A NOVEL COMPACT SUSPENDED DOUBLE SIDE CMRC MILLIMETER BANDPASS FILTER WITH WIDE STOPBAND

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Abstract—This paper presents a novel compact suspended double side millimeter bandpass filter (BPF) with wide stopband using Suspended Compact Microstrip Resonant Cell (SCMRC). For SCMRC exhibits slow-wave band-stop characteristics, two distributed SCMRC structures are designed to achieve wide stopband characteristic. By applying SCMRC structure and double side design, this novel BPF is size reduced. Back-to-back rectangular waveguide to suspended microstrip probe transitions at different millimeter bands are designed and fabricated to verify transmission characteristics of novel SCMRC bandpass filter. Experimental results show low insertion loss (< 1.2 dB) in the passband and sharp, wide rejection in the stopband with about 150% bandwidth (below $-15 \, dB$, from 50 GHz to 100 GHz), with good agreement with simulated results.

1. INTRODUCTION

With increasing security need for point-to-point communications as well as high-speed broadband communication systems, tremendous progress has been made in millimeter wave communication technology. Microstrip filter is a critical part in communication systems.

Traditional microstrip filters usually use high/low step-impedance line or open-circuit microstrip structure, which lead to impedance restriction subject to maximum/minimum transmission line width. Structure mentioned doomed traditional microstrip filters to have narrow stop-band and hard to control microstrip filters parasitic passband. Modern microstrip filter circuits committed these

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shortcomings, focused on using two structures, electromagnetic band gap structure (EBG) [1] and defected ground structure (DGS) [2]. EBG and DGS could be equivalent to capacitance and inductance, make them achieve much higher impedance, thereby greatly improve the performance of the filter.

2. SUSPENDED CMRC STRUCTURE

Compact microstrip resonance cell (CMRC) structure [3] was firstly proposed by Professor Xue Quan called one-dimensional (1-D) microstrip PBG cells. Traditional two (1-D) microstrip PBG cells, PBG Cell 1 and PBG cell 2 structure [3] are shown in Fig. 1, which exhibits characteristics of band-stop and slow-wave characteristics which can be exploited to reject unwanted frequency and to reduce the dimensions of the microstrip circuit [4]. RLC resonant circuit could be formed by etching part of the metal in the normal 50-ohm microstrip line. CMRC is constituted by the upper and lower horizontal narrow microstrip lines connected by narrow vertical thin microstrip line, and tapped microstrip as follows.





Following CMRC structure firstly proposed, scholars have developed several transformed one-dimensional CMRC electromagnetic band gap structures to achieve more prominent slow-wave characteristics, such as the spiral microstrip resonance cell (Spiral CMRC) [5], dual behavior resonators (DBRs) [6,7], in-line beeline CMRC [8], etc. All these structures have distinct characteristics of slow wave effect and can be easily applied in microwave circuits.

Scholars also applied CMRC structure in components such as subharmonic mixer [4], low noise amplifier [9], antenna switch [10] and LPF [5], BPF [11].

But transformed CMRC structures aforementioned are all based on microstrip structure. In this part, Suspended Compact Microstrip Resonant Cell (SCMRC) is proposed for its advantages of higher Q value (quality factor) and double side circuit to make more



Figure 2. Suspended-substrate CMRC structure and its parameters distribution.

 Table 1.
 Double side SCMRC BPF geometric parameters (Unit: millimeter).

Geometric parameters	a1	a2	a3	a4	a5	a6	w1	w2	w3	w4	w5	w6
SCMRC-1	0.1	0.36	0.6	0.8	1.15	1.8	0.1	0.38	0.6	0.65	0.2	0.3
SCMRC-2	0.1	0.4	0.84	1.04	1.39	2.2	0.1	0.38	0.6	0.65	0.2	0.3
Gap between SCMRC-1/ SCMRC-2					0.39	Gap between SCMRC-2/ Microstrip						0.1

potential applications. Suspended-substrate CMRC structure and its parameters distribution are shown in Fig. 2.

SCMRC structure could be equivalent to RLC resonant circuit which shows band-stop characteristic by etching part of the metal in the microstrip line. By adjusting the length of unit and the size of etching graphics, SCMRC structure can get slow wave effect in different frequency bands. Two optimized SCMRC structures with different lengths and sizes of etching graphics (detailed in Table 1), are designed based on 0.127 mm thick Rogers RT/duroid 5880 substrate with $\varepsilon_r = 2.2$ and 0.017 mm metal copper on surface. Optimization process is carried out by commercial software HFSS.

As investigation results shown in Fig. 3, SCMRC-1 shows stopband of 95 GHz–120 GHz, SCMRC-2 shows stopband of 75 GHz– 105 GHz, respectively. Making comparison of S-parameters between SCMRC-1 and SCMRC-2, stopband central frequency would increase by shortening SCMRC length. For SCMRC-1 and SCMRC-2 have the same port microstrip width and cavity dimension, the two structures show the same port structure and impedance. If cascading SCMRC-1 with SCMRC-2, stopband of whole W-band would be achieved from 75 GHz to 110 GHz, according to cascading S matrix multiplication



Figure 3. Different length SCMRC structures and its *S*-parameters with.



Figure 4. SCMRC structure distributive equivalent circuit.

principle.

For SCMRC transmission characteristics differ in structure length, here come to a conclusion that lowpass filter with wide stopband characteristic could be achieved by cascading different length SCMRC structures and let every SCMRC stopband cover over etceteras SCMRC passband.

SCMRC circuit topology is similar to CMRC by replacing tapered microstrip by step impedances microstrip based on suspendedsubstrate structure, which would increase series inductance and parallel capacitance. Through SCMRC structure circuit topology, its distributive equivalent circuit is shown in Fig. 4.

3. DOUBLE SIDE SCMRC WIDE STOPBAND BPF

Bandpass filter (BPF) is one of the most important components in millimeter wave circuits. To meet the requirement of modern communications systems, compact millimeter wave BPFs with low

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insertion loss, low cost and wide stopband are in high demand. Recently, scholars have an increasing interest in planar BPFs, because planar BPFs are easy to be fabricated. Filters using various planar resonators such as open loop [12], miniaturized hairpin [13, 14], stepped-impedance, and quarter-wave resonators have been proposed for either performance improvement or size reduction.

However, nearly all of the filters mentioned are based on microstrip structure and working at microwave frequency. With planar filters working frequency increasing to millimeter and research focusing on specific structures such as electromagnetic band gap structure (EBG) and defected ground structure(DGS), suspended substrate microstrip structure gradually gets more attention for its higher quality factor and supporting double side circuit building. This paper presents a novel suspended double side wide stopband BPF using three SCMRCs.

As shown in Fig. 5, this novel suspended double side wide stopband 3 SCMRC BPF consists of two input/output suspended microstrip and three different SCMRC structures including SCMRC-1 at upside and two SCMRC-2 at downside respectively.



Figure 5. Double side 3 SCMRC structure and its S-parameters.

Compared with SCMRC BPF at one side, SCMRC BPF circuit at double side compresses circuit dimension, because the distance between microstrip and SCMRC could be negative value. Beside this, the beeline distance between every part of SCMRC BPF is slantwise, which could help to reduce circuit dimension, and the wavelength in the substrate is smaller than that in vacuum cavity.

For CMRC exhibits characteristics of band-stop and slow-wave characteristics, adjusting the length of every SCMRC unit could have different frequency selective properties, which has been demonstrated in Section 2 of the article. Comparison are made and shown in Fig. 3. Based on above principle and planar microstrip coupling BPF theory, this novel suspended double side wide stopband 3 SCMRC BPF is designed and fabricated. Simulation results show novel 3 SCMRC BPF's passband at 40 GHz with 10% bandwidth and stopband (S_{21} above -15 dB) at 50 GHz ~ 100 GHz reaches about 150% bandwidth. The designed SCMRC filter is then fabricated to experimentally verify all the predicted parameters. W-band experimental 3CMRC BPF with well-designed w-band probe transition and reduced-dimension cavity (to achieve whole w-band probe transition, cavity dimension should be reduced to depress higher transmission mode) is fabricated, and experimental results show good sideband rejection generally consistent with simulation results shown in Fig. 5. This 3 SCMRC BPF passband at Q-band experimental results are shown in Fig. 6.

In order to verify transmission characteristics of this novel SCMRC BPF, Q-band back-to-back rectangular waveguide to suspended microstrip probe transition is designed and fabricated corresponding to its passband shown in Fig. 6, and Ka band, W band transition to its low and up stopband respectively. The investigation results show a



Figure 6. Q band double side 3 SCMRC BPF with Trans and its *S* parameters.



Figure 7. Photograph of substrate at double side and different frequency band cavities of SCMRC BPF.

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good agreement between experimental and simulated results.

Ka band and W band probe transition are specially fabricated and tested to prove the characteristic of energy transmission cutoff is not caused by transition itself at BPF stopband. The experimental and simulated results are also in good agreement. Photograph of 5 sets novel double side SCMRC BPF and its cavities at different bands are shown in Fig. 7. The lines that make connection between graph and edges is used for gold-plating, which would be removed after goldplated have completed.

4. CONCLUSION

This paper presents a novel compact suspended double side wide stopband millimeter bandpass filter using SCMRC. For SCMRC exhibits characteristics of band-stop and slow-wave characteristics, three SCMRC structures are designed by adjusting the length of every SCMRC unit and the size of etching graphics to achieve wide stopband characteristic. This compact novel bandpass filter is size reduced by applying SCMRC structure and double side design, which have advantages of low insertion loss (< 1.2 dB) in the passband and sharp, wide rejection in the stopband with about 150% (below $-15 \, \rm dB$, from 50 GHz to 100 GHz) bandwidth. Different band back-to-back rectangular waveguide to suspended microstrip probe transition are designed and fabricated to verify transmission characteristics of novel SCMRC bandpass filter. Experimental and simulated results are in good agreement.

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