Design of transition from WR-15 to inverted microstrip gap waveguide

Citation for the original published paper (version of record):
Liu, J., Uz Zaman, A., Kildal, P. (2016)
Design of transition from WR-15 to inverted microstrip gap waveguide
2016 Global Symposium on Millimeter Waves, GSMM 2016 and ESA Workshop on Millimetre-Wave

(article starts on next page)

Design of Transition from WR-15 to Inverted Microstrip Gap Waveguide

Jinlin Liu
Antenna Division
Chalmers University of Technology
Gothenburg, Sweden.
jinlin.liu@chalmers.se

Ashraf Uz Zaman
Antenna Division
Chalmers University of Technology
Gothenburg, Sweden.
zaman@chalmers.se

Per-Simon Kildal
Antenna Division
Chalmers University of Technology
Gothenburg, Sweden.
per-simon.kildal@chalmers.se

***Abstract*—Currently gap waveguide technology has revealed strong competitiveness for millimeter wave wireless applications. Specifically, this new topology of waveguide technology provides advantages of low loss, high quality factor and easy RF packaging. In this paper we present the design methodology of millimeter-wave transition from standard WR-15 rectangular waveguide to inverted microstrip gap waveguide. Furthermore, a more practical power divider from standard WR-15 rectangular waveguide to inverted microstrip gap waveguide is also introduced. Both structures are vertical and there is no additional need for any complex modification of the waveguide structure to achieve compatibility between the two structures. The proposed two transitions cover the whole unlicensed 60 GHz band from 57 to 66 GHz in order to be widely utilized as an interface between gap waveguide feed networks and equipment components with WR-15 ports. The simulated results show promising S-parameters.**

I. Introduction

Recently, there is a growing amount of interest and attention for wireless applications at 60-GHz frequency band [1-3]. Traditional planar circuit technologies such as microstrip are typically applied for integration of active and passive components, and designing planar array antennas. However, the losses become especially critical for designing microstrip feed networks as increasing of frequency. On the other hand, hollow waveguide shows advantage of low loss. Nevertheless, as the frequency increases the size of the rectangular waveguide becomes smaller and the tolerance requirements for good conducting joints between the split metal blocks become impossible to satisfy. Therefore, a new guiding structure called gap waveguide [4-5] was proposed to overcome the above-mentioned limitations of traditional technologies at millimeter-wave frequencies. Theoretically, gap waveguides consist of parallel PEC (Perfect Electric Conductor) and -PMC (Perfect Magnetic Conductor) plates separated by an air gap [6]. This PMC layer is usually realized by a high impedance surface which is able to create a stopband over a specific frequency range. Until now this ideal concept can be built up in four major forms: ridge, groove, inverted microstrip [4] and microstrip-ridge gap waveguide [7]. In this paper we particularly deal with the inverted microstrip gap waveguide, whose fundamental illustration is shown in Fig. 1. In addition, we have synthesized the geometrical parameters of pins in

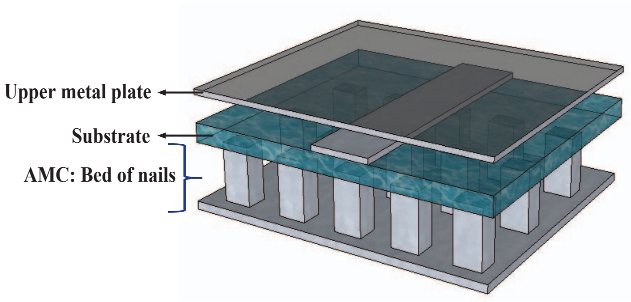


Fig. 1. Basic geometry of the inverted microstrip gap waveguide.

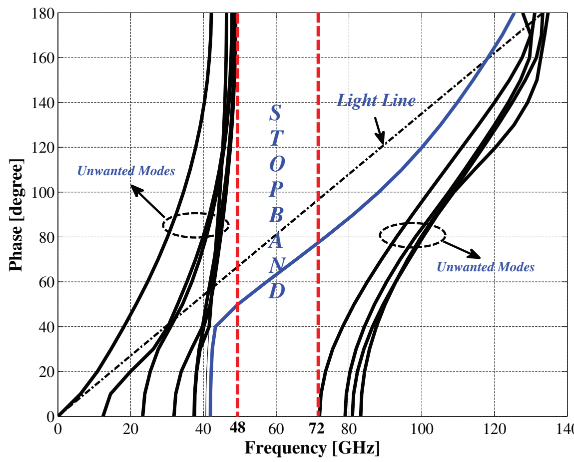


Fig. 2. Dispersion diagram for inverted microstrip gap waveguide gap in the work. Blue line indicates the Quasi-TEM mode crossing the frequency stopband.

order to obtain a stopband covering the unlicensed 57-66 GHz frequency band. Fig. 2 shows the corresponding dispersion diagram with a stopband from 48 to 72 GHz. As shown in Fig. 2, this large stopband allows a quasi-TEM mode to propagate in the air gap above the metal strip and this single quasi-TEM mode can correspondingly be utilized for microwave and millimeter wave circuits. Until now there are already some useful applications of gap waveguide technologies. References

978-1-5090-1348-7/16/$31.00 ©2016 IEEE

[8-9] present several different types of bandpass filters based on inverted microstrip and groove gap waveguide. In [10] a novel V-band diplexer based on groove gap waveguide technology is presented. In [11-12] we have already succeeded in design and manufacture two different transitions from normal microstrip and coaxial line to ridge gap waveguide. Furthermore, there are also some completed research on design new gap waveguide radiating slot array antennas introduced in [13-16]. Therefore, the gap waveguide approach is able to merge the benefits of traditional millimeter-wave technologies. In this paper we present two specific transitions from standard WR-15 to inverted microstrip gap waveguide at the 60-GHz band: one is a geometrically symmetric 2-way divider transition and the other is an asymmetric transition. These two structures will be very helpful to us when designing antennas, filters and other microwave components at the 60-GHz band because it covers the band of a standard V-band rectangular waveguide (e.g. WR-15).

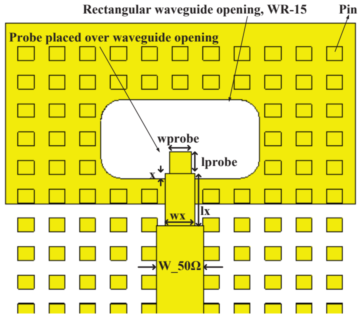
II. Non-symmetric Transition from WR-15 to Inverted Microstrip Gap Waveguide

As described in the previous section, the inverted microstrip gap waveguide technology constitutes an attractive alternative to standard microstrip. However, a critical obstacle has been the absence of good transitions that allow connection of the inverted microstrip gap waveguide to measurement equipment and input signals at millimeter wave frequencies. Up to now

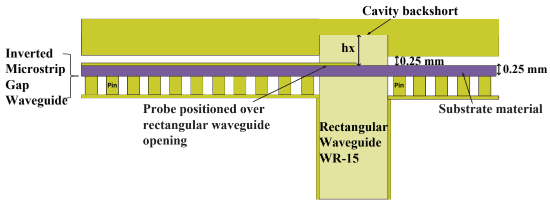
TABLE I
Design Parameters of the Structure in Fig. 3

Parameter	Value
Height of air gap	0.25 mm
Height of the pin	1.05 mm
Width of the pin	0.4 mm
Thickness of substrate	0.25 mm
Length of Cavity Backshort [L_{cbx}]	2.998 mm
Width of Cavity Backshort [L_{cby}]	1.785 mm
hx	0.575 mm
wx	0.767 mm
lx	2.770 mm
wprobe	0.754 mm
lprobe	1.398 mm
$W50$	0.7278 mm

we can mainly distinguish three types of transitions: inline transitions, vertical transitions and aperture coupled patch transitions. The best selection for our case would be the vertical transitions. The main reason for this is that any possible higher order modes are eliminated by the gap waveguide. In addition, the transition is easily integrated into the rectangular waveguide and no complex modifications of the waveguide are needed. The whole transition structure is composed by three major parts — WR-15 rectangular waveguide, cavity backshort and inverted microstrip feeding circuits, as shown in Fig. 3. First of all, a Printed Circuit Board (PCB) is located over a bed of pins and it contains a feeding line $W50$ terminated by a two-step tapered matching microstrips. These two-step tapered-line sections work as an impedance transformer and



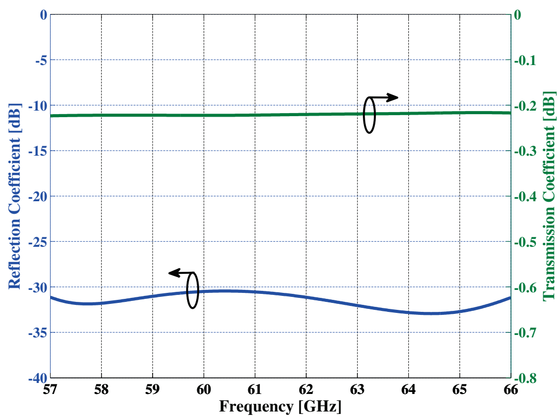
(a)



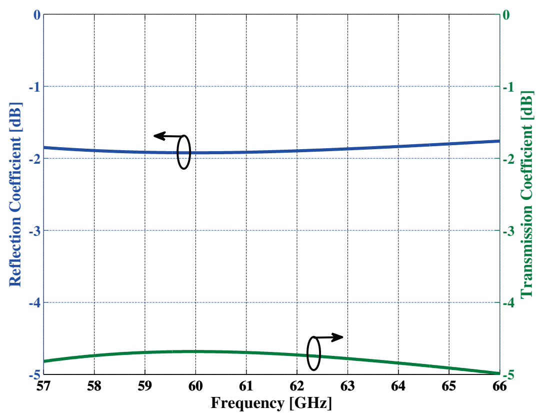
(b)

Fig. 3. (a) Top view transition geometry. In order to observe the microstrip and waveguide open details the substrate is hidden. (b) Cross-sectional view for complete non-symmetric transition geometry.

are properly placed over the rectangular waveguide opening. Secondly, the transition geometry is complemented by adding a cavity backshort on the upper metallic lid. This cavity should theoretically be placed at a distance equal to $\lambda/4$ from the inverted microstrip in order to establish an open boundary condition on the PCB plane. In this way, we force TE_{10} mode from WR-15 to propagate along the microstrip circuits as Quasi-TEM mode. Thereby, the cavity backshort together with the tapered line contained in the PCB contributes to provide field matching as well as impedance matching over a wide bandwidth. The layout and simulation of the transition structure are carried out by CST Microwave Studio and all parameter values are listed on Table I. Additionally, it is suitable to utilize a PMC shielding port for gap waveguide technology in numerical simulator because the high impedance surface of the metallic pins supply PMC boundary condition [17]. In order to certify the effect of cavity backshort we have accordingly added an S-parameter chart obtained by same transition structure without cavity backshort, as shown in Fig. 4(b). According to the comparison with Fig. 4(a) the cavity backshort radically improves the transition from WR-15 to inverted microstrip. The reflection coefficient S_{11} is even below -30 dB from 57 to 66 GHz. This result is promising that the structure is able to be utilized in most passive microwave components based on this type of gap waveguide structures.



(a)

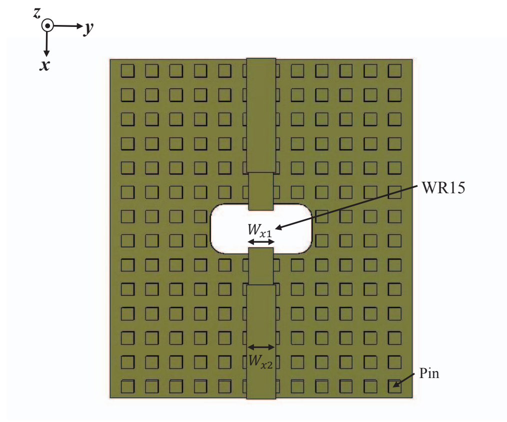


(b)

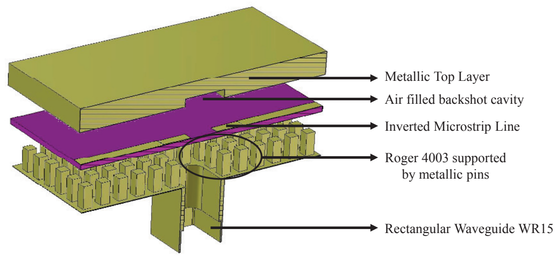
Fig. 4. (a) S-parameters obtained from an asymmetric transition from WR-15 to inverted microstrip gap waveguide shown in Fig. 3. (b) S-parameters obtained from same transition structure shown in Fig. 3 but without cavity backshort.

III. Symmetric Transition from WR-15 to Inverted Microstrip Gap Waveguide

In the previous section we have already introduced a single vertical transition from WR-15 to inverted microstrip gap waveguide. In practice it is more convenient for us to have a symmetric transition from WR-15 to inverted microstrip gap waveguide instead of the asymmetric one so that we save power divider layer and thereby can get a lower overall input reflection coefficient. The overall geometry of the symmetric transition introduced in this work is illustrated in Fig. 5. It is obvious that the symmetric transition has two output ports whose phases are 180^o different from each other, as shown in Fig. 7. The table II shows the critical parameter values of the structure in this work. By tuning of the geometry of the cavity backshort in the upper metallic lid we are able to obtain the desired bandwidth and reflection coefficient at frequency band from 57 to 66 GHz. The simulated S-Parameters are shown in



(a)



(b)

Fig. 5. (a) Top view transition geometry. In order to observe the microstrip and waveguide open details the substrate and upper metallic lid are hidden. (b) Cross-sectional view for complete symmetric transition geometry.

Fig. 6. The reflection coefficient $S_{11} < 20$ dB in the frequency band 57-66 GHz. This transition structure can be employed to design feed-network in inverted microstrip gap waveguide for slot array antenna at 60 GHz. Similarly, the geometrical size of structure is possibly modified so that it can be applied either at another corresponding frequency band.

TABLE II
Design Parameters of the Structure in Fig. 5

Parameter	Value
W_{x1}	0.815 mm
W_{x2}	0.961 mm
Height of air gap	0.25 mm
Height of the pin	1.05 mm
Width of the pin	0.4 mm
Thickness of substrate	0.25 mm
Length of Cavity Backshort [L_{cbx}]	3.150 mm
Width of Cavity Backshort [L_{cby}]	1.820 mm
Height of Cavity Backshort [L_{cbz}]	0.375 mm

IV. Conclusion

In this work we have presented two transitions from WR-15 to inverted microstrip gap waveguide. The numerical simulation of asymmetric transition shows that the reflection coefficient S_{11} is lower than -30 dB from 57 to 66 GHz. This makes it very useful as an input port to passive microwave

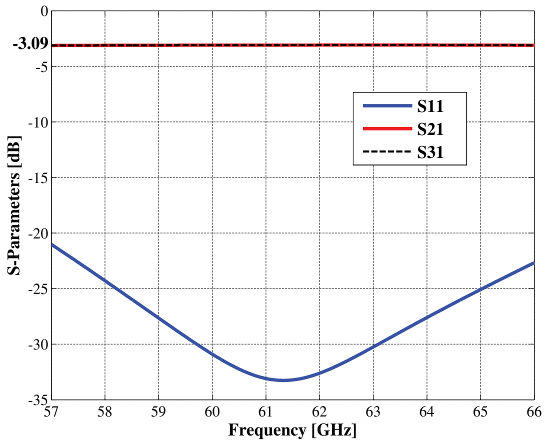


Fig. 6. S-Parameter of symmetric transition from WR-15 to inverted microstrip gap waveguide.

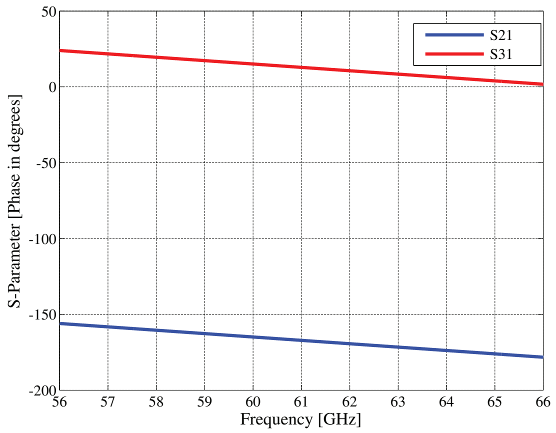


Fig. 7. Phase difference of S-Parameter of symmetric transition from WR-15 to inverted microstrip gap waveguide.

components based on inverted microstrip gap waveguide excited by WR-15. Furthermore, a symmetric 2-way divider transition has also been presented and the numerical simulated result shows that the reflection coefficient S_{11} is lower than -22 dB from 57 to 66 GHz. This transition can also be very useful in future works.

ACKNOWLEDGEMENT

This work has been supported by European Research Council (ERC) via an advanced investigator grant ERC-2012-ADG 20120216, and Swedens innovation agency VINNOVA within the VINN Excellence Center Chase at Chalmers.

REFERENCES

[1] P. Smulders, "Exploring the 60 GHz band for local wireless multimedia access: Prospects and future directions, " *IEEE Communications Magazine*, vol. 40, no. 1, pp. 140-147, Jan. 2002.

[2] S. K. Yong and C.-C. Chong "An overview of multigigabit wireless through millimeter wave technology: Potentials and technical challenges, " *EURASIP Journal on Wireless Communications and Networking*, vol. 2007, pp. 1-10, Jan. 2007.

[3] T. S. Rappaport, J. N. Murdck, and F. Gutierrez, "State of the art in 60-GHz integrated circuits and systems for wireless communications, "*Proceedings of the IEEE*, vol. 99, no. 8, pp. 1390-1436, Aug. 2011.

[4] P.-S. Kildal, "Three metamaterial-based gap waveguides between parallel metal plates for mm/submm waves", *3rd European Conference on Antennas and Propagation EUCAP* 2009, Berlin, Germany, March 23-27, 2009.

[5] P.-S. Kildal, E. Alfonso, A. Valero, and E. Rajo, "Local metamaterial-based waveguides in gaps between parallel metal plates ", *IEEE Antennas and Propagation Letters,* vol. 8, pp. 84-87, 2009.

[6] P.-S. Kildal, "Artificially soft and hard surfaces in electromagnetics, " *IEEE Trans. Antennas Propag.*, vol. 28, no. 10, pp. 1537-1544, 1990.

[7] H. Raza, J. Yang, P.-S. Kildal, and E. Alfonso, "Microstrip-ridge gap waveguide - study of losses, bends, and transition to WR-15, " *IEEE Trans. Microw. Theory Tech.*, vol. 62, no. 9, pp. 1943-1952, 2014.

[8] A. Algaba. Brazalez, A. Uz. Zaman, P.-S. Kildal, "Improved Microstrip Filters Using PMC Packaging by Lid of Nails", *IEEE Transaction on Components, Packaging and Manufacturing Technology,* vol. 2, no. 7, July. 2012.

[9] A. U. Zaman, P.-S. Kildal, and A. A. Kishk "Narrow-Band Microwave Filter Using High-Q Groove Gap Waveguide Resonators With Manufacturing Flexibility and No Sidewalls", *IEEE Transaction on Components, Packaging and Manufacturing Technology,* vol. 2, no. 11, Nov. 2012.

[10] Rezaee, M., Zaman, A.U., Kildal, P.-S. "V-band groove gap waveguide diplexer", *9th European Conference on Antennas and Propagation EuCAP* 2015, Lisboa, Portugal, March 23-27, 2015.

[11] A. U. Zaman, T. Vukusic, M. Alexanderson, and P. S. Kildal "Design of a Simple Transition From Microstrip to Ridge Gap Waveguide Suited for MMIC and Antenna Integration", *IEEE Antennas and Wireless Propagation Letters,* vol. 12, pp. 1558-1561, 2013.

[12] A. U. Zaman, E. Rajo-Iglesias, E. Alfonso, and P. S. Kildal "Design of transition from coaxial line to ridge gap waveguide ", *Antennas and Propagation Society International Symposium, APS/URSI IEEE*, 2009, pp. 1-4. Charleston, SC.

[13] Zaman, A.U., Kildal, P.-S. "Wide-Band Slot Antenna Arrays With Single-Layer Corporate-Feed Network in Ridge Gap Waveguide Technology", *IEEE Transactions on Antennas and Propagation,* vol. 62, no. 6, pp. 2992-3001, June, 2014.

[14] Seyed Ali Razavi, P.-S. Kildal, Liangliang Xiang, Esperanza Alfonso Alos and Haiguang Chen, "2 × 2-slot Element for 60 GHz Planar Array Antenna Realized on Two Doubled-sided PCBs Using SIW Cavity and EBG-type Soft Surface fed by Microstrip-Ridge Gap Waveguide", *IEEE Transactions on Antennas and Propagation,* vol. 62, no. 9, September. 2014.

[15] Pucci, E. , Rajo-Iglesias, E. , Vazquez-Roy, "Planar Dual-Mode Horn Array with Corporate-Feed Network in Inverted Microstrip Gap Waveguide", *IEEE Transactions on Antennas and Propagation,* vol. 62, no. 7, pp. 3534 - 3542, July, 2014.

[16] A. Vosoogh and P.-S. Kildal, "Corporate-Fed Planar 60 GHz Slot Array Made of Three Unconnected Metal Layers Using AMC pin surface for the Gap Waveguide ", *IEEE Antennas and Wireless Propagation Letters,* no. 99, Dec. 2015.

[17] J. L. Liu, A. Uz Zaman, P.-S. Kildal, "Optimizing Numerical Port for Inverted Microstrip Gap Waveguide in Full-Wave Simulators", *Antennas and Propagation (EUCAP), Proceedings of the 10th European Conference on*, 10-15 April 2016.