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A V-band Inverted Microstrip Gap Waveguide End-coupled Bandpass Filter

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***Abstract*—This letter presents an end-coupled bandpass filter based on the recently introduced inverted microstrip gap waveguide technology. The inverted microstrip gap waveguide is advantageous for millimeter wave applications because of its low-loss, self-packaging characteristics, and cost-effectiveness. A fourth order Chebyshev-type end-coupled bandpass filter is designed to provide a 2 GHz bandwidth at 60 GHz center frequency. The fabricated prototype embedded within a 10 cm inverted microstrip gap waveguide, containing two back-to-back transitions to rectangular waveguide, exhibits an insertion loss of 3 dB in the passband. However, the insertion loss of the filter itself is better than 1.6 dB.**

***Index Terms*—Bandpass filter, end-coupled filter, inverted microstrip gap waveguide, millimeter wave, transition.**

I. Introduction

THERE is a growing interest in millimeter wave applications such as 77 GHz high resolution automotive radar and 60 GHz high data rate communication system terminals. Bandpass filters are essential passive components for most wireless communication systems, and need to be designed efficiently for these new high frequency applications. Low loss, inexpensive and suitable for mass-production are some of the required features of bandpass filters for these frequencies. Moreover, many applications highly require planar bandpass filters for compact integration with active components such as amplifiers and monolithic microwave integrated circuits (MMIC). At microwave frequencies bandpass filters are commonly realized in hollow waveguide structures, due to low insertion loss and high power handling capability. However, the manufacturing cost of the hollow waveguide filters becomes too high at millimeter wave frequencies due to the strict tolerance requirements in the split-block technique.

Planar technologies such as microstrip, coplanar waveguide (CPW) and substrate integrated waveguide (SIW), are more suitable for integration with active and passive components and easier to fabricate compared to standard waveguide structures. However, these transmission lines suffer from high dielectric and ohmic losses and radiation leakage, especially for increasing operating frequency. A V-band third order bandpass filter realized in SIW technology is presented in [1]. The fabricated prototype shows an insertion loss of 3 dB at the center frequency of 62 GHz, mainly due to dielectric loss. The radiation loss in the microstrip bandpass filters due to the presence of discontinuities (such as open-ends) is a serious problem, especially if it is not properly packaged. Although microstrip bandpass filters have a simple structure, their applications are limited to microwave frequencies due to high losses.

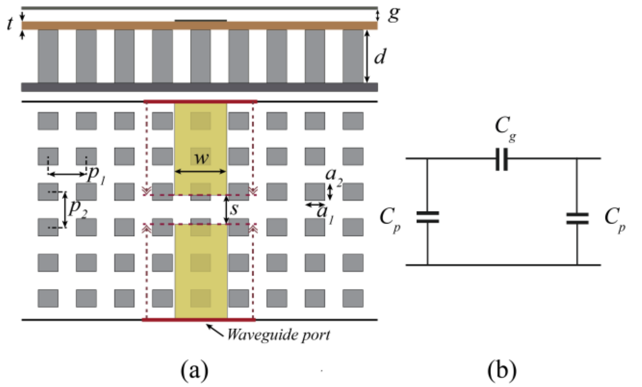

Fig. 1. (a) Inverted microstrip gap waveguide (b) Equivalent π-network of microstrip gap.

The recently introduced inverted microstrip gap waveguide technology shows promising characteristics such as low loss, flexible manufacturing, cost effectiveness and self-packaging [2]. This planar technology is composed of a printed circuit board (PCB) without ground plane and supported by a bed of nails as illustrated in Fig. 1. A metal plate is placed above the PCB separated by an air gap, which should be smaller than a quarter wavelength. A local wave is allowed to propagate between the strip line of the PCB and the upper metal lid within the air gap. The field propagation is forbidden outside the strip, so any possible leakage is removed. In [3-4] different bandpass filters based on groove gap waveguide type, operating at different millimeter-wave frequency bands have been proposed. Moreover, the PMC packaging realized with gap waveguide technology efficiently improves a microstrip-type parallel coupled-line bandpass filter as shown in [5].

In this letter, a V-band end-coupled bandpass filter based on inverted microstrip gap waveguide is presented. The pin surface together with the dielectric and the air gap dimensions

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TABLE I
DIMENSIONS OF INVERTED MICROSTRIP GAP WAVEGUIDE
(REFERS TO FIG. 1)

Parameter	Value (mm)	
w	1	*Width of the strip*
g	0.25	*Air gap*
t	0.253	*Thickness of substrate*
d	1.05	*Height of pins*
p_1	0.73	
p_2	0.68	
a_1	0.38	
a_2	0.33	

set up a stopband where undesired parallel-plate modes and surface waves are removed [6]. Since the wave propagates mainly in the air and surface waves do not exist, the width of the lines in gap waveguides become wider than typical microstrip and SIW. A V-band transition between inverted microstrip gap waveguide and rectangular waveguide was presented and validated with both simulations and measurements in [7]. Measurement results confirmed that the overall loss in inverted microstrip gap waveguide is lower than in conventional microstrip and SIW. Therefore, inverted microstrip gap waveguide has advantages of both easy PCB fabrication, and packaging characteristics of gap technologies. The designed filter has a planar structure and acceptable loss, thereby becoming suitable for integration with active and passive components.

II. INVERTED MICROSTRIP GAP WAVEGUIDE END-COUPLED FILTER DESIGN

The designed filter is based on the end-coupled microstrip filter geometry, which has been widely studied in the literature at microwave frequencies [8]. However this filter, in microstrip form, has not shown its potential at millimeter wave frequencies due to high dielectric and radiation loss. In this paper we show that this type of filter is feasible in inverted microstrip gap waveguide at V-band. First, the bed of nails composing the inverted gap geometry must be designed. For this purpose, the same transitions as in [7] have been re-used and these dimensions are shown in Fig. 1(a) and Table I. We have used Rogers RO3003 as dielectric material with permittivity ε_r = 3 and loss tangent *tanδ* = 0.003 evaluated at millimeter wave frequencies in [9], (Rogers material data sheet provides *tanδ* = 0.0013 @ 10 GHz which is not realistic at 60 GHz). With all this data, the corresponding stopband appears between 50.55 and 75 GHz, which means almost the whole V-band [7].

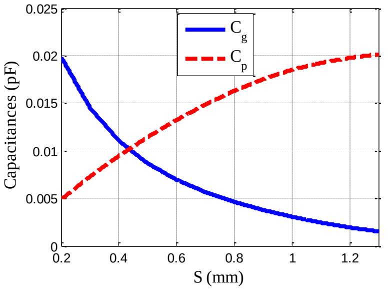


Fig. 2. Simulated capacitances.

TABLE II
INITIAL AND OPTIMIZED FILTER PARAMETER VALUES

Parameter	s_1	l_1	s_2	l_2	s_3
Initial value (mm)	*0.33*	*1.74*	*0.99*	*1.75*	*1.087*
Optimized value (mm)	*0.26*	*1.72*	*0.88*	*1.76*	*1.06*

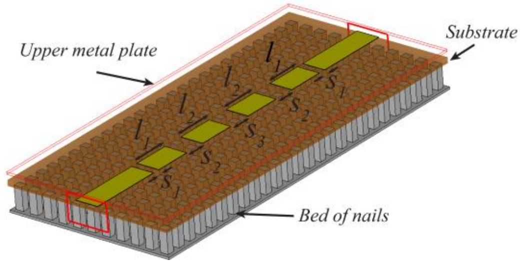


Fig. 3. Fourth order inverted microstrip gap waveguide bandpass filter.

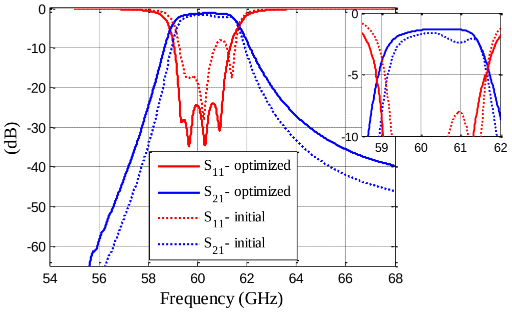


Fig. 4. Simulated filter response for initial and optimized parameter values.

The end-coupled filter consists of a series of approximately half wavelength open-end transmission line resonators, being capacitively coupled to each other through gaps. We have used the same design guidelines as in [8] in order to determine the physical parameters of the filter. The microstrip gap can be modeled as a π-network of capacitors, as shown in Fig. 1(b). These capacitances are the design parameters for evaluating the dimensions of the filter. The two-port network shown in Fig. 1(a) is simulated with CST Microwave Studio, and the *Y*-parameters of the two-port network are calculated for different microstrip gap sizes. Then, the capacitance C_g and C_p can be found by using (1) and (2), where ω_0 is the angular frequency in center frequency.

$$C_g = -\frac{\mathrm{Im}(Y_{21})}{\omega_0} \tag{1}$$

$$C_p = \frac{\mathrm{Im}(Y_{11}+Y_{21})}{\omega_0} \tag{2}$$

As shown in Fig. 1(a), the waveguide ports are de-embedded to the gap position as the reference planes. The calculated capacitance values for different microstrip gaps are illustrated in Fig. 2. A fourth order Chebyshev end-coupled bandpass filter is designed with a fractional bandwidth FBW=3.3% and 0.1 dB passband ripple at center frequency of 60 GHz. After the initial design, all filter parameters are optimized by using CST Microwave Studio. The initial and optimized parameter values are presented in Table II. The

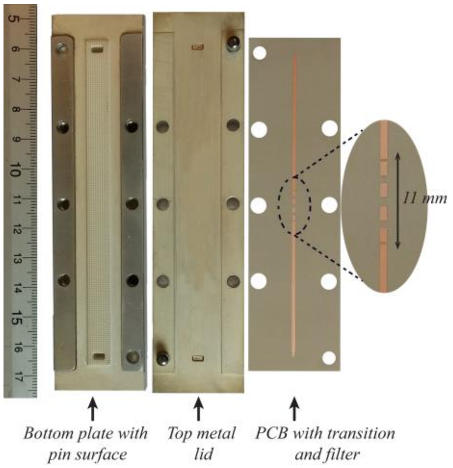
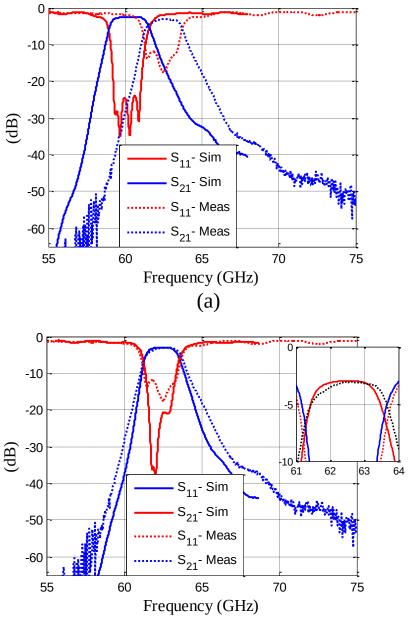


Fig. 5. Manufactured filter in a 10 cm inverted microstrip gap waveguide transition prototype.



(a)

(b)

Fig. 6. Measured and simulated results of filter respond with different air gap. (a) g = 0.25 mm and (b) g = 0.2 mm.

layout of the end-coupled inverted microstrip gap waveguide bandpass filter is illustrated in Fig.3. Fig. 4 shows the comparison of simulations with initial and optimized values. The initial parameter values based on the theoretical design procedure are a good starting point for the optimization routine. The minimum simulated insertion loss of the filter is 1.3 dB. It is shown in [7] that the conductive loss constitutes the main contributor to the overall loss of the inverted microstrip gap waveguide.

III. MEASUREMENT AND DISCUSSION

The designed filter has been embedded within a 10 cm back-to-back inverted microstrip gap waveguide transition prototype. The transition ensures compatibility between inverted microstrip gap and the standard WR-15 waveguide interface. The fabricated inverted microstrip gap waveguide bandpass filter together with the transitions is illustrated in Fig. 5. The simulated and measured S-parameters of the prototype are presented in Fig. 6. As it can be seen in Fig. 6(a), the measured filter response is shifted to higher frequencies.

We found out that the fabricated gap waveguide prototype had an air gap of 0.2 mm instead of 0.25 mm. When we applied this data to the CST model, we observed in Fig. 6(b) a better agreement between the simulated and measured results. The insertion loss is smaller than 3 dB, and the return loss is better than 12.5 dB. It is clear that the excessive length of the prototype adds loss to the overall response. The insertion loss of a straight inverted microstrip line with the same two transitions to WR-15 is 1.4 dB at 62 GHz [7]. Therefore, the corresponding insertion loss of the filter itself is lower than 1.6 dB. The third order SIW bandpass filter in [1] on a 5 mil-thick alumina substrate shows 3 dB insertion loss at a center frequency of 62 GHz, so the proposed inverted microstrip gap waveguide filter shows approximately half of that loss.

IV. CONCLUSION

A V-band end-coupled bandpass filter using inverted microstrip gap waveguide has been designed, manufactured and measured. The fourth order Chebyshev-type filter is embedded within a 10 cm inverted microstrip gap waveguide with two transitions to WR-15 on both sides. The measured results show that insertion loss of the inverted microstrip gap waveguide filter is around half of a corresponding SIW filter in [1]. The proposed filter has a simple and planar structure.

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