Invited Paper

Overview of the application of periodic structure for the W-band circuit and system

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Abstract: In this paper, the application of periodic structure for the W-band circuit and system is overviewed, and its future development is also discussed. Among the characteristics of the periodic structure, the stopband characteristic, which is also called electromagnetic bandgap (EBG), is focused in this overview paper. Two typical applications including EBG waveguide (gap waveguide) and EBG packaging are overviewed and summarized for the W-band circuit and system. For the gap waveguide, the stopband characteristic of the periodic structure prevent the electromagnetic wave leakage into the sides and the electromagnetic wave is guided within the designed paths. To integrate with the other passive and active components, three different W-band transitions have been proposed by the author for different kinds of the gap waveguides. Besides, a W-band gap waveguide bandpass filter has also been proposed by the author to study the passive component application of such technology. For the EBG packaging, two cases have been researched. The EBG packaging technique has been applied for improving the performances of a W-band coupler, and it has also been used for a low-profile and light W-band front-end integration. Finally, some discussions are given for this area.

Keywords: Periodic structure, Electromagnetic bandgap, W-band, Circuit and system, Gap waveguide

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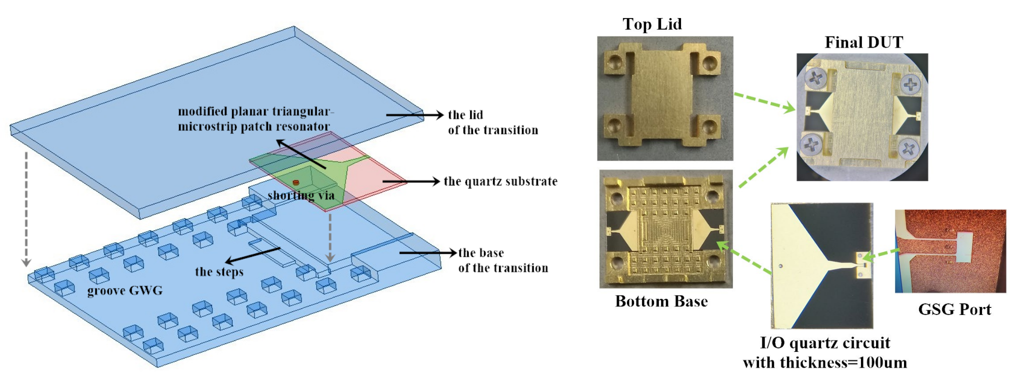
1. Introduction

W-band frequency spectrum has many potential applications in the future wireless communication and radar sensor [1-5]. However, there are many challenges for the W-band circuit and system design. For example, the circuit performances are sensitive for the fabrication tolerances. The traditional waveguide shielding in the front-end will enlarge the size and weight of the system. To overcome some of these issues, the applications of periodic structure for the W-band circuit and system are investigated and researched by the author's group.

Apart from the metamaterial [6], artificial magnetic conductor [7], frequency selective surface [8], frequency selective absorber [9], electromagnetic bandgap (EBG) is an important application area of the periodic structure. To construct the circuit and system, EBG waveguide is proposed and EBG's stopband characteristic is applied to prevent the electromagnetic wave leakage, resulting in the electromagnetic wave forced to propagate within the designed paths, which is also called gap waveguide [1-3]. In these gap waveguide, the EBG unit cells are arranged at the two sides of the waveguide paths. There are two typical unit cells (*i.e.* pin and mushroom). Both have noncontact characteristic, and air gap is usually used between the upper and lower metallic plates to reduce the substrate losses. This noncontact characteristic makes the gap waveguide transmission quality not sensitive with the fabrication tolerances, which is suitable for W-band and THz-band electromagnetic propagation. However, the transitions between such gap waveguide and other traditional planar transmission lines are needed at these high frequency bands. On the other hand, the EBG packaging is also proposed to protect the circuit and system. The application of the EBG packaging technique can remove the traditional waveguide shielding, which will effectively miniaturize the circuit and system. The noncontact characteristic also makes the EBG packaging robust. However, there is few report work of the EBG packaging for the circuit and system at W-band.

To enhance the research area of the application of periodic structure for the W-band circuit and system, three W-band transitions between gap waveguide and microstrip line have been proposed by the author, and one W-band gap waveguide bandpass filter has been proposed using the Micro-electromechanical Systems (MEMS) technology. Besides, two W-band EBG packaging for the coupler and TRx front-end have also been investigated by the author. These works are overviewed in this paper intensively, to help the readers learn more information in such area. Finally, future expectation of the application of periodic structure for THz-band heterogeneous integration is discussed.



(a) (b)

Fig. 1 Gap waveguide planar transition I [10]: (a) 3-D view, (b) back to back fabricated prototype.

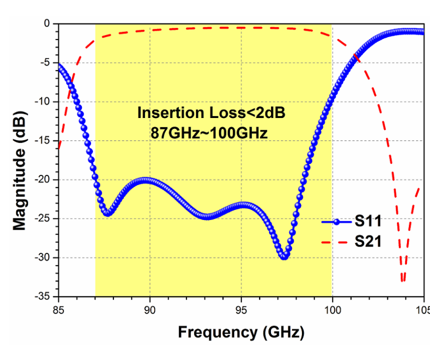
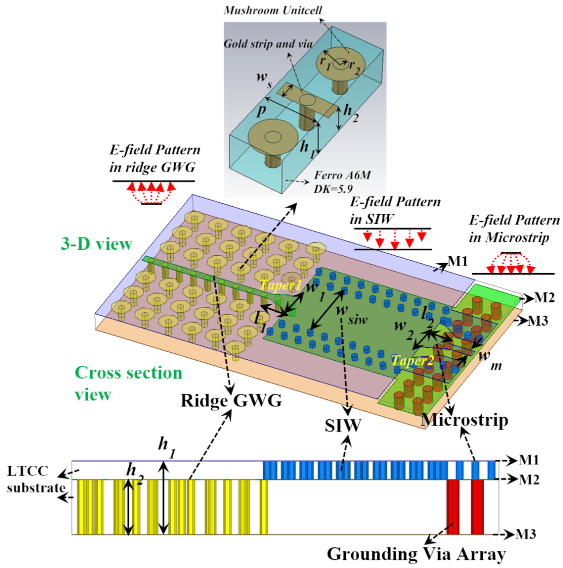
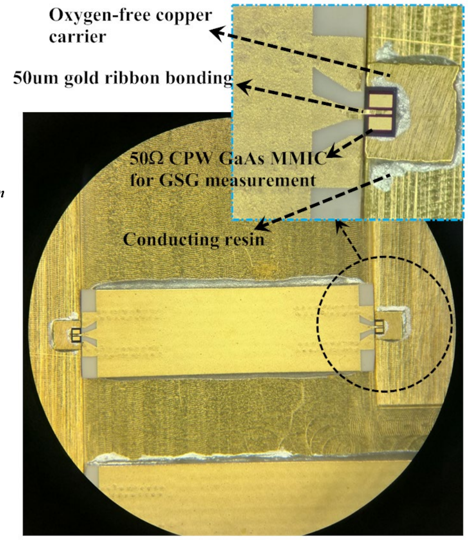


Fig. 2 Simulated performances of a single transition I.





(a) (b)

Fig. 3 Gap waveguide planar transition II [11]: (a) 3-D view, (b) back to back fabricated prototype.

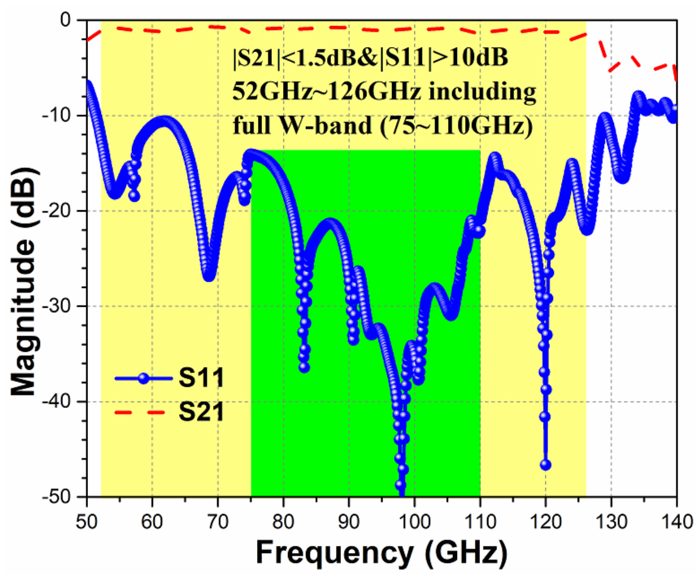


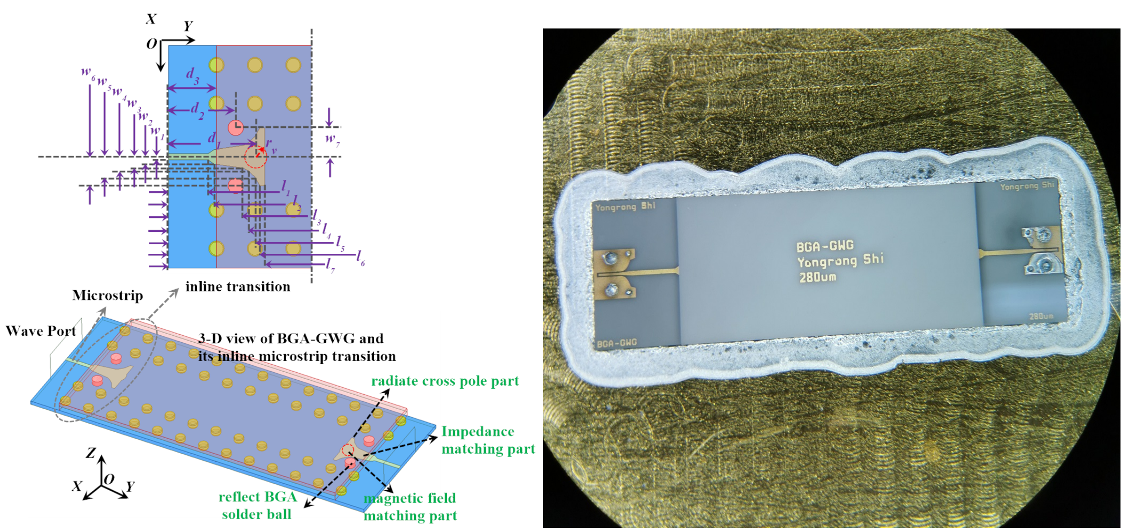
Fig. 4 Simulated performances of a single transition II.

2. EBG/gap waveguide and its planar transitions

Transitions act as the role of bridge between the gap waveguide and other passive components and active chips, to construct the front-end system. As shown in Fig. 1, the planar transition I was proposed for the groove gap waveguide [10]. Its design concept originated from the waveguide-coaxial line transition, and it was designed by the shorting via and planar resonator on the substrate. Its 3-D view is depicted in Fig. 1 (a), and its fabricated and assembled prototype is shown in Fig. 1 (b). Fig. 2 gives the simulated transmission performances of a single transition I in Fig. 1(a). Considering the transition can be achieved by different fabrication processes for different frequency bands, the ideal simulated results are given instead of the measured results in this overview paper. The readers can refer to the related references for more information in details. The transmission frequency band is from 87 *GHz* to 100 *GHz*, covering the 94 *GHz* atmospheric window frequency.

Fig. 3 (a) and (b) give the 3-D view of the proposed gap waveguide planar transition II and its fabricated back to back prototype using Low Temperature Co-Fired Ceramic (LTCC) technology, respectively [11]. The substrate integrated waveguide (SIW) plays the role of the connecting bridge between ridge gap waveguide and the microstrip line. The tapers make the electromagnetic field transition and impedance matching between the TE_{10} mode in the SIW and the quasi-TEM modes in the ridge gap waveguide and the microstrip line. Fig. 4 gives its simulated transmission performances, and the single transition can provide a wide working frequency band from 52 *GHz* to 126 *GHz*, which covers the full W-band.

Fig. 5 (a) and (b) depict the 3-D view of the proposed planar transition III for a special groove gap waveguide and its fabricated prototype, respectively [12]. This special groove gap waveguide consists of the ball grid array and top/bottom substrates, which has the advantages of low-profile and light weight. It is similar to the SIW, but metallic vias are not needed. Besides, such gap waveguide can be integrated with the chips packaged by the wafer level packaging (WLP) technique. It can also evolve into the ridge type gap waveguide to support the quasi-TEM propagation. Its inline microstrip transition was designed by the concept of the Yagi-Uda antenna, and its simulated transition transmission performances are provided in Fig. 6. Its operating frequencies range from 90 *GHz* to 98.8 *GHz*.



(a) (b)

Fig. 5 Gap waveguide planar transition III [12]: (a) 3-D view, (b) back to back fabricated prototype.

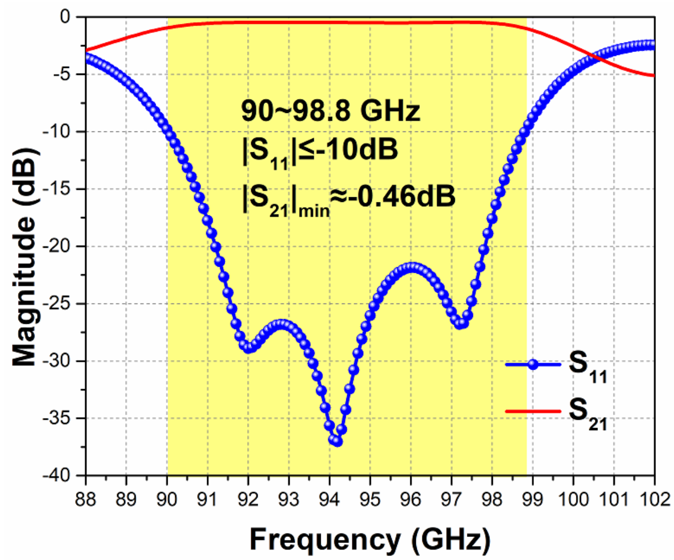
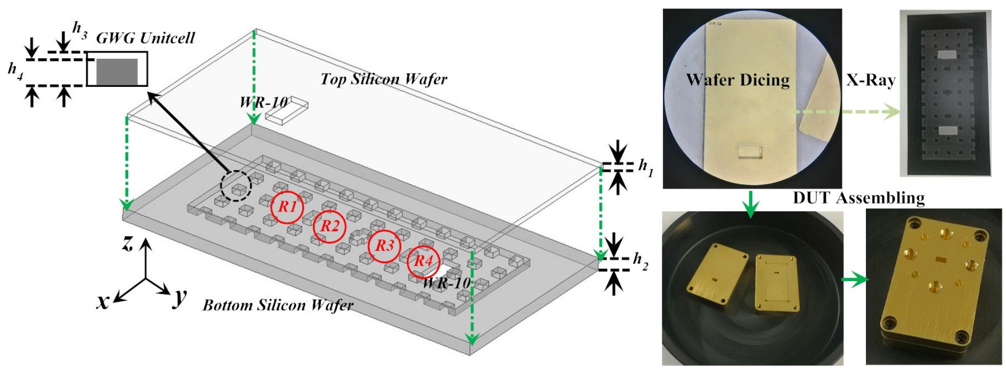


Fig. 6 Simulated performances of back to back transition III.



(a) (b)

Fig. 7 Gap waveguide bandpass filter [13]: (a) 3-D view, (b) fabricated prototype.

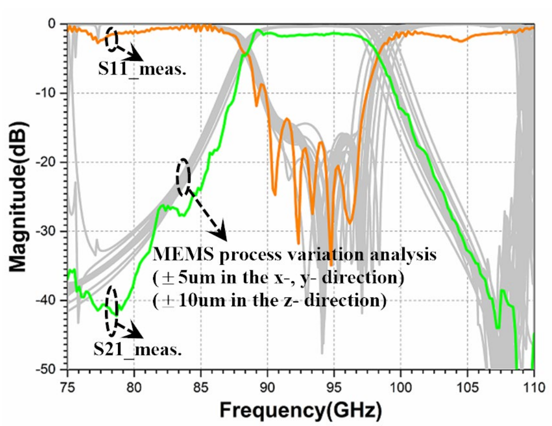
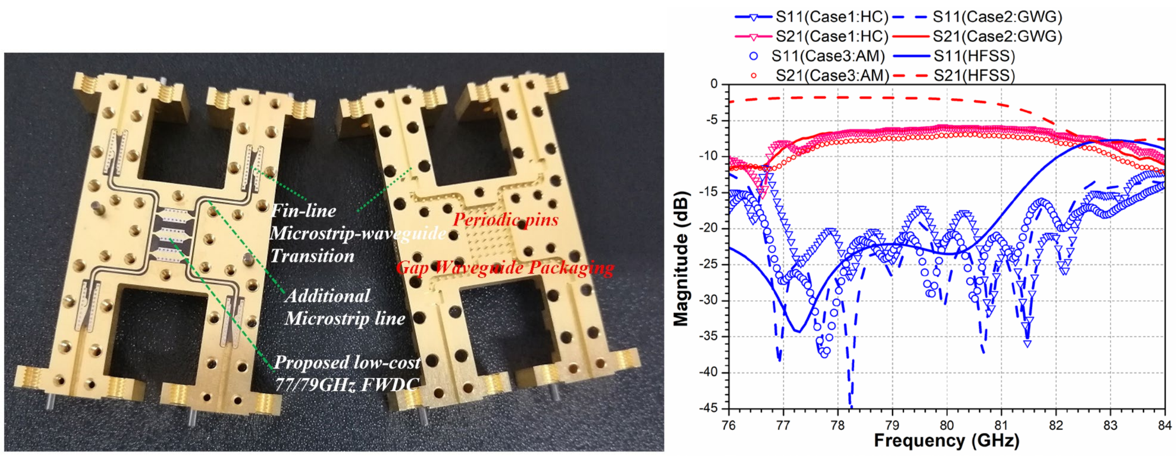


Fig. 8 Simulated and measured performances of the gap waveguide bandpass filter.

The gap waveguide can construct the above interconnect for the system, and it can also be applied to design the passive components including filter, coupler, divider and so on. To achieve a low-profile and light weight surface mounted W-band bandpass filter, a gap waveguide bandpass filter was proposed and depicted in Fig. 7 (a) using the MEMS technology. Fig. 7 (b) shows its fabricated prototype, and the waveguide interfaces are located on the top and bottom layers for the traditional waveguide measurement system. Fig. 8 gives the simulated and measured performances of the MEMS gap waveguide bandpass filter, and the effect on the filtering performances of the fabrication tolerances is also analyzed. The electric performances and size of such bandpass filter are competitive for the application in the W-band front-end system.



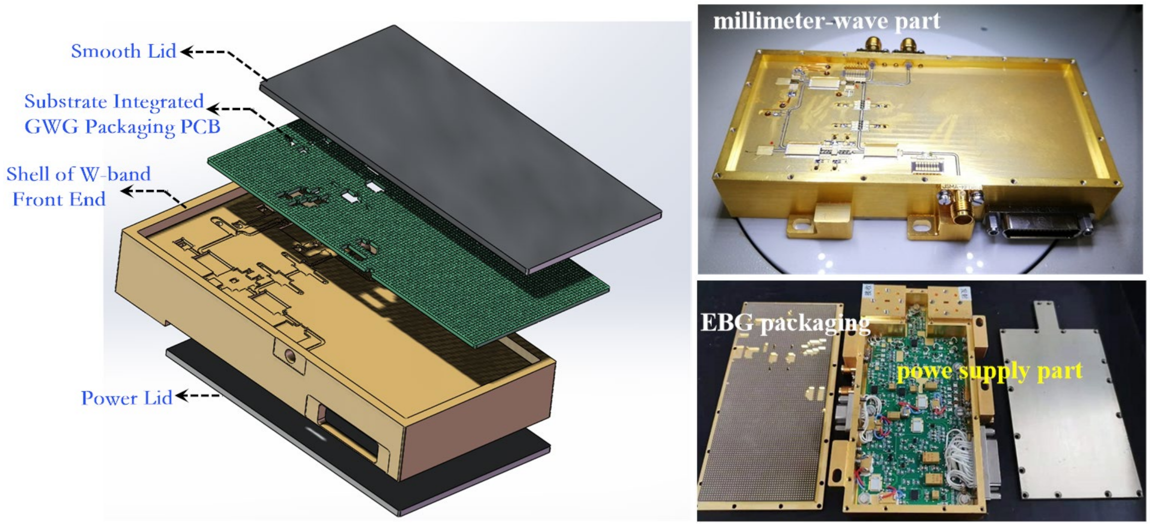
(a) (b)

Fig. 9 EBG packaging for the W-band forward wave directional coupler [16]: (a) fabricated prototype, (b) simulated and measured performances.

3. EBG packaging

The inherent stopband characteristic of the EBG can be used to suppress the cavity resonate mode noise of the front-end system which is packaged by the metallic box within the designed frequency range [14, 15]. Fig. 9 (a) gives an example of the EBG packaging for the single W-band forward wave directional coupler. The EBG unit cells are the traditional periodic pins, which are designed and located within the upper lid. The W-band forward wave directional coupler is soldered on the top layer of the bottom metallic base, and the fin-line microstrip to waveguide transitions are used for the input/output waveguide interfaces. The simulated and measured results are shown in Fig. 9 (b). The EBG packaging is donated as case 2, and the performances are better than the other cases. The discrepancies of the insertion losses and frequency shift between the measured results and the simulated ones are caused by the copper layer covered by the nickel/gold and via diameter increase of the SIW.

Fig. 10 (a) gives a substrate integrated EBG packaging solution for the W-band front-end, which has advantages of low-profile and light weight. The inner planar design without the traditional waveguide packaging is due to the substrate integrated EBG layer which is soldered at



(a) (b)

Fig. 10 EBG packaging for the W-band front-end [17]: (a) 3-D view, (b) fabricated prototype.

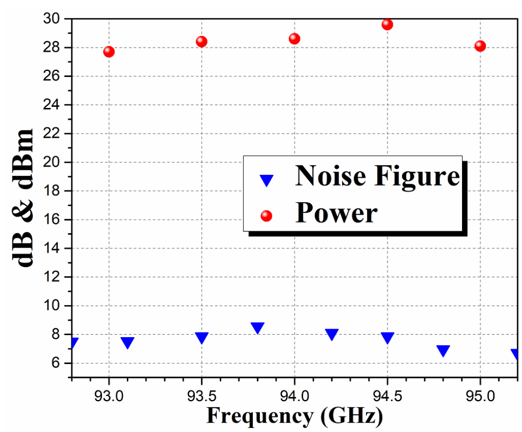


Fig. 11 Measured transmit power and receive noise figure of the W-band EBG packaged front-end.

the bottom of the lid. Fig. 10 (b) gives the fabricated prototype, and its millimeter-wave part looks like the microwave front-end module design. The substrate integrated EBG packaging PCB assembled on the metallic lid is inserted at the left bottom of Fig. 10 (a). Fig. 11 gives the measured performances of the transmit power and receive noise figure of such a W-band front-end by the proposed EBG packaging solution. The transmit power and receive noise figure are around 28 *dBm* and 7.5 *dB*, respectively.

4. Discussion

The above EBG/gap waveguide and EBG packaging researches are overviewed which focus on the W-band. Similarly, there are performances and packaging challenges at the THz. With the trend of frequency increasing, the sizes of the components and chips decrease. At present, monolithic microwave integrated circuit is widely used for the THz circuit and system. Heterogeneous integration may be the potential THz packaging solution, which is more and more popular at microwave and millimeter-wave frequencies [5, 18]. For THz heterogeneous integration, the EBG periodic structure fabricated by the semi-conductor techniques can be used as the micro-waveguide to connect the THz MMIC integrated with the transition probe. These micro-fabricated EBG waveguide can also be applied to design the THz passive components and antenna array. Besides, the EBG packaging of the ball grid array or through silicon vias can be integrated with THz system for noise suppression.

5. Conclusions

W-band EBG/gap waveguide and its passive component are overviewed in this paper, which can provide efficient interconnect solution and high-performance component. Besides, the EBG packaging is also introduced for single component and a whole front-end, which can optimize the performances and miniaturize the system size. Finally, a discussion of the application of EBG periodic structure for the THz-band heterogeneous integration is given briefly for the readers to explore such an area.

Acknowledgement

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