Prototype of compact Microstrip lowpass filter for active phased antenna array with ultra-wide stopband using funnel shaped resonator

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***Abstract*—This paper deals with the design of a prototype microstrip filter, which would be suitable for integration into active phased array antennas. This novel compact microstrip lowpass filter is based on funnel shaped resonator and semi elliptical patches. The proposed filter is designed, modeled, and fabricated to achieve an ultra-wide stopband with a sharp transition band. Furthermore, the LC equivalent circuit and transfer function of funnel shaped resonator are extracted. The cut-off frequency of proposed filter at -3 dB is 1.4 GHz and this filter has an ultra-wide stopband begins from 1.66 GHz to 17 GHz with the suppression level of 20 dB. Moreover, this lowpass filter has a sharp transition band of 0.26 GHz and compact size of $0.138\ \lambda_g \times 0.05\ \lambda_g$. The proposed structure is printed on Rogers_Rt 5880 and the measured results are coincided with the simulation results.**

Keywords— Microstrip, filter, resonator, stopband

I. INTRODUCTION

Antenna arrays have become one of the most important applications recently and researchers are investigating this topic in their articles. Design of Antenna-in-Module (AiM) is presented in [1] to realize active and reconfigurable antenna arrays for potential 5G applications at millimeter-wave frequencies. In [2] the authors focused on the designing and implementation of an active multibeam antenna system for massive MIMO applications in 5G wireless communications. The practical active antenna array configuration was proposed for Massive MIMO systems and evaluate the system-level performance with the form factor at the base stations operating in cellular frequency band [3]. Miniature microstrip filters are important components of active phased arrays, where individual elements of the array have integrated low noise amplifiers, power amplifiers, phasing cells and filters. There are a lot of different types resonator to design microstrip lowpass filter like T-shaped [4], Trapezoid-shaped [5], and triangular and square-shaped structures [6]. In [7], a LPF with an ultra-wide stopband has been designed by replacing the low-impedance lines with lowpass transmission lines. A lowpass filter using a coupled-line hairpin resonator has been designed with compact size and wide stopband [8]. Moreover, a lowpass filter using two stepped impedances has been designed which has a compact size [9], although, the designed filters [8-9] are compact, but the sharpness of their transition band are not acceptable. In [10], a high-impedance microstrip line (HIML) with a pair of radial stubs has been combined in designing a lowpass filter with Ultra-Wide stopband. T-shaped and L-shaped resonators are adopted to create a sharp transition band in the designed lowpass filter. Several resonators have been used in this lowpass filter, so this design has a large size [11]. A microstrip lowpass filter with two resonators with different triangular patches and four high-low impedance resonators as suppressing cells was designed in [12]. A modified radial stub resonator was used to design a microstrip lowpass filter with a wide stopband in [13], although, the sharp roll-off should be improved. An asymmetric-shaped microstrip lowpass filter (LPF) using a stepped impedance resonator was proposed in [14] with a weak sharpness. Authors in [15] designed a microstrip lowpass filter with three cascaded resonators and different semi-circle patches. A modified E-type feeding structure and a pair of symmetrical parallel coupled lines were applied to design a lowpass filter in [16]. A microstrip planar lowpass filter with a sharp roll-off and ultra-wide stopband was proposed in [17]. Stepped impedance resonator hexangular unit was utilized in [18] to design a microstrip lowpass filter with a compact size, low insertion loss, and wide stopband. Defected ground structures are one of the proposed methods to design lowpass filters [19-20]. A compact and wide stopband lowpass filter design using open complementary split-ring resonator and defected ground structure (DGS) was proposed in [20]. A compact microstrip lowpass filter with quasi-elliptic response was presented in [21] which the attenuation level is not admissible.

II. FILTER DESIGN

This paper presents the design and fabrication of a novel compact microstrip lowpass filter using funnel shaped resonator with an ultra-wide stopband.

A. Funnel shaped resonator

The proposed funnel shaped resonator consist of a triangular and rectangular shaped resonators as shown in Fig. 1a. Moreover, the LC equivalent circuit of these resonators is described in Fig. 1b. Unfortunately, there is no explicit formula for the funnel shaped resonator. Instead of that the LC equivalent circuit of the proposed resonator is extracted from the triangular and rectangular resonators. As illustrated in Fig. 1b, (L1, L2 and C1) are related to transmission line, (C2 and L3) are calculated by triangular resonator, (L4 and C4) are computed by rectangular resonator, and C3 is related to both resonators. The LC equivalent circuit parameters of funnel shaped resonator and its scattering parameters are illustrated in Fig. 1c and Fig. 1d, respectively. This structure has a

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transmission zero (TZ) at 7.1 GHz. This transmission zero is important because it is suitable for achieving a wide stopband and has to be controlled. For achieving the appropriate location of the transmission zero, the LC equivalent circuit is used to calculate the transfer function [11] as follow:

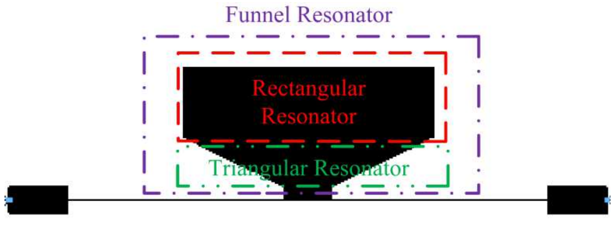
The transfer function and transmission zero equations of funnel resonator (Fig. 1c) are given in Eq.(1) and Eq. (2).

$$\frac{V_o}{V_i} = \frac{d\times r}{(L_1+r)(2d+L_1+r)} \tag{1}$$

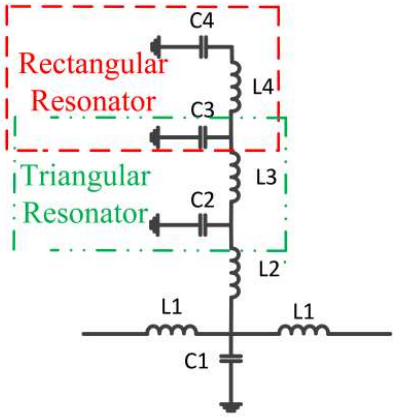
Where:

$$d = \frac{1 + \left(CF_2L_2 + CF_3(L_2 + LF_3)\right)s^2 + (CF_2CF_3L_2LF_3)s^4}{s(C_1 + CF_2 + CF_3 + (C_1(CF_2 + CF_3)L_2 + (C_1 + CF_2)CF_3LF_3)s^2 + C_1CF_2CF_3L_2LF_3s^4)}$$

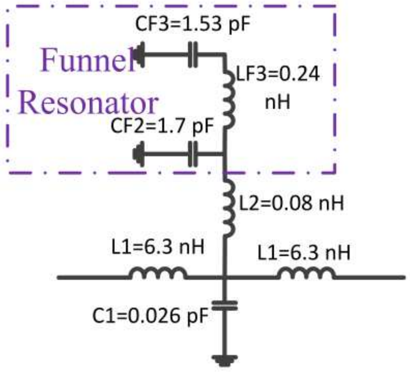
$$T_z = \frac{\sqrt{\dfrac{\dfrac{1}{CF_2L_2} + \dfrac{1}{CF_2LF_3} + \dfrac{1}{CF_3LF_3} + \sqrt{4CF_2CF_3L_2LF_3 + (CF_2L_2 + CF_2LF_3 + CF_3LF_3)^2}}{CF_2CF_3L_2LF_3}}}{2\pi\sqrt{2}} \tag{2}$$



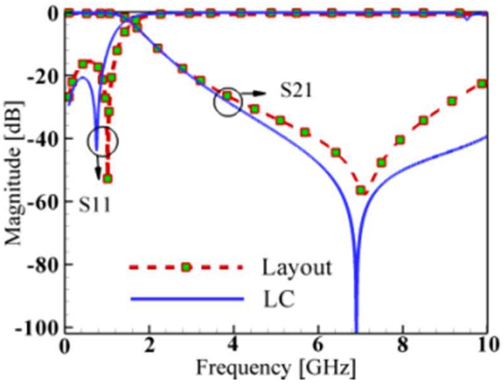
(a)



(b)



(c)



(d)

Fig. 1 Triangular, Rectangular and Funnel Resonators(a) Layout (b) LC equivalent circuit of triangular, rectangular resonators (c) LC equivalent circuit of Funnel shaped resonator (d) Frequency response

The parameters CF2 and CF3 can change the location of the transmission zero. To achieve the location of selected transmission zeros frequency, Fig. 2 is drawn based on CF2, CF3 and frequency of transmission zero.

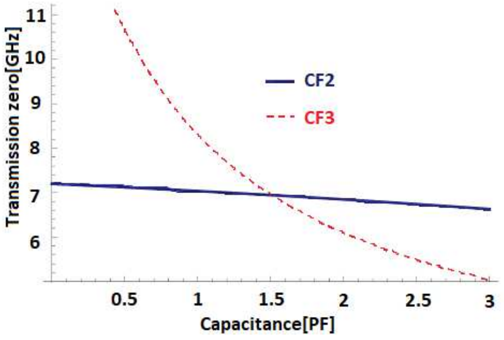


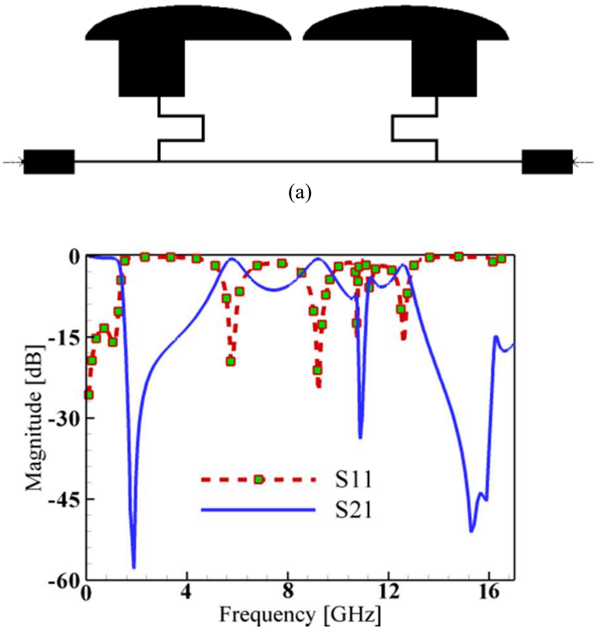
Fig. 2 Transmission zero based on CF2 and CF3 values

B. *Semi elliptical patch*

Semi elliptical patches are used for obtaining a suitable transition in the proposed lowpass filter, because it can generate a transmission pole and a transmission zero which are near each other. Fig. 3a and Fig. 3b show the structure and frequency response of semi elliptical patches are used in the proposed filter. To achieve more bandwidth of stopband, two open stubs are added to semi elliptical patch. Finally, the layout of proposed LPF is shown in Fig. 4a, where the dimensions are in millimeter.

III. FINAL FILTER AND RESULTS OF SIMULATION AND FABRICATION

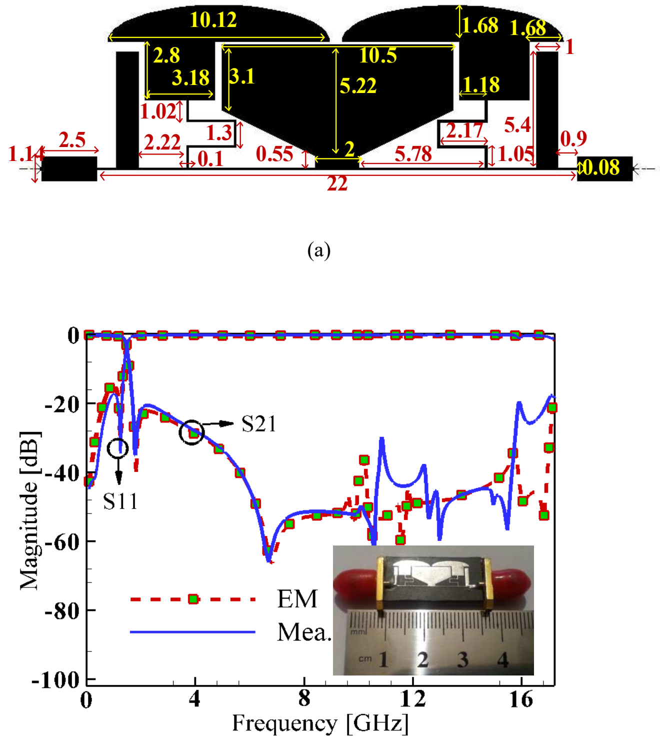
The proposed lowpass filter has been fabricated on a Rogers_Rt 5880 substrate with a relative dielectric constant of 2.2, thickness of 15 mil and loss tangent 0.0009. Simulations are done by an EM-simulator ADS based on the method of moment. The S-parameters are measured by an Agilent network analyzer N5230A. Simulated and measured responses of the proposed filter are shown in Fig. 4b. While, Fig. 5 demonstrates the fabricated shape of this structure. The proposed filter has a cut off frequency of 1.4 GHz and compact size of 0.138 λg×0.05 λg. The measured results have showed that filter has an ultra-wide stopband from 1.66 GHz to 17 GHz, and a transition band about 0.26 GHz. The filter has been compared with other recent published work in Table 1 in terms of parameters such as fc, Roll off rate (ξ), relative stop bandwidth (RSB), suppressing factor (SF), normalized compact size (NCS), architecture factor (AF) and figure of merit (FOM) [21] and it showed a good achievement.



(a)

(b)

Fig. 3 Semi elliptical patch (a) Layout (b) Frequency response



(a)

(b)

Fig. 4 Lowpass filter layout (a) frequency response of simulation and measurement (b)

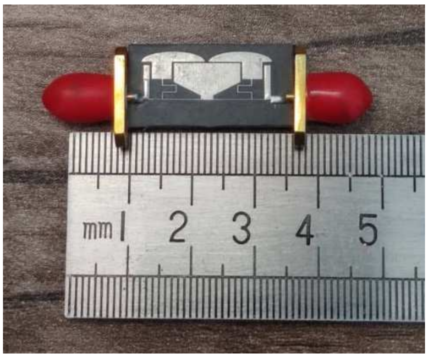


Fig. 5 Fabricated lowpass filter

TABLE I. COMPARISON BETWEEN THE PROPOSED FILTER AND PUBLISHED WORKS

Ref.	ξ	RSB	SF	NCS(λg^2)	AF	FOM
[7]	74	1.74	2.4	0.1224	1	25274
[8]	63	1.42	1.7	0.0222	1	7550
[9]	52.8	1.529	2	0.0091	1	17640
[10]	62	1.66	2	0.0088	1	23178
[11]	220	1.6	2.1	0.0147	1	50285
[12]	228	1.78	2.1	0.0320	1	26583
[13]	72	1.71	2	0.0123	1	28873
[14]	35	1.7	2	0.0199	1	6263
[15]	203.5	1.61	3.2	0.0432	1	24241
[16]	40.2	1.6	1.5	0.0117	1	8246
[17]	104	1.8	2.5	0.0228	1	16421
[18]	48.5	1.61	2	0.0213	1	7332
[19]	61.62	1.87	2.05	0.009	1	26250
[20]	48.57	1.09	2	0.0128	1	8272
[22]	100	1.592	1.8	0.032	1	8955
[23]	58.62	1.18	2	0.0135	1	10247
[24]	308	1.54	2.2	0.0576	1	18134
[25]	68	1.86	2.2	0.0073	1	38117
This Work	**115**	**1.65**	**2**	**0.0069**	**1**	**55000**

IV. CONCLUSION

Active phased antenna arrays contain both RF active and passive circuits in each element of array, but they must be implemented in a limited space with sufficient technical properties. Filters are one of the important passive circuits of active antenna arrays that prevent overdriving of low-noise amplifiers by out-of-band signals during reception and reduce out-of-band unwanted emissions during transmission. Therefore, a novel lowpass filter using funnel shaped resonator is presented that achieves a wide stopband. Also, the transmission zero is calculated based on capacitances and inductances of equivalent LC circuit of the triangular and rectangular resonators. This filter has a compact size of 0.0069 λg^2, ultra-wide stopband from 1.66 GHz to 17 GHz, and suitable return loss of 15 dB. The fabricated lowpass filter with such performance can be utilized in 5G Wireless Communications.

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