Microstrip Dual-Mode Band Reject Filter

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Abstract — Novel microstrip dual-mode band reject filters using triangular patch resonators are investigated. It is shown that with simple circuit topologies highly selective notch filters can be realized. Full-wave electromagnetic (EM) simulations and circuit modeling are performed in order to understand the operation of this type of filter. Two demonstrators, i.e. single-patch and double-patch dual-mode band reject filters are presented with simulated and measured results.

Index Terms — Microstrip filters, band reject filters, notch filters, band stop filters, dual-mode filters.

I. INTRODUCTION

Band reject filters have been widely used in many microwave circuits and systems. In particular, narrow-band band reject or notch filters have become more and more important in most microwave communications and radar systems as there exist more unwanted signals or interferences at air-interfaces. This has stimulated new developments of band reject filters [1]-[2]. In general, a band reject filters may be designed using single-mode or dual-mode resonators. Dual-mode resonators are attractive because each of dual-mode resonators can be used as a doubly tuned resonant circuit, and therefore the number of resonators required for a given degree filter is reduced by half, resulting in a compact filter topology or configuration. To date, however, only waveguide dual-mode band reject filters have been reported [3]-[5], and little has been known for microstrip dual-mode band reject filters.

Although there are several well-known microstrip dual-mode resonators, including the circular ring [6], the meander loop [7], the circular disk and the square patch [8]-[9], they have been used mainly for band pass filter applications. The patch resonators appear more attractive for filter applications where low loss and high power handling are of primary concern [10]. In addition, at millimeter waves the size may not be the issue and the use of patch resonators can also ease the fabrication.

Recently, we have reported a new dual-mode microstrip triangular patch resonator and its applications for band pass filters only [11]. It has been shown that the dual-mode triangular patch resonator exhibits a distinct characteristic that is totally different from that of other dual-mode resonators above mentioned. This characteristic shows that the two degenerate modes in a dual-mode triangular patch resonator are not coupled even after mode splitting. Therefore, it would be of interest to see (i) if this characteristic can have a good use for designing band reject filters; (ii) how to implement band reject filters with this type of dual-mode resonators; and (iii) what kind of band rejection characteristics are attainable.

To this end, this paper reports, for the first time, an investigation into novel microstrip dual-mode band reject filters using triangular patch resonators. The development of single-patch and double-patch dual-mode band reject filters will be described. Both theoretical and experimental results are presented.

II. SINGLE-PATCH DUAL-MODE BAND REJECT FILTER

The proposed microstrip single-patch dual-mode band reject filter is depicted in Fig. 1(a), where a dual-mode triangular patch resonators is coupled to the main transmission line of width $W$, through a coupling gap of $g$. The triangular patch has equal sides of $a$ and a slit in the middle. The size of slit is $l$ by $s$. The coupling structure for this filter is illustrated in Fig. 1(b), in which the two numbered black nodes represent the two modes of the dual-mode resonator, and the full lines represent direct couplings.

![Fig. 1. Single-patch dual-mode band reject filter. (a) Topology. (b) Coupling structure.](image-url)
the dual-mode triangular patch resonator used in Fig. 1(a). The two modes are coupled to the input (port 1) and the output (port 2) in parallel, resulting in two parallel signal channels. For the configuration of Fig. 1(a), in general two narrow-band reject bands (notches) resulting from the two resonant modes can be observed in the frequency response as shown in Fig. 2. The field distributions of the two resonant modes are illustrated in Fig. 3, which were obtained using a full-wave EM simulator [12].

![Image](https://via.placeholder.com/150)

**Fig. 2.** Typical dual-band rejection responses of a single-patch dual-mode filter.

![Image](https://via.placeholder.com/150)

**Fig. 3.** Current distributions of the two split modes, where \( jx \) denotes the horizontal component while \( jy \) the vertical component.

It is shown that the mode 1 is an even mode and the mode 2 an odd one. It appears that when coupled to the main transmission line, the model 1 results in an open circuit at its resonant frequency, whereas the mode 2 produces a short circuit at resonance, both have the same effect to block the transmission resulting in a notch at individual resonant frequency. The resonant frequencies of the two modes can easily be controlled by the slit length of \( l \), as shown in Fig. 4. Note that varying the slit length only changes the resonant frequency of the odd mode while the resonant frequency of the even mode is almost not changed.

![Image](https://via.placeholder.com/150)

**Fig. 4.** Dual-mode band reject frequency responses for the slit lengths of 6.25, 7, and 8 mm respectively.

By adjusting the mode 2 resonant frequency close to the mode 1 resonant frequency, a band reject filter with a single reject band can be obtained. Fig. 5 shows such a band reject filter designed using the EM simulation. The dimensions of the filter, as referring to Fig. 1(a), are given in the caption of the figure. It is evident that the designed single-patch dual-mode band reject filter exhibits an excellent performance with high selectivity. It would seem that such selectivity would not be attainable with a conventional 2-pole Chebyshev filter. In order to explain this type of selective response, establishing a circuit model for the single-patch dual-mode band reject filter is desired. To this end, we have investigated its operation in more details as the follows.

![Image](https://via.placeholder.com/150)

**Fig. 5.** Full-wave EM simulated responses for a single-patch dual-mode band reject filter with dimensions: \( a = 15 \text{ mm}, g = 0.25 \text{ mm}, l = 5.25 \text{ mm}, s = 0.5 \text{ mm}, \) and \( W = 1\text{ mm} \) on a 1.27-mm thick substrate with a relative dielectric constant of 10.8.

By cutting the dual-mode resonator in Fig. 1(a) along its symmetrical axis and moving away a half of the cut resonator, we obtain a filter structure as shown in Fig. 6(a). The full-wave EM simulations were then carried out to find the field distributions and frequency responses of this structure. The current distribution in Fig. 6(b) has the same pattern as that of the corresponding half part of Mode 1 in Fig. 3. The charge distribution in Fig. 6(b) indicates that this half resonator is electrically coupled to the main line and results in an open circuit at resonance to block the transmission by its own. This is confirmed by the simulated frequency responses plotted in
Fig. 6(c). It can also be shown that the center band rejection frequency is exactly the same as that of uncut dual-mode resonator.

![Fig. 6(c)](image)

The foregoing discussions would suggest that the mode 1 (even-mode) of the dual-mode resonator in the band reject filter configuration of Fig. 1(a) could have a double attenuation effect similar to two extracted poles at the same frequency on the both ends of the filter. On this ground and taking into account another fact that the mode 2 (odd-mode) produces only a short circuit in the middle of the filter from its current distributions (see Fig. 3), a circuit model has been established and used for circuit modeling as shown in Fig. 7. It can be seen that the circuit-modeled responses are matched well to the EM simulated responses of Fig. 5. The modeling was done using a commercially available tool [13].

![Fig. 7](image)

To verify the design, a demonstrator was fabricated (see the insert in Fig. 8) and tested. In general, the measured responses showed a similarity to the predicted ones, confirming the operation of this type of filter. Less in-band attenuation in the measured responses is due to the loss that was not taken into account in the simulation or modeling. Assembling the filter into a proper test housing can reduce the loss with an improved performance.

![Fig. 8](image)

### III. DOUBLE-PATCH DUAL-MODE BAND REJECT FILTER

We have also investigated a double-patch dual-mode band reject filter. A demonstrator of this type as shown in Fig. 9(a) was designed, fabricated and tested. Some preliminary results are presented here. As compared to the single-patch dual-
mode filter, the use of double dual-mode resonators in such a compact filter configuration can increase the selectivity and in-band attenuation for the same bandwidth; or can allow increasing the rejection bandwidth while maintaining the similar selectivity and in-band attenuation. The later is demonstrated by the example given in Fig. 9, where both simulated and measured results responses showed the desired characteristics.

![Demonstrator of a double-patch dual-mode band reject filter](image)

Fig. 9. (a) Demonstrator of a double-patch dual-mode band reject filter. (b) Simulated responses. (c) Measured responses.

### IV. CONCLUSION

Novel microstrip dual-mode band reject filters using triangular patch resonators have been, for the first time, introduced. The operation of the new type of filter has been studied in the light of full-wave EM simulations and a circuit model has been established for the basic filter-building element. Two demonstrators have been presented with simulated and measured results. It has been shown that with simple and compact topologies highly selective narrow-band reject (notch) filters can be realized. Further developing higher-order filters of this type is feasible. The new filters, which offer alternative designs to the existing microstrip bandreject filters, are also expected to find applications in microwave superconductivity, RF MEMS and LTCC technologies.

### REFERENCES


