandwidth was improved to the 450 MHz and 880 MHz at -15 dB and – 10 dB, respectively.

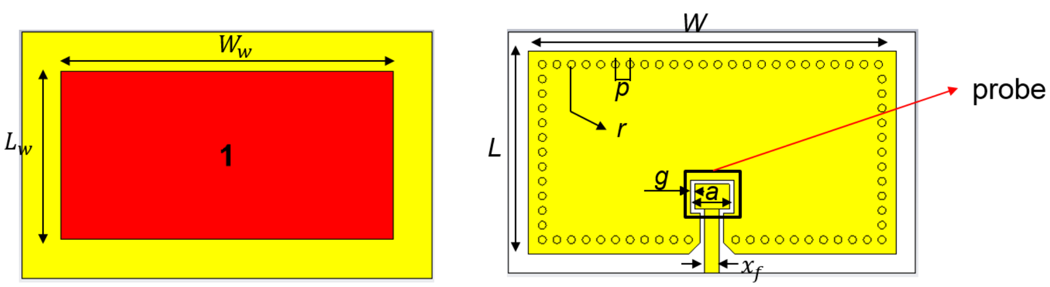


Figure 4. *Improved impedance matching transition.*

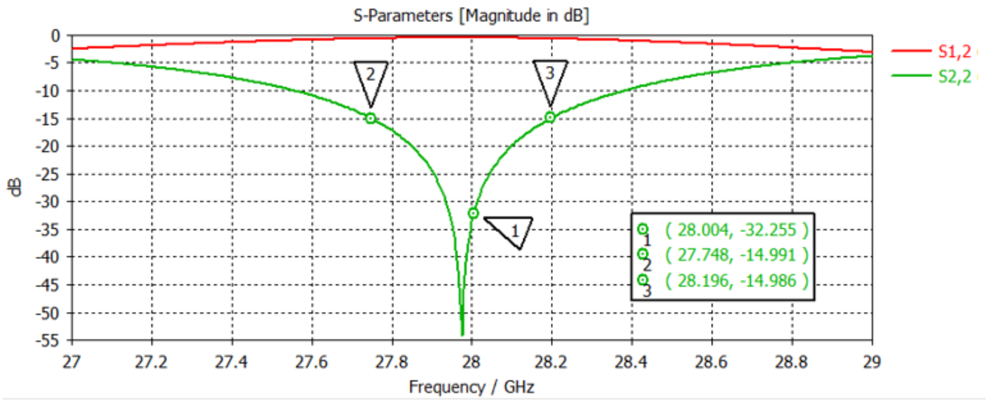


Figure 5. *Reflection coefficient from port 2.*

Table 1. *Dimension parameters of the proposed broad bandwidth transition.*

W (Width of patch element)	3.379 mm
L (Length of patch element)	4.7 mm
x_f (Width of microstrip line)	1.9 mm
a (Width of Probe)	0.65 mm
Overlap length of the inserted probe	1.5 mm
g (With of gap)	0.12 mm
h (Thickness of substrate)	0.127 mm
r (Diameter of via hole)	0.2 mm
p (Space between via holes)	0.381 mm
L_w (Length of waveguide RW-34)	8.636 mm
W_w (Width of waveguide RW-34)	4.318 mm

Table 2. *Comparison with related works.*

Reference	Center Frequency (GHz)	Bandwidth (%) at -10 dB	Insertion loss (dB)	Structure	Waveguide name, dimension
[11]	76.5	4.5%	-5	1 layer	WR-12, 1.5 mm
[8]	76.5	6.9%	-3.2	2 layers	-
[9]	85.5 GHz	4%	-3 to -1	1 layer	WR-10, 2.54 mm
This work	28	3%	-0.5	1 layer	WR-34, 4.3 mm

The proposed transition is compared to the previous single-layer transition and listed in table 1. It is apparent that the performance of the proposed transition gives a very low-loss, smallest bandwidth but easy to be fabricated. The works in [11] and [9] have wider bandwidth and higher insertion loss than the proposed, but the work in [9] and [11] used the taper structure. This structure is complicated and not easy to fabricate. The work in [8] are 2 layers with higer insertion loss.

4. CONCLUSIONS

In this paper, a simple microstrip-to-waveguide transition is studied and designed using RT 5880 substrate. A low loss of 0.5 dB and 3% of bandwidth at a center frequency of 28 GHz are obtained. The simple structure is an advantage of this transition.

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TÓM TẮT

MẠCH CHUYỂN ĐỔI ĐƯỜNG DẪN SÓNG DẠNG VI DẢI SANG ỐNG DẪN SÓNG ỨNG DỤNG CHO ANTEN THU PHÁT GỐC CÔNG NGHỆ 5G

Bộ chuyển đổi một lớp từ các đường dẫn sóng vi dải sang ống dẫn sóng ở dải tần mm-Wave được đề xuất và mô phỏng sử dụng cấu trúc ghép nguồn tiệm cận. Tấm patch nhỏ được đặt trong vùng mở để tăng chất lượng hệ số nén và hệ số phản xạ. Băng thông tại -10 dB đạt 3%. Kết quả mô phỏng cho thấy, hệ số suy hao khi truyền và nhận tín hiệu thấp, được triển khai tại tần số 28 GHz băng tần mmWave để phù hợp cho ứng dụng 5G ở dải tần này.

Từ khóa: Anten mili-mét; Đường truyền vi dải; Ống dẫn sóng; Bộ chuyển đổi; 5G.

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Author affiliations:

Trường Đại học Bách khoa Hà Nội;

* Corresponding author: thuy.leminh@hust.edu.vn.