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V-Band Groove Gap Waveguide Diplexer

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***Abstract*— In this paper a novel V-band diplexer, based on the newly introduced groove gap waveguide technology is presented. The diplexer structure consists of an H-plane T-junction and two RX and TX filters having 1.5% relative bandwidth at 59.5GHz and 62.5GHz center frequencies, respectively. Also, two groove gap waveguide to WR-15 transitions are designed. The main advantages of the groove gap waveguide diplexer compared to the classical rectangular waveguide diplexer are that there is no need for electrical contact between the top and bottom metal plates, and it adds an opportunity of packaging the active transceiver circuits together with the diplexer. The design procedure and the simulated results are presented.**

***Index Terms*—coupled resonator filter, gap waveguide, groove gap waveguide, microwave diplexer.**

I. INTRODUCTION

Diplexer is an important element of a transceiver front end that separates the RX and TX signals and connects the RX and TX circuits to the antenna port. Conventionally, the diplexer is realized using classical waveguide technology [1]-[2]. To obtain a good performance for millimeter wave applications, this approach causes high product cost. Moreover, connecting the classical waveguide components to the front end electronic circuits mounted on the printed circuit board increases the complexity and size of the system.

The gap waveguide technology was introduced in [3] and it is based on a detection of local quasi-TEM waves in a parallel-plate waveguide with a single hard surface [4]. There are four different versions of it. The basic groove, ridge and microstrip gap waveguides are described in [5], and the fourth microstrip-ridge gap waveguide in [6]. The gap waveguides have relations to so-called waffle-iron filters, a technology that was used to realize waveguide phase shifters in [7-8]. The first experimental demonstration of a ridge gap waveguide was described in [9] (ridge gap waveguide). The main advantages of gap waveguides become evident above 30 GHz: they have much lower losses than microstrip and coplanar waveguides, and they can be manufactured without metal sidewalls (which normal rectangular waveguides need). In recent time, some gap waveguide slot array antennas were realized in ridge gap waveguide [10, 11], groove gap waveguide technology [12] and inverted microstrip gap waveguide technology [13]. The first mmWave gap waveguide antenna was the microstrip-ridge gap waveguide based slot array antenna described in [14].We are presently in the process of designing planar directive gap waveguide antennas for 60GHz microwave link, based on microstrip-ridge gap waveguide that has been described in [13]. The present paper presents a groove gap waveguide diplexer for such a 60 GHz radio link, and it can easily be extended to package even the MMICs connected to the RX and TX ports.

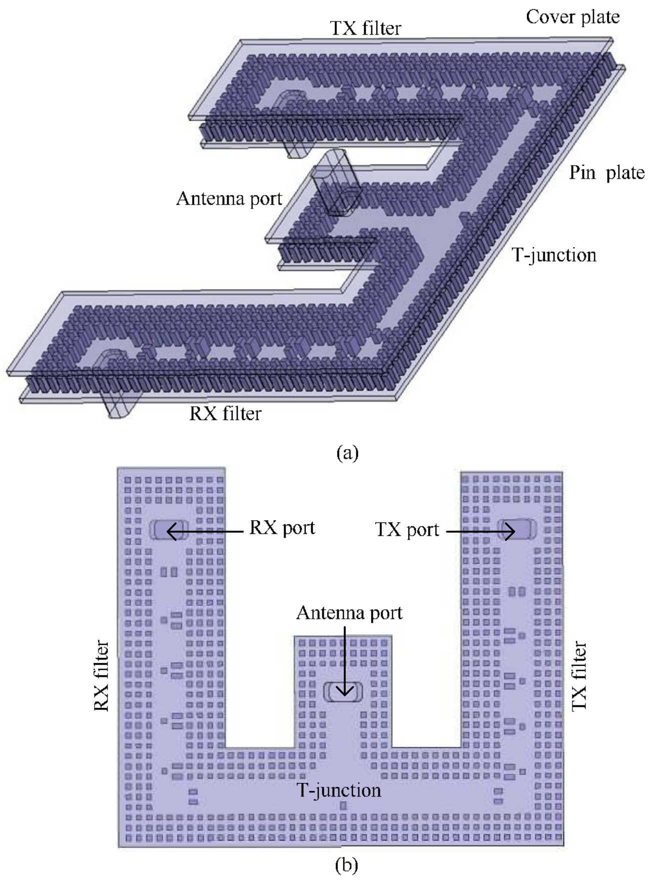

Fig. 1. Proposed 60GHz groove gap waveguide diplexer. (a) 3D view and (b) top view.

The gap waveguides consist of two parallel metal plates one of which has a textured surface, such as a bed of nails [15]. This bed of nails acts as a Perfect Magnetic Conducting (PMC) surface and provides a stopband for normal parallel plate modes, thereby forcing the waves to follow the groove, ridge or microstrip [16]. Using the gap waveguides technology, the integration of the transceiver system between two plates can be provided, and the need for conducting contact between the

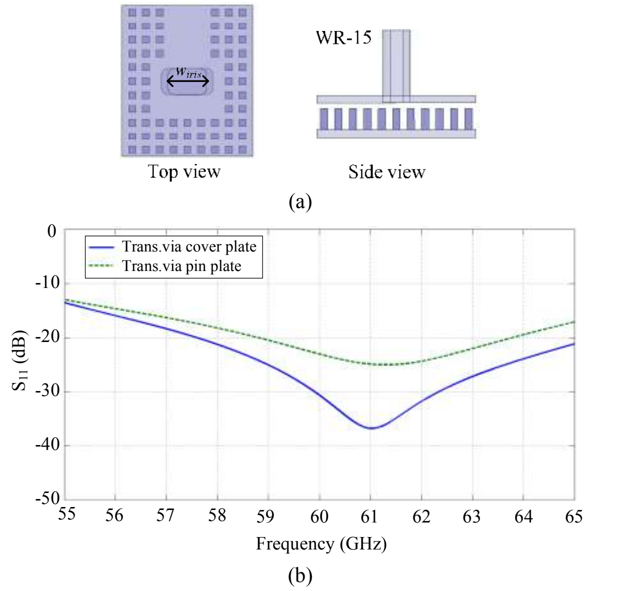

Fig. 2. (a) Groove gap waveguide to WR-15 transition for the antenna port via the cover plate. (b) Frequency response of transitions.

metal split blocks can be eliminated. Thereby, they can also be used to package active components such as RF MMICs [17].

Among the various types of gap waveguides, the groove gap waveguide works similar to the classical rectangular waveguide and has the highest value of quality factor [18]. The first groove gap waveguide filter (at 14GHz) was published in 2012 [19] and at 38 GHz in [20]. In the present paper a diplexer at 60GHz is presented. Firstly, the transitions to WR-15 flanges, the T-junction, and the RX and TX filters are designed. Finally, these different parts are connected to each other and the overall structure of the diplexer is realized.

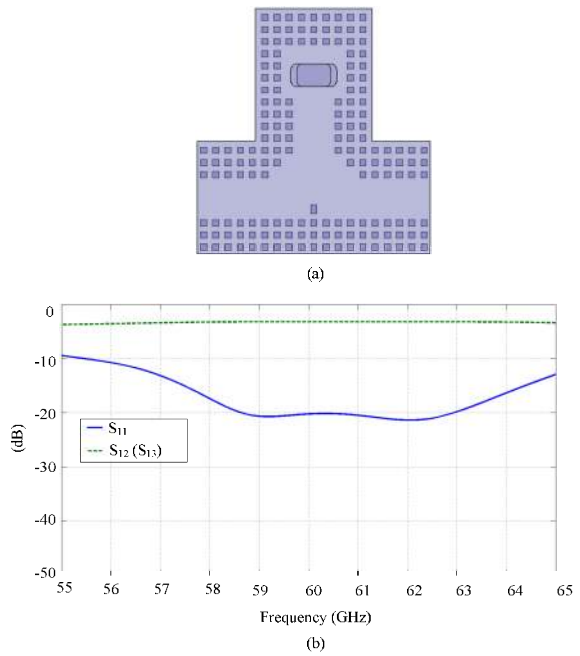

Fig. 3. (a) Groove gap waveguide T-junction and (b) its frequency response.

II. Diplexer Design

Fig. 1 shows the proposed 60GHz diplexer and we see that it consists of two parallel plates, called cover plate and pin plate. Part of the pin plate contains a bed of pins. These periodic pins, with height of λ/4 and period of less than λ/2, create an Artificial Magnetic Conductor (AMC). Parallel plate modes cannot propagate between this AMC and the cover metal plate provided the air gap between them is smaller than λ/4. The groove generated between the pins guides the TE_{10} type mode [21], such as in the rectangular waveguide, and therefore, the T-junction and coupled resonator filters can be realized in similar to that of classical waveguide. A WR-15 flange is used to connect the diplexer to the antenna port via the cover plate and two WR-15 flanges are also used to connect the diplexer to the RX and TX ports via the pin plate.

Fig. 2(a) shows the designed transition from groove gap waveguide to WR-15 via an aperture in the cover plate for the antenna port. The height and period of pins are selected to be 1.5mm and 1mm, respectively, and the air gap between the pins and cover plate is 0.4mm. Similar transitions are used for RX (and TX) port via an aperture in the pin plate. The return loss of these two transitions, as shown in Fig. 2(b), is better than 20dB from 59GHz to 63GHz. The H-plane T-junction, shown in Fig. 3(a), is used to connect the WR-15 antenna port to the RX and TX filters. The frequency response of this T-junction is shown in Fig. 3(b) that its return loss is better than

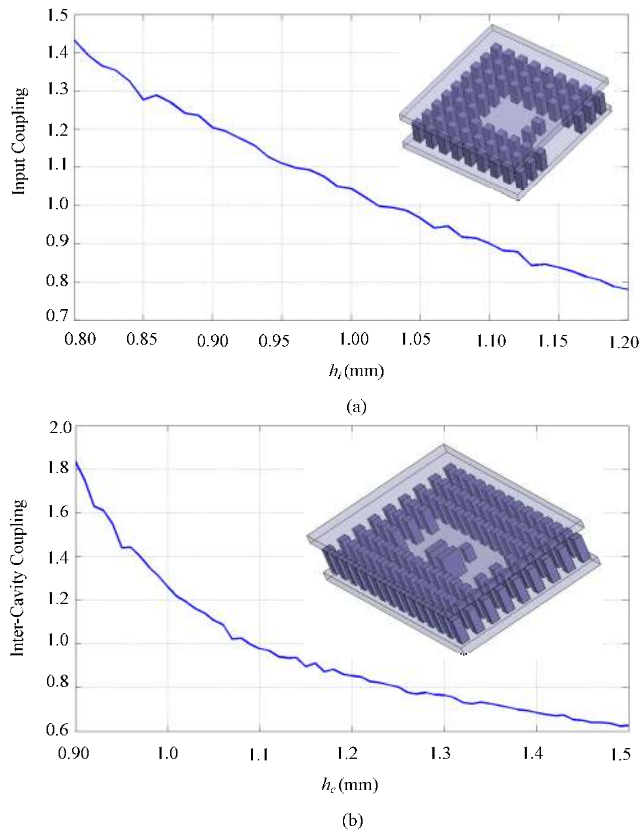

Fig. 4. (a) Input coupling coefficient, M_{S1} (or M_{L5}), versus height of ridge h_i and (b) inter-cavity coupling versus height of coupling pin h_c.

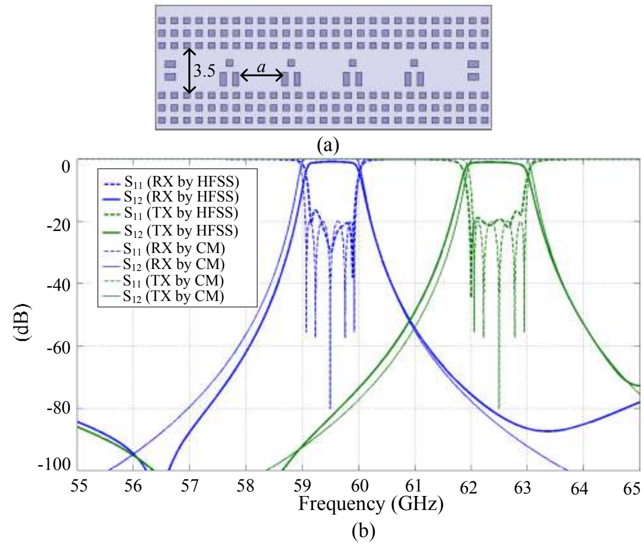

Fig. 5. (a) Structure of the fifth-order groove gap waveguide RX filter. (b) The simulated and calculated frequency response of RX and TX filters, separately.

20dB from 59GHz to 63GHz.

The coupling coefficients for designing a fifth-order Chebyshev filter with synchronously tuned resonators are

$$M_{S1} = M_{L5} = 1.0136, \quad M_{12} = M_{45} = 0.8653$$

$$M_{23} = M_{34} = 0.6357$$

Square shape groove gap waveguide cavity is used as the filter resonators with side length a. The input (output) coupling to the first (last) resonator, that is M_{S1} (M_{L5}), can be realized as is seen in the inset of Fig. 4(a). Two metal ridges are located at the middle of the groove gap waveguide to control the coupling. The variation of coupling versus the height of ridges, h_i, is shown in Fig. 4(a) with ridge length of 0.8mm. The inter-cavity coupling between ith and jth resonators, M_{ij}, is also realized using the structure shown in the inset of Fig. 4(b). The height of coupling pin, h_c, controls the inter-cavity coupling as can be seen in Fig. 4(b). The designed fifth-order RX filter using design graphs in Fig. 4 is depicted in Fig. 5(a). A comparison of the calculated frequency response of the RX filter and also the TX filter obtained from the coupling matrix and the simulated frequency response by using HFSS is shown in Fig. 5(b).

Finally, the different parts of diplexer are connected to each other, as shown in Fig. 1. In this structure, the RX and TX filters are folded to have a square-shaped structure of the complete diplexer. Two groove gap waveguide sections are also added with proper electrical lengths between the RX (TX) filter and T-junction because of the effects of the reflected signal from the TX (RX) filter within its stopband. The detailed dimensions of the proposed diplexer are listed in Table I. The simulated frequency response of the proposed diplexer is shown in Fig. 6. The return loss in the RX and TX bands is better than 10dB. The minimum insertion loss is 1dB assuming silver-coating of both the cover and pin plates. Also, the isolation between two bands is better than 80dB.

TABLE I
DIMENSIONS OF THE PROPOSED GROOVE GAP WAVEGUIDE DIPLEXER (IN MILLIMETER)

a (RX)	a (TX)	h_i	h_c (M_{12},M_{45})	h_c (M_{23},M_{34})	w_{iris}
3.42	2.94	1	1.2	1.48	2.75

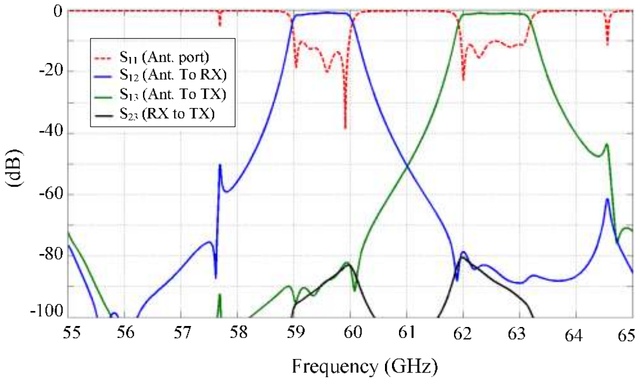

Fig. 6. Simulated frequency response of the proposed diplexer in Fig. 1.

III. CONCLUTION

V-band H-plane groove gap waveguide diplexer consisting of an H-plane T-junction and two filters was studied. Using the gap waveguide technology, system integration can be done between the two parallel-metal plates, without any conducting joint between them. The coupling matrix approach was used to design the fifth-order Chebyshev RX and TX filters which were realized by high–Q groove gap waveguide resonators. Transitions via cover plate and also pin plate to WR-15 were designed. Airing and cooling is allowed due to open structure and therefore the sensitivity to temperature drift is low for such filter structure.

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