Received: 8 September 2023 | *Revised: 21 December 2023* | *Accepted: 28 December 2023*
DOI: 10.37917/ijeee.21.1.16 *Vol. 21 | Issue 1 | June 2025*

Open Access

Iraqi Journal for Electrical and Electronic Engineering
Original Article

Design of Dual-Passband Microstrip Filtering Antenna Using Dual-Mode Closed Loop Resonators and Defected Ground Structure

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Abstract
This paper presents a new microstrip dual-mode closed-loop resonator (DMCLR) that is used to design lower insertion loss and better transmission dual-passband filtering antenna. The dual passband center frequencies of the presented filtering antenna are located at f_o^I=5.52 GHz and f_o^{II}= 6.65 GHz. The presented dual-mode, dual-passband microstrip filtering antenna results are simulated and optimized by using Computer Simulation Technology (CST) software and defected ground structure technique. Three modes of dual-mode resonators have been utilized to design the dual-passband microstrip filtering antenna and compare their results. The presented dual-mode, dual-passband microstrip filtering antenna is established on FR-4 epoxy dielectric material which has a relative permittivity ε_r= 4.3 which has height thickness h = 1.6 mm and loss tangent tan δ=0.002. Defected Ground Structure (DGS) technique has been utilized to improve the performance of the presented dual-mode, dual-passband microstrip filtering antenna.

Keywords
Filtering antenna, CST, DGS, Dual-passband, Dual-mode resonator.

I. Introduction

Several years ago, many researchers investigated dual-mode microstrip resonators for use in both wired and wireless applications such as bandpass filters and filtering antennas [1]. The researchers focus on the filtering antenna topic due to its prospect of overcoming problems such as large volumes, heavy weight, convoluted structure, and high insertion loss between the components [2]. In recent years, two frequency passbands particularly using variable-frequency transformation have been presented by the synthesis approach of microwave filters [3]. Various structures of dual-mode resonators have been proposed such as Stepped Impedance Resonators (SIRs), parallel coupling lines, and square closed-loop resonators which are used to design bandpass filters [4]. Nowadays, the rapid expansion in wireless communication and data transmission requires the necessity for more bandwidth where the accumulation of scattered assigned frequency bands cannot be avoided [5]. Although the wideband design is necessary for most RF/microwave components, the bandpass (BPF) filter should have a multi-bandpass behavior [6]. Thus, many researchers have focused on multi-bandpass designs [3]. In [7] the authors have proposed a dual-ring resonator to design a dual-passband BPF have two center frequencies located at f_o^I = 2.45 GHz and f_o^{II} = 3.5 GHz. A dual−passband BPF which has a single dual−mode microstrip ring resonator has been presented in [8]. This dual-passband BPF is consist of two coupled line sections at both feed lines. The band frequencies of the dual-band BPF are centered at f_o^I = 2.3 GHz and f_o^{II} = 4.1 GHz. A dual-band BPF using the technique of centre frequency controlled by a dual-mode meandered loop microstrip resonator has been proposed in [9], the dual bands are centered at f_o^I =1.2 GHz and f_o^{II} = 1.6 GHz. A high selective dual-band BPF using meandered loop resonator has been presented in [10] , the dual-passbands are located at center frequencies f_o^I = 2.406 GHz and f_o^{II} = 3.491 GHz. A Defected Ground Structure (DGS) is one of the important and active techniques used to reduce the size of RF/microwave circuits [11]. The DGS can be realized by making a uniform or nonuniform simple shape etch pattern in the microstrip ground plane structure [12]. The ground plane surface current distribution has been interrupted by the DGS, which eventually changes the characteristics of this plane such as line inductance and capacitance. DGS is a suitable manner to realize the slow-wave effect and it has been widely used to improve the performance of RF/microwave circuits [13]. This paper introduced a new dual-mode microstrip closed-loop resonator (DMCLR), which is used to design lower insertion loss and better transmission dual-passband microstrip filtering antenna. The filtering antenna has four dual-mode resonators of mode 1, every two are connected to achieve one resonator and microstrip feed line which feeds the patch antenna. The dual-passbands are located at f_o^I = 5.52 GHz and f_o^{II} = 6.6 5 GHz. The presented dual-mode, dual-passband, filtering antenna design results are simulated and optimized by using Computer Simulation Technology (CST) software and the DGS technique.

II. Methodology

Three modes of the dual-mode CLR have been studied to choose the best for the design of the dual-passband filtering antenna as shown in Fig. 1. Input impedances (Z_{in1}) and (Z_{in2}) of the mode 1 dual-mode resonator shown in Fig. 1 can be determined as [14]:

$$Z_{in1} = jZ_1 \frac{Z_2 \tan\theta_1 + Z_1 \tan\theta_2}{Z_1 - Z_2 \tan\theta_1 \tan\theta_2} \tag{1}$$

$$Z_{in2} = Z_2 \frac{Z_{in1} + jZ_2 tan\theta_1}{Z_2 + jZ_{in1} tan\theta_1} \tag{2}$$

where the Z_1, Z_2, L_1, and L_2 represents the impedances and the lengths of the microstrip lines respectively and θ_1=βL_1, θ_2=βL_2 are the electric lengths of the microstrip lines, and β is the wavelength number as shown in Fig. 1. To analyze the proposed filtering antenna two modes are used, the odd mode and the even mode. In an odd mode, the electromagnetic field distribution within the resonator is asymmetric. Usually, in an odd-mode the current and voltage distributions within the resonator have opposite polarities, and have a lower resonant frequency compared to an even-mode in many dual-mode

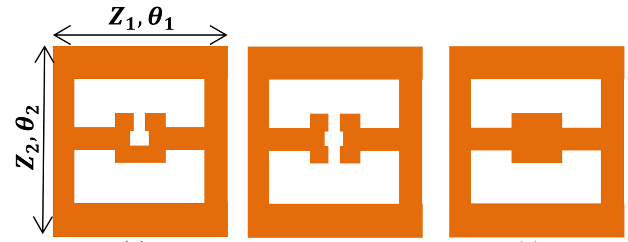

Fig. 1. The dual-mode microstrip CLR (a) mode 1 (b) mode 2 (c) mode 3.

resonators. In an even-mode the electromagnetic field distribution within the resonator is symmetric. Generally, in an even mode, the current and voltage distributions have the same phases (polarities) and often have a higher resonant frequency. The odd-mode input impedance can be expressed as [15]

$$Z_{in,\ odd} = \frac{jtan\theta_1}{Z_1} \tag{3}$$

The odd-mode frequency of the dual-mode resonator can be expressed as [16]:

$$f_{odd} = \frac{(2n-1)c}{2L_1\sqrt{\varepsilon_{eff}}} \qquad n=1,2,3,\ldots\ldots \tag{4}$$

where c is the speed of light (3×10^8 m/s) and ε_{eff} is the effective value of the dielectric constant. To miniaturize the size of the microstrip filtering antenna, n is chosen equal to 1. So, n =1 is utilized to keep the compactness of the microstrip filtering antenna design. The frequency at even mode can be expressed as [17]:

$$f_{even} = \frac{nc}{(L_1 + 2L_2)\sqrt{\varepsilon_{eff}}} \tag{5}$$

The center frequencies of the first passband and the second passband can be managed by scaling the electrical length sections of the resonator $\theta_1$and θ_2. The computer simulation technology used to simulate and analyze the presented dual-passband filtering antenna structure that has a mode 1 resonator with its optimized dimensions is depicted in Fig. 2.

III. Design Results

The presented dual-mode, dual-passband microstrip filtering antenna is established and simulated on FR-4 epoxy dielectric material has a relative permittivity ε_r= 4.3, and height thickness$h$ = 1.6 mm. The loss tangent of the dielectric material tanδ=0.002. The S_{11} parameter and gain of the presented

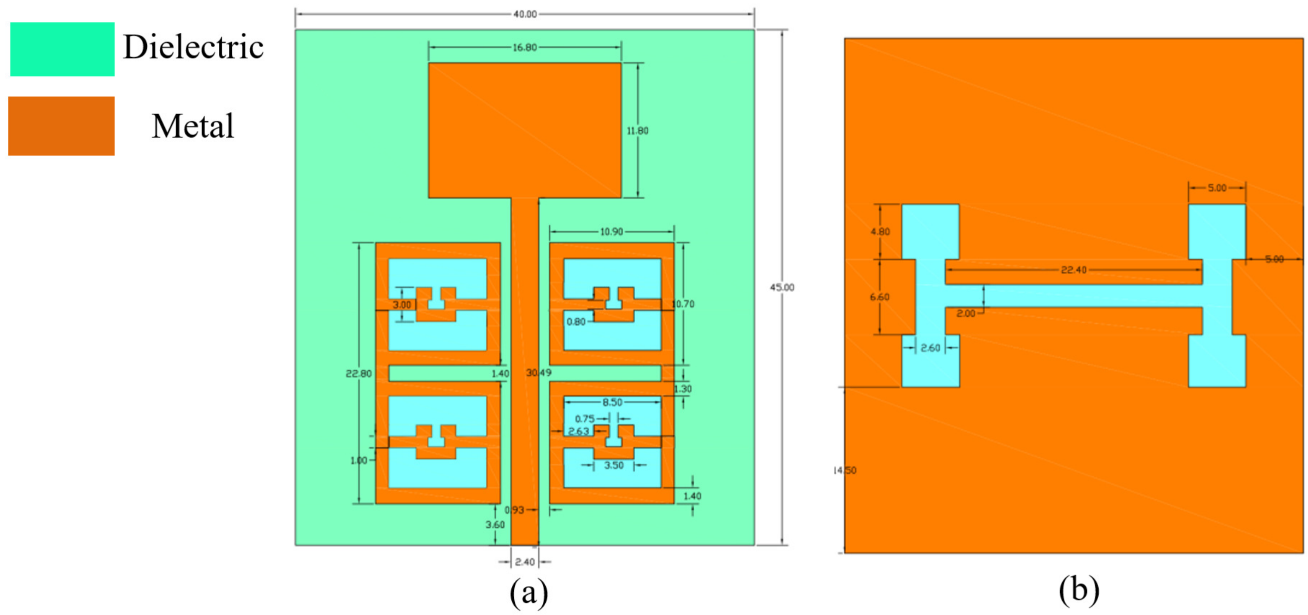

Fig. 2. Dual-passband microstrip filtering antenna structure (a) Top view (b) Bottom view.

dual-passband microstrip filtering antenna using a mode 1 resonator are depicted in Fig. 3.

Fig. 3 shows that the filtering antenna has good specifications in both frequency bands when using a mode 1 resonator in its design. This can be seen in Table I which contains all design parameters. The Voltage Standing Wave Ratio ($VSWR$) is the ratio of the maximum voltage to the minimum voltage throughout the length of the transmission line structure [18]. The mathematical definition of $VSWR$ in terms of a return loss can be expressed as [19].

$$VSWR = \frac{1+10^{\frac{-R_L}{20}}}{1-10^{\frac{-R_L}{20}}} \tag{6}$$

The quality factor (Q) of any resonant circuit describes the ability of the resonator to store the energy, and can be prescribed the stored energy in the resonator to the energy dissipated in it multiplied by the angular frequency ω, and can be expressed as [20]

$$Q = \omega \frac{energy\ stored\ resonator}{energy\ dissipated} \tag{7}$$

The equivalent circuit of the distributed resonator is represented by an *RLC* lumped circuit. The energy is excited to the resonator either magnetically or electrically coupling. Because of the input/output loading effect, the loaded quality factor Q_L, the unloaded quality factor Q_u, and the external quality factor Q_{ex} can be broken down by the quality factor of the structure. The loaded quality factor Q_L can only be measured, and the loading effect of the external circuit also the loading of the resonator itself must be taken into account, so the loaded quality factor at the passband is expressed in terms of 3 dB bandwidth as [21]:

$$Q_L = \frac{f_o}{\Delta f_{3\ dB}} \tag{8}$$

All design parameters of the dual-passband microstrip filtering antenna are stated in Table I. The comparison of the S_{11}-parameter of the filtering antenna consists of four resonators that used the mode1 resonator and the other one that used the mode 2 resonator is shown in Fig. 4. Fig. 5 shows the comparison between the S_{11}-parameter of the presented microstrip filtering antenna using a mode 1 resonator and the microstrip filtering antenna using a mode 3 resonator.

Fig. 4 and Fig. 5 show the technical advantage of using a mode 1 resonator in the design of the filtering antenna over using mode 2 and mode 3 resonators. The reason for this is the density of the surface current inside and around the resonators, which directly affects the quality of filtering and radiation.

IV. Discussion of The Design Results

Dual-mode resonators are more adaptable and provide high-quality factors, size reduction, and enhanced frequency selec-

TABLE I.
ALL DESIGN PARAMETERS OF THE DUAL-PASSBAND FILTERING ANTENNA.

Parameter	First band	Second band
Frequency (GHz)	5.52	6.65
Fractional Bandwidth (FBW)	0.0742	0.0721
Quality Factor Q_L	13.463	13.854
VSWR	1.16	1.257
Return Loss (dB)	-22.56	-18.86
Gain (dB)	3.36	3.46
Radiation Efficiency %	62.34	63

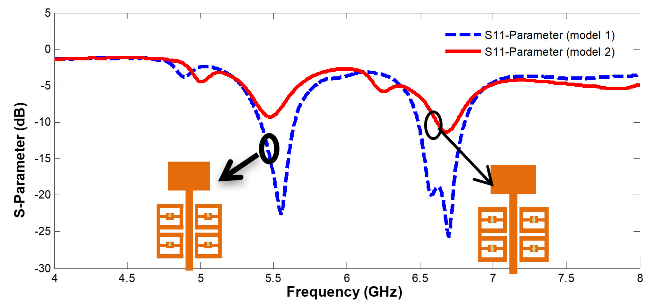

Fig. 4. S11-parameter of the dual-passband microstrip filtering antenna using resonators of mode 1 and mode 2.

tivity. They can be utilized to create multiple passbands and stopbands. The effect of the DGS on the S_{11}-parameter of the dual-passband microstrip filtering antenna is depicted in Fig. 6. As shown in Fig. 6, DGS plays an essential role in the development and improving the performance of the dual-passband filtering antenna. Surface waves, which can cause interference and signal loss in RF/Microwave equipment are successfully suppressed by DGS. This reduces undesired radiation and enhances the overall quality of the transmission. The comparison results of the three modes of the dual-mode resonators used in the design of the dual-passband microstrip filtering antenna are stated in Table II.

The antenna efficiency η is defined as the ratio of the total power radiated to the total input power [22]. The filtering antenna radiated power and the power losses are included in the total input power. The simulated power efficiency of the proposed dual-band filtering antenna is depicted in Fig. 7. The frequencies of the first band and the second band used in this design are selected within the C – band (4 – 8 GHz) for long-distance telecommunication applications.

The maximum radiation efficiency of the proposed filtering antenna is 62.34 % in the first band and 63 % in the second band, while the maximum radiation efficiency of the dual-band filtering antenna stated in Ref. [1] is 68.67 % in the first band and 58.85 % in the second band.

V. CONCLUSION

A new dual-passband microstrip filtering antenna based on a dual-mode closed-loop resonator is presented in this paper. Three modes of dual-mode resonators have been used to design the dual-passband microstrip filtering antenna and compare their results. The dual-passband frequencies of the presented microstrip filtering antenna are located at $f_o^I = 5.52$ GHz and $f_o^{II} = 6.6\ 5$ GHz. The center frequencies of the first passband and the second passband can be managed by scaling the electrical length sections of the resonator θ_1 and θ_2. The defected ground structure plays an essential role in the development and improvement of the performance of the dual-passband filtering antenna. The dual-passband microstrip filtering antenna design results are simulated and improved by using computer simulation technology (CST) software on FR-4 epoxy dielectric material that has $\varepsilon_r = 4.3$, height thickness $h = 1.6\ mm$, and loss tangent tan $\delta = 0.002$. The dual-passband filtering antenna using the dual-mode resonator of mode 1 shows good simulation results compared to other designs.

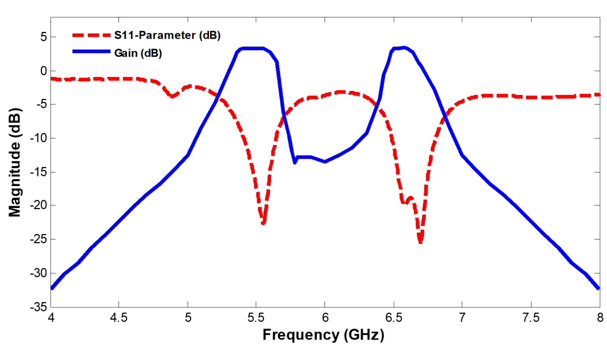

Fig. 3. The S11-parameter and gain of the presented dual-passband microstrip filtering antenna.

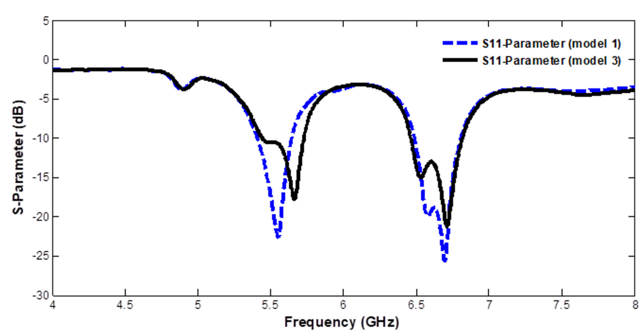

Fig. 5. S11-parameter of the dual-passband microstrip filtering antenna using resonators of mode 1 and mode 3.

TABLE II.
COMPARISON RESULTS OF THE THREE DUAL-MODE RESONATOR MODES.

Parameter	Filtering antenna using mode 1 resonator		Filtering antenna using mode 2 resonator		Filtering antenna using mode 3 resonator	
	1st band	2nd band	1st band	2nd band	1st band	2nd band
Frequency (GHz)	5.52	6.65	5.47	6.67	5.55	6.63
FBW	0.0742	0.0721	0.056	0.044	0.082	0.065
Quality factor	13.463	13.854	17.76	22.307	12.06	15.276
VSWR	1.16	1.257	2.02	1.71	1.87	1.6
Return loss (dB)	-22.56	-18.86	-9.259	-11.314	-10.489	-12.913
Gain (dB)	3.36	3.46	0.453	0.9674	0.7684	1.204

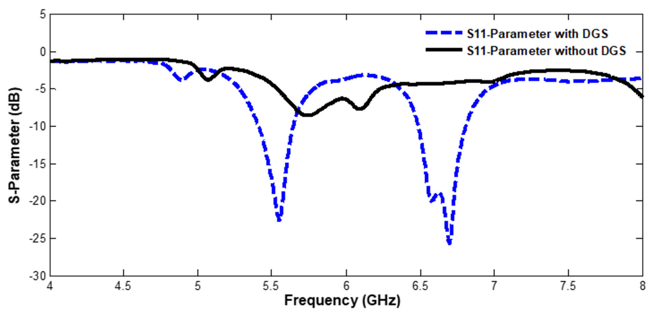

Fig. 6. S11-parameter of the dual-passband microstrip filtering antenna with and without DGS.

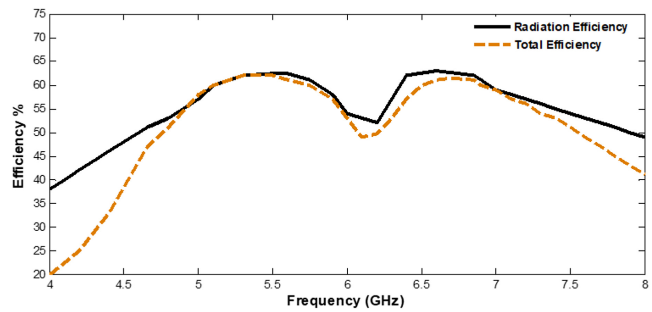

Fig. 7. Total efficiency and radiation efficiency of the dual-passband microstrip filtering antenna.

CONFLICT OF INTEREST

The authors have no conflict of relevant interest to this article.

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