TELKOMNIKA Telecommunication, Computing, Electronics and Control
Vol. 18, No. 1, February 2020, pp. 545~551
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v18i1.13532

Design and optimization of microstrip filtering antenna with modified shaped slots and SIR filter to improve the impedance bandwidth

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Article Info

Article history:

Received Jul 7, 2019
Revised Oct 10, 2019
Accepted Oct 22, 2019

Keywords:

Chebyshev low pass filter prototype
Computer simulation technology (CST)
Glass epoxy FR-4 substrate
Impedance bandwidth
Microstrip filtering antenna
Modified shaped slots

ABSTRACT

This paper presents a new compact microstrip filtering antenna with modified shaped slots to improve the impedance bandwidth. The proposed microstrip filtering antenna consists of three parts; the monopole radiating patch antenna, the SIR filter, and the feeding microstrip line. The design structure is achieved on one sided glass epoxy FR-4 substrate with dielectric constant ε_r = 4.4 and thickness of h = 1.6 mm. The design procedures of the proposed filtering antenna starts from the second order Chebyshev low pass filter prototype. The simulation results throughout this article are done by a computer simulation technology (CST) software. The simulated results have been achieved show good performance of S11-parameter and broad side antenna gain on +z-direction. This design has two transmission zeros at 5.4 GHz and 7.7 GHz, and bandwidth (B.W) of about 1.66 GHz so; it is suitable for high speed data communication. This design has good skirt selectivity.

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1. INTRODUCTION

Increasing demand for compact transceiver applications continues to impact the field of microwave and radio frequency communications [1-4]. Some of the most important modules in such systems are the microstrip antennas and filters [5-17]. Microstrip patch antenna (MPA) has been designed are widely characterized a few years ago, for several reasons, the most important was that it had a low profile, lightweight, and low fabrication cost [18]. Different techniques have been developed in order to achieve rapid solutions to enhance radiation specificationssuchasbandwidth and gain.The radiating patch can take any possible geometry for example rectangle, circle, square, dipole, and triangular [19]. The microstrip monopole patch antenna is designed as a single-layer which usually consists of four parts: patch, dielectric substrate, half ground plane, and feedline [20].Generally, the physical dimensions of a microstrip monopole patch antenna are small, but the electrical dimensions measured in wavelength λ is not small [21]. The designers of the microstrip antennas should also consider the electrical characteristics of these antennas such as center frequency f_o, voltage standing wave ratio (VSWR), return loss, gain, and radiation pattern [22]. Rapid data transfer requires high channel capacities and needs more complex and bulky systems. Modern trends in electronic and communication systems proposed more compact and portable systems, therefore the designers of such systemsfacing a major challenge in realizing these complex systems and in the same time are compact and portable enough to meet the commercial market needs [23]. One way to minimize the overall circuit size and increasing the bandwidth is to integrate the Stepped Impedance Resonator (SIR) filter with the monopole patch antenna in one single module [24]. This integrationchanges the structure of the circuit; improves the performance of the circuit, and simplifies the connection among various components. This paper presents a compact second-order filtering antenna utilizing SIR and modified shaped slots on the monopole patch antenna. By using SIR bandpass filter and adopting the modified shaped slots on the monopole patch antenna the performance of the circuit has been improved especially bandwidth.

2. DESIGN OF THE FILTERING ANTENNA

The 3-D view of the proposed microstrip filtering antenna design circuit is described in Figures 1 and 2. The design structure is printed on one side of a glass epoxy FR-4 substrate with dielectric constant ε_r = 4.4 and thickness h = 1.6 mm. The microstrip filtering antenna consists of three parts; the monopole radiating patch antenna, the SIR filter, and the feeding microstrip line. The monopole patch antenna has dimensions of $w_p \times l_p$, with l_p about 0.863 λ_g at the operating frequency. Figure 3 shows the microwave equivalent circuit model of the proposed filtering antenna. SIR and the monopole patch antenna are modelled by parallel L_1C_1 [25] and $L_2C_2\,R_p$ [26] lumped circuits respectively. Filter synthesis approach theory [27] considered thatthe SIR as a 1st stage resonator and the monopole patch antenna considered as the 2nd stage resonator with the load.

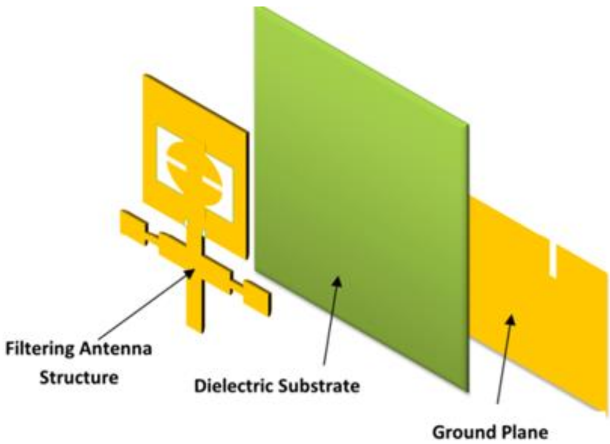
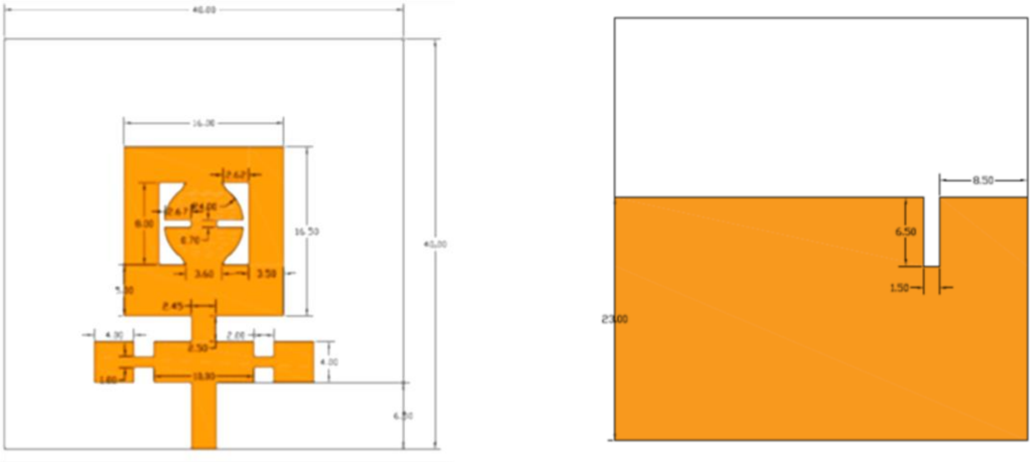


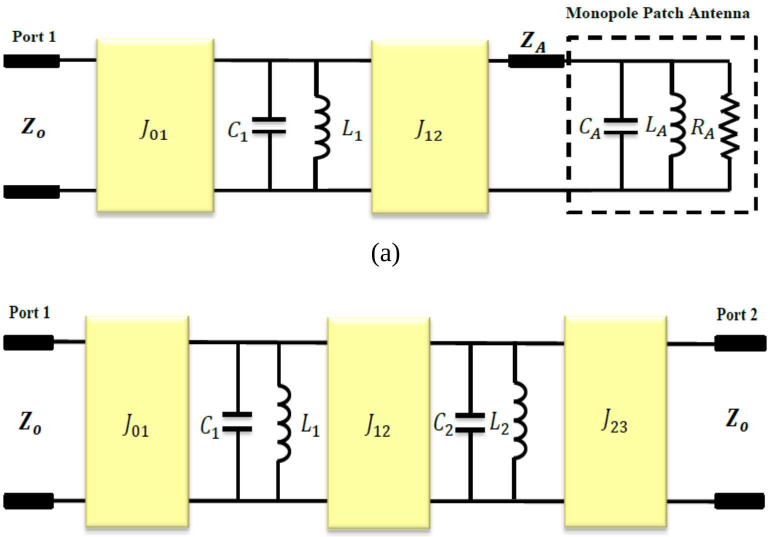
Figure 1. 3-D view structure of the proposed filtering antenna

Precisely the equivalent circuit of the proposed filtering antenna is the same of the band pass filter prototype, by utilizing filter synthesis method, the filtering antenna can be designed with the filter response. The design procedures of the proposed filtering antenna start from the second-order Chebyshev low pass filter prototype. The design parameters, such as the center frequency, the fractional bandwidth (FBW), return loss, and insertion loss are calculated. The lumped elements values of the microwave circuit model shown in Figure 3 are available in the literature [23]. The following step is to design the resonator via the SIR structure and monopole patch antenna with a modified slot-shaped, respectively. Finally, set them all together and implement some fine-tuning. The simulation results throughout this research paper are accomplished by computer simulation technology (CST) software [28]. The design structure with its optimized dimensions of the proposed filtering antenna is presented in Figure 2. The proposed filtering antenna shown in Figure 2 can be expressed by its equivalent circuit shown in Figure 3 (a). The equivalent circuit of the proposed filtering antenna shown in Figure 3 (a) can be transferred to the conventional second-order band pass filtere quivalent circuit shown in Figure 3 (b) [29].



(a) (b)

Figure 2. Geometry of the proposed filtering antenna with its optimized dimensions:
(a) top view, (b) bottom view



(a)

(b)

Figure 3. Microwave equivalent circuit:
(a) the proposed filtering antenna, (b) the second-order band pass filter

The resistance R_A in the equivalent circuit of the monopole patch antenna is considered as the load impedance of the band pass filter to be synthesized, and the parallel L_A - $C_A$isthe last circuit resonator of the filter, then:

$$f_o = \frac{1}{2\pi\sqrt{L_A C_A}} \tag{1}$$

the second-order band pass filter is chosen to be a Chebyshev equal-ripple response, with the ripple level $L_A(dB)$ = 0.5, f_o = 6.45 GHz, and port characteristic impedance Z_o= 50 Ω. The minimum return loss $R_L(dB)$ in passband for an ideal Chebyshev bandpass filter is given as [30]:

$$R_L(dB) = -10\ log(1 - 10^{-L_A(dB)/10}) \tag{2}$$

in this design example, R_L= -18.2 dB, and the FBW = 25.7 %

The quality factor is one of the most important parameters of the resonant circuit, and increasing its value means that lower loss in the resonant circuit. The quality factor of the monopole patch antenna can be derived from the equivalent circuit of the proposed filtering antenna shown in Figure 3 (a), and used for synthesizing the filtering antenna [31].

$$Q_A = \frac{2\pi f_o L_A}{R_A} \tag{3}$$

The values of LC components of the resonators are given by:

$$L = \frac{2Z_o}{\pi f_o} = 4.93 \text{ nH}, \qquad C = \frac{1}{L f_o^2} = 4.87 \text{ pF} \tag{4}$$

As mentioned earlier the second-order (N = 2) Chebyshev low pass filter prototype with passband ripple of 0.5 dB, the element values are $g_o = 1$, $g_1 = 1.4029$, $g_2 = 0.7071$, $g_3 = 1.9841$. Generally, for the equivalent circuit of the bandpass filter shown in Figure 3 (b) the theoretical values of the J-inverters can be readily obtained [32] as follows:

$$J_{01} = \frac{1}{Z_o}\sqrt{\frac{\pi FBW}{4 g_o g_1}} \tag{5}$$

$$J_{n-1,n} = \frac{1}{Z_o}\frac{\pi FBW}{4\sqrt{g_{n-1} g_n}} \tag{6}$$

the second-order Chebyshev bandpass filter parameter values are stated in Table 1.

Table 1. The Parameter of the second-order Chebyshev bandpass filter

Parameter	Value
FBW	0.257
g_o	1
g_1	1.4029
g_2	0.7071
g_3	1.9841
J_{01}	7.48×10^{-3}
J_{12}	4.688×10^{-3}
J_{23}	3.942×10^{-3}

3. SIMULATION RESULTSAND DISCUSSION

The simulated S_{11}-parameter and gain of the proposed filtering antenna are shown in Figure 4. Based on these results, it is found that with the center frequency f_o = 6.45 GHz, the filtering antenna has two transmission zeros at 5.4 GHz and 7.7 GHz, and bandwidth (B.W) of about 1.66 GHz. Broadband is one of the most important requirements for modern digital communication which required transmitting and receiving a huge bit rate. Therefore, this design is suitable for high speed data communication.

Defected ground structure (DGS) was common use in the microstrip filters and antennas to realize the S-parameters performances and small size [33]. Realization of the DGS is performed by inserting a defected shape on the ground plane in order to disturb the shield current distribution. Establish upon on the shape and dimensions of the DGS, the disturbance at the ground shield current distribution will control the current flow and the input impedance of the proposed filtering antenna [34]. The excitation of the electromagnetic waves propagating inside the dielectric substratelayer can also be controlled bythe DGS. The S_{11}-parameter of the proposed filtering antenna with and without DGS is shown in Figure 5. Recently, the DGS is used to enhance the stop band rejection characteristics as shown in Figure 5. Figure 6 shows the S_{11}-parameter of the proposed filtering antenna for different shaped slots loaded. The radiation characteristics of the filtering antenna are roughly invariant, with good performance of S_{11}-parameter and broad side antenna gain on +z-direction. The peak gain of the simulated pattern is about 2.02 dB and provides good skirt selectivity. The simulated 3-D view radiation pattern of the proposed filtering antenna is shown in Figure 7.

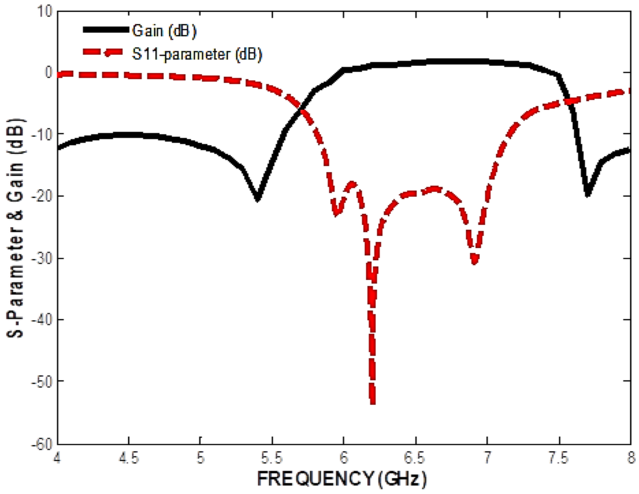


Figure 4. S_{11}-parameter and gain of the proposed filtering antenna

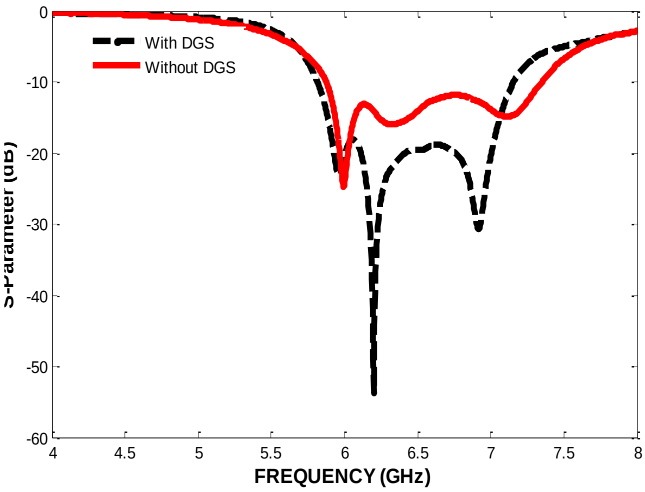


Figure 5. S_{11}-parameter of the proposed filtering antenna with and without DGS

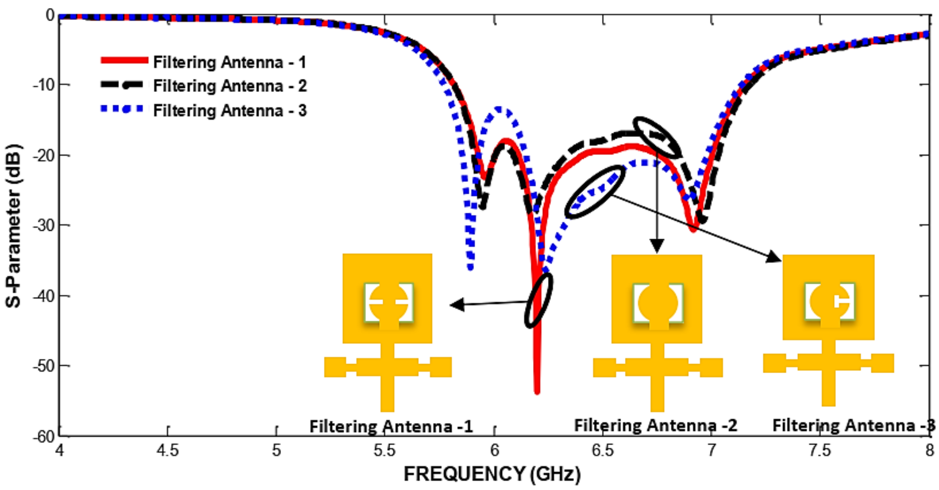


Figure 6. S_{11}-parameter of the proposed filtering antenna for different shaped slots

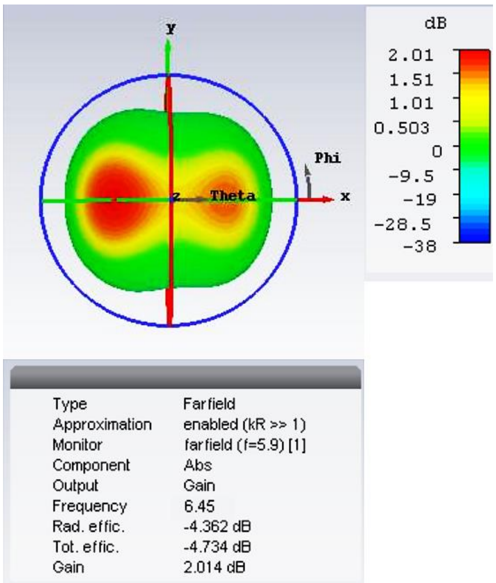


Figure 7. 3-D view radiation pattern of the proposed filtering antenna at f_o = 6.45 GHz

4. CONCLUSION

A compact filtering antenna with modified shaped slots has been proposed and successfully simulated in a microstrip transmission line. The proposed filtering antenna is designed by utilizing the filter synthesis approach. Depending on the equivalent circuit and specifications of the second-order Chebyshev lowpass filter, the proposed filtering antenna has been designed and simulated. The design shows good performance, suitable for high-speed communication applications. The proposed filtering antenna structure with SIR technique provides good skirt selectivity.

ACKNOWLEDGEMENTS

Authors wish to express their thanks for the support provided by the innovation programme under grant agreement H2020-MSCA-ITN-2016 SECRET-722424.

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