Comments on “Ka-Band Coplanar Magic-T Based on Gap Waveguide Technology”

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***Abstract*—In the title paper, the author proposes a Ka-Band Coplanar Magic-T Based on Gap-Waveguide (GW) Technology. The major novelty claimed in the paper is the combination of ridge-gap and E-plane groove-gap waveguides for Ka-band applications. However, such combination of these two types of waveguides in GW technology was firstly proposed in 2017. This combination allows for the realization of numerous devices, and distribution networks in the millimeter-wave band. This comment aims to properly frame the evolution of the use of RGW-GGW networks and how their use can be useful for new mm-wave band devices. While the author's Magic-T introduces a new feature by using a 4-port network, it is clear that the concept relies on previous ideas not mentioned in the manuscript and this can lead to confusion about its actual novel contributions. In addition, we intend to give the microwave community a proper perspective of the above work's frame of reference.**

***Index Terms*—— E-plane Groove Gap Waveguide (GGW), Ridge Gap Waveguide (RGW)**

I. INTRODUCTION

Power dividers are building blocks of many millimeter-wave components and networks. These blocks are especially useful in millimeter-wave integrated circuits or low-loss feeding systems. The Gap-Waveguide (GW) technology, which emerged in 2008 [1], is especially useful in the millimeter-wave band since permits the fabrication of low-loss structures without requiring perfect contact between metallic pieces. Therefore, the field leakage problem, typically present when miniaturizing devices in the millimeter-wave band, is minimized.

In 2017, [2] introduced for the very first time a power distribution network combining two different types of waveguides in GW technology. Until then, the networks and devices implemented in GW used a single type of waveguide, either Ridge Gap Waveguide (RGW) or Groove Gap Waveguide (GGW), but without combining them.

The main advantage of such waveguide combination is that it introduces a very profitable versatility in the design of millimeter-wave power dividers and combiners. While RGW leads to symmetrical networks, GGW sections provide a more compact structure. This hybrid network was the main outcome of the work published in 2017 [2]. From then on, this type of network has been widely adopted to design power dividers for feeding networks in array antennas [3], [4], [5], [6], [7], [8].

II. PREVIOUS COMMENTS

The article “Ka-Band Coplanar Magic-T Based on Gap Waveguide Technology” [9] presents a network of 4 accesses. It can be seen as two power dividers 1-to-2 facing each other. The first one is an RGW-GGW power divider, and the second one uses GGW only. While the second divider is trivial, the first one allows the particular features of the Magic-T that is presented. Any reader could think that this is the relevant contribution of the article since it does not reference to the 2017 paper [2], the germinal idea taking advantage of the RGW-GGW combination. In [9], only a vague reference of RGW-GGW usage is included [4], but no comment is made on it and it is only given as one more of the references for antennas in the millimeter-wave band. No reader could deduce that the idea was also used in [4] from the way the reference is used in the text.

This comment correctly frames the evolution of the use of RGW-GGW combined networks, explain their advantages and drawbacks and how they can be useful for novel mm-wave band devices.

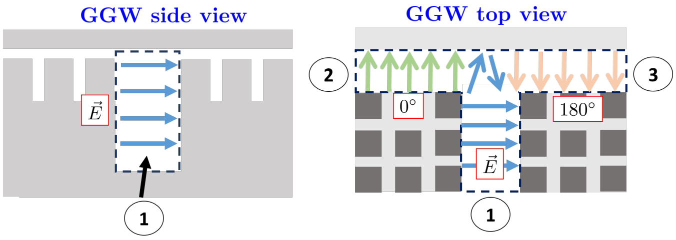

Fig. 1: E-plane power divider in GW technology.

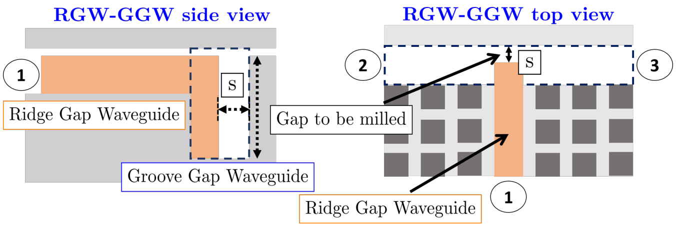

Fig. 2: RGW-GGW power divider.

III. RGW-GGW COMBINED NETWORK FEATURES

A GGW behaves similarly to a conventional rectangular waveguide, while the behavior of a RGW is similar to that of a conventional ridge waveguide [10]. The main difference between Gap waveguides and conventional waveguides lies in the fact that, in GW technology, the pieces may not have

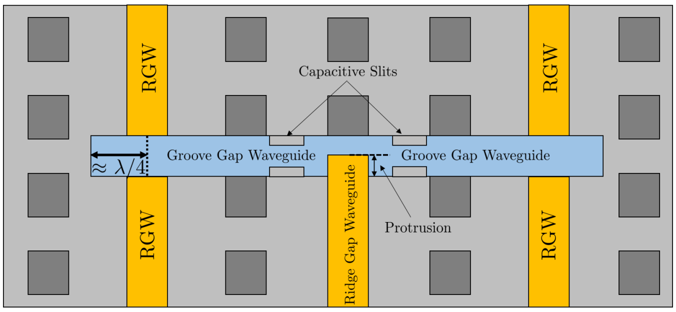

Fig. 3: Upper view of the two-level GGW-RGW divider.

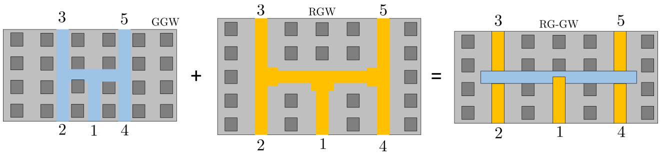

Fig. 4: Outline of the approach to merge GGW with RGW.

	GGW	RGW	RG-GW
Compact	✓	✗	✓
Phase	✗	✓	✓

Fig. 5: Features of 1:N power dividers depending on waveguide used.

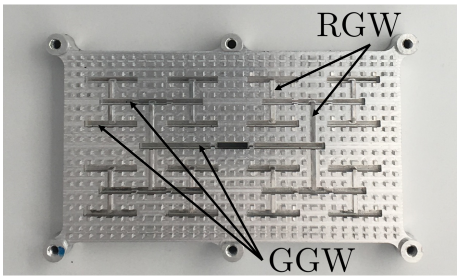

Fig. 6: 1:16 RGW-GGW power divider as a feeding network of a slot array, presented in [3].

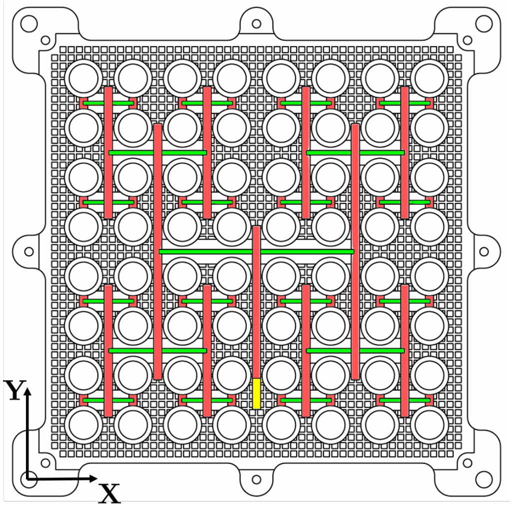

Fig. 7: 1:64 RGW-GGW power divider as a feeding network of an aperture array, presented in [6]. GGW is colored in red and RGW in green.

contact with each other, still ensuring the confinement of the field within the structures [11].

Thus, the early designs of distribution networks using GW technology resembled those typically made with conventional hollow waveguides. Many examples of H-plane dividers in GGW and RGW dividers can be found in the literature [12], [13], [14], [15]. E-plane GGW power dividers are rather scarce because they introduce a 180° phase difference between both output arms, which is not usually of interest, as shown in Fig. 1. However, there were some successful attempts using only E-plane power dividers in corporate-feed networks [16].

As it is well known, all the output ports in a network using ridged waveguides have the same phase. Besides that, RGW power dividers are more compact than those based on rectangular waveguides or vertically-polarized GGW, but much less compact than E-plane dividers. Hence, the latter are able to provide very compact distribution networks, but as commented above, their inherent 180° phase difference must be faced. The RGW network avoids such problem but more room is needed. The described design trade-off could be solved by combining both types of networks, leading to a compact in-phase approach. That was firstly proved in [2].

In [2], the propagation constant of RGWs and GGWs for a certain height, width and periodicity of nails of the GW Technology was studied. Interestingly, a straightforward tuning of these parameters gives the same propagation constant in both waveguides. This study was initially performed in the V-band, though it can be easily extrapolated to any band by scaling dimensions. The design strategy for each divider is as follows:

- RGW to GGW: In order to couple the propagation modes from RGW to GGW, the ridge must protrude a little bit into the GGW to be able to couple the field from the RGW to the GGW. The behavior of the electric field and how it rotates from the RGW to the GGW was demonstrated in [2], and depicted in [4]. Also, capacitive slits can be included on both sides of the input RGW-GGW transition to improve the frequency bandwidth as also demonstrated in [2].
- GGW to RGW: In this case, there is one fundamental parameter to be taken into account for a proper design. To optimally match a GGW and a RGW in a power divider, the RGWs must be placed at a distance of approximately $\lambda_g/4$ from the GGW short end, as indicated in Fig. 3. In this way, the maximum of the E-field occurs just at the input of the RGW for a proper power coupling.

One issue never discussed about RGW-GGW combined network in subtractive fabrication, such as CNC, is commented now. Typically, horizontally-polarized GGWs are quite narrow

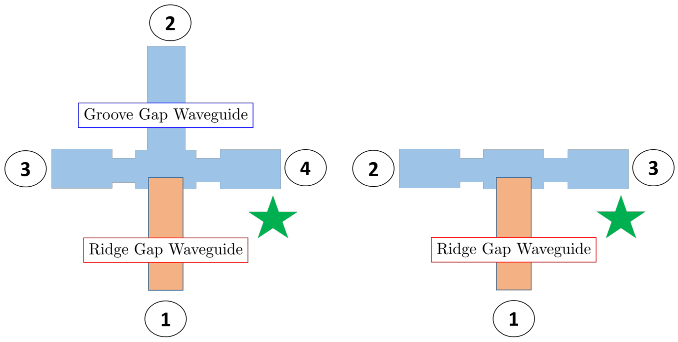

Fig. 8: Outline of the contributions in [9] (left) and [2] (right).

and deep. Thus, when the RGW is protruded into the GGW there is a small gap between the RGW and the inner wall of the GGW. Then, a trade-off must be reached. This gap must be small enough so that the field can be coupled from the RGW to the GGW but at the same time not so narrow that a milling cutter cannot access and mill that gap. Typically, extremely long and thin drills are not available. This situation is illustrated in Fig. 2. Note that this issue appears in subtractive manufacturing but not in additive manufacturing techniques.

Finally, once the design guidelines have been discussed with their advantages and disadvantages, a complete RGW-GGW-RGW power divider is shown in Fig. 3. An outline of the approach to merge GGW with RGW is depicted in Fig. 4. A table comparing the features of a 1:N power dividers depending on the type of waveguide used is described in Fig. 5. In addition, Figs. 6 and 7 show two examples of 1:N dividers using the combination of E-plane GGW and RGW. Regarding the contribution object of this comment it is clear that the same strategy proposed in [2] has been followed in [9], i.e., the protrusion of the RGW is required and slits are used on both sides. In [9] are called *windows*, though they are clearly the same element.

Fig. 8 compares the design proposed by Farahbakhsh in [9], and in the initial design proposed in [2]. As we can see, in the first case the network has 4 ports, while in the second case the network has 3 ports. Likewise, the similarities in the RGW-GGW divider are evident. Of course, we do not object to variations on pre-existing designs as this is the key to scientific progress but it should not be overlooked to cite the background to properly frame the progress in each case.

Thanks to the interesting features of the RGW-GGW, ultra-compact distribution networks are now available, allowing for the design of single-layer devices in the millimeter-wave band, as the Magic-T proposed in [9]. In recent years the finding favored the appearance of bi-dimensional single-layer antennas in GW technology, although the horizon is open for new implementations such as hybrid-couplers, phase shifters or diplexers. Table I shows some relevant references helpful in framing the use of RGW-GGW power dividers in millimeter-wave band devices.

TABLE I: Relevant works where the GW distribution network was a fundamental part of the device.

Work	Year	Band	Authors	Power divider
[17]	2014	V-band	Zaman et al.	RGW
[18]	2015	Q-band	Sáez et al.	GGW
[19]	2016	V-band	Zarifi et al.	RGW
[20]	2017	V-band	Farahbakhsh et al.	GGW
[2]	2017	V-band	Ferrando-Rocher et al.	RGW-GGW
[4]	2018	Ka-band	Ferrando-Rocher et al.	RGW-GGW
[21]	2018	Ka-band	Ferrando-Rocher et al.	RGW-GGW
[5]	2018	Ka-band	Ferrando-Rocher et al.	RGW-GGW
[3]	2018	Ka-band	Ferrando-Rocher et al.	RGW-GGW
[4]	2018	K and Ka-band	Ferrando-Rocher et al.	RGW-GGW
[6]	2019	K and Ka-band	Ferrando-Rocher et al.	RGW-GGW
[7]	2019	K and Ka-band	Sánchez et al.	RGW-GGW
[20]	2019	D-band	Farahbakhsh et al.	RGW-GGW
[9]	2020	Ka-band	Farahbakhsh	RGW-GGW

IV. CONCLUSION

As the author of [9] claims in the conclusions of his work, the coplanar Magic-T is based on a combined RGW and E-plane GGW. Thanks to this transition, Magic-T can be implemented in a single layer, facilitating stacking problems. In addition, an additive manufacturing technique is used for the prototype. The genesis of the idea dates to 2017 [2], and it is not cited or commented anywhere in the paper, which can lead to confusion to the reader. This comment correctly frames the evolution of RGW-GGW networks and their use, as well as provides useful design guidelines. Moreover, a key aspect to take into account in the design of RGW-GGW power dividers in subtractive manufacturing is provided.

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