Performance Enhancement of a Dielectric Resonator Antenna by Using Cross-resonator Based Filtering Feed-Network

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Abstract

In this paper, a broadband filtering dielectric resonator antenna (DRA) has been aimed to design by cascading a third order band-pass filter (BPF) in the feeding network. A hairpin shaped cross-resonator based BPF is integrated with a slot coupled rectangular DRA to achieve a third order filtering response. Introduction of the BPF in the feed network helps to modify the conventional response of a slot coupled rectangular DRA. The proposed filtering DRA offers an impedance bandwidth of 13.9% from 3.00 GHz to 3.45 GHz with an S-parameter response analogous with pass-band of the BPF. Electric field distribution of DRA within the passband confirmed that the rectangular DRA drive in TE_{111} mode which ensured the broadside radiation. A satisfactory stable gain pattern of 5.0±0.3 dBi within the pass-band has been achieved. The gain response falls sharply with a radiation-null alike of transmission zero of the BPF at 3.74 GHz which aid to increase the selectivity of the antenna.

1. Introduction

With the enormous growth of wireless communication in recent years, the design of antennas integrating with multiple components has become a significant issue to the researchers. Integration of multiple components of wireless systems helps to reduce the overall size, design complexity whereas overall system efficiency increases. The RF spectrum is congested with the transmission of various types of signals. In most of the RF front-end systems, the antenna is always coexisted with a bandpass filter to minimize the problem of overloading by out of band signals [1-2]. Typically, the antenna and filter are usually modeled individually and then cascaded via a matching network. This additional matching network may not produce a stable response within the whole frequency range in interest. Also the self-resonant frequency of the matching circuits causes interference. Again radiation properties of the antenna cannot be improved by any kind of additional networks, it's required an effectively designed antenna. In recent times, a co-design procedure has been followed to implement the bandpass filter and the antenna into a single module, formally called as filtering antenna or filtenna, with both the filtering and radiation ability [3-4]. The filtering antenna is not only improved the return loss characteristics but also produced filtering gain response. Such versatile antennas find their application in mobile base station, military application, security application etc. Several studies have been performed on printed antenna, horn antenna, substrate integrated waveguide based antenna to achieve filtering performance [5-8]. But very few studies have been performed so far to achieved filtering performance of dielectric resonator antenna (DRA). DRAs have some inherent advantages compared to the metallic antenna such as smaller size, high gain, no conductive loss, higher radiation efficiency, and so on [9]. A filtering DRA is designed in [10] by using hybrid microstrip feeding technique. Whereas an omnidirectional filtering DRA is modeled by hybrid coaxial feeding technique in [11].

In the present study, a broadside filtering DRA has been designed based on a triple transmission pole cross-resonator [12] based feeding network. The triple-pole band pass response achieved in [12] by shorting the three quarter wavelength resonators through a ground via. We have cascaded the above-mentioned band pass filter with a microstrip line fed rectangular slot coupled DRA which not only increase the impedance bandwidth of DRA but also helps to provide filtering gain response with high selectivity. As energy is coupled to DRA from feed network via a rectangular slot, degradation in antenna performance is negligible due to modification in feed network. The filtering DRA operate from 3.00 GHz to 3.45 GHz with a -10 dB bandwidth of 13.9%. The DRA provides a stable broadside gain of 5.0±0.3 dBi throughout the operating band with a radiation null equivalent of transmission zero of bandpass filter at 3.74 GHz. Since DRA support lots of modes, sometimes few spurious modes also excited with the desired fundamental modes which cause unnecessary interference. By designing filtering DRA problem of spurious modes also resolved. A relative performance comparison is also shown between the conventional rectangular slot coupled DRA and filtering DRA.
2. Description of The Filtering Network And DRA

2.1 Cross-resonator based filtering network

The filtering feeding network for the proposed DRA is consist of a hairpin shape half-wavelength resonator, an open stub, and a short stub are intersected at the center point of the hairpin resonator. The ground via of short stub is offering the main coupling between the resonators. From the basic topology of cross-resonator as shown in Figure 1, three independently controllable resonant modes can be evaluated using odd and even-mode approach [12-13] because of the existence of symmetrical plane SS'. The resonance condition of the odd-mode is

\[
\frac{\gamma_{\text{odd}}}{j\tan(\theta_{\text{odd}})} = 0
\]

(1)

Resonance frequency of the odd-mode can be derived from equation (1) as

\[
f_{\text{odd}} = \frac{c}{2\lambda_{\text{odd}}\sqrt{\varepsilon_{\text{eff}}}}
\]

(2)

Where \( \theta_{\text{h}} = \beta l_{\text{h}} \), \( \beta = \) propagation constant and \( \varepsilon_{\text{eff}} = \) effective dielectric constant . Similarly the resonance condition for even mode is

\[
Y_{\text{even}} = jY = \frac{2\tan(\theta_{\text{even}})+\tan(\theta_{\text{odd}})-\cot(\theta_{\text{even}})}{1-\tan(\theta_{\text{h}})+\tan(\theta_{\text{even}})-\cot(\theta_{\text{odd}})} = 0
\]

(3)

From equation (3) even mode resonance frequencies \( f_{\text{even1}} \) and \( f_{\text{even2}} \) are derived. Based on the observation given in [], we can write

\[
\frac{f_{\text{even1}}}{f_{\text{odd}}} = k_{1} \quad \text{and} \quad \frac{f_{\text{even2}}}{f_{\text{odd}}} = k_{2}
\]

(4)

Where \( k_{1} \) and \( k_{2} \) can be tuned by varying \( \theta_{\text{even}} = \beta l_{\text{e}} \) and \( \theta_{\text{odd}} = \beta l_{\text{o}} \) respectively. For \( k_{1} \approx 1 \) and \( k_{2} \approx 1 \), we get the third order bandpass response with a transmission zero at the upper side of the passband. The response of the filtering circuit is shown in Figure 2. It is operating from 2.98 GHz to 3.46 GHz with insertion loss of 1.9 dB.
size \( l_{sub} = 40 \text{ mm}, \ w_{sub} = 42.3 \text{ mm}, \) thickness \( h_{sub} = 0.79 \text{ mm} \). Size of the slot on the ground plane is \( l_a \times w_b = 18 \times 1.5 \text{ mm}^2 \) to guide the signal from the feed line to the dielectric resonator. As the filtering network has the bandpass response for 2.98 GHz to 3.46 GHz, initial dimensions of rectangular DRA is chosen in such a way that it operates in fundamental mode at the center frequency. Using DWM technique [14] we have figured out the dimensions of the rectangular DRA for the resonance frequency of \( \text{TE}_{111} \) mode at 3.2 GHz. From the electric field configuration as given in next section, it is verified that the DRA is exited in \( \text{TE}_{111} \) mode. All the required dimensions are provided in tabular form in Table.1. A relative performance between conventional slot-fed DRA (Antenna-Conv.) and proposed filtering DRA is discussed next. \( S_11 \)-plots of both antennas are shown in Figure 4. The dimensions of the rectangular DRA has remained the same in both cases. From Figure 4 it is clear that Antenna-Conv. resonates at 3.27 GHz in the fundamental mode. On the other hand, the response of the proposed filtering DRA is analogous with third order band-pass filter.

Figure 4. Comparison of \( S_11 \) response of the conventional slot fed rectangular DRA and the proposed filtering DRA

3. Results and discussions

Figure 5. presents electric field distributions within the DRA for three different frequencies within the passband.

![Electric Field distributions](image)

Figure 5. Simulated Electric Field distributions within the DRA for three different frequencies within the passband

Figure 6. shows the simulated \( S_11 \) response for both the Antenna-conv. and the filtering DRA. Where gain response of the Antenna conv. not fall beyond the operational band, a sharp transition of gain response beyond the passband is clearly visible with radiation null at 3.74 GHz for the proposed antenna. The radiation null is occurred due to the use of cross-coupled resonator mainly controlled by the ground-via in the feed network. The DRA possess flat gain responses with an average gain of 5.0 dBi within passband with a sharp roll off near the passband edge. The radiation pattern for both E and H-plane in three different frequencies of 3.04 GHz, 3.18 GHz and 3.4 GHz in the passband is shown in Figure 8. Stable broadside beam pattern is obtained over the passband with co-to-cross-pol isolation greater than 20dB.

![Gain vs Frequency plot](image)

Figure 7. Comparison of gain vs frequency response of the conventional slot fed rectangular DRA and the proposed filtering DRA
Figure 8. Simulated radiation pattern of the antenna (a) \( f = 3.04 \) GHz (b) \( f = 3.18 \) GHz (c) \( f = 3.4 \) GHz

4. Conclusion

A broadband filtering DRA has been introduced excited by a third order cross-resonator based feeding network. In comparison with the conventional aperture coupled DRA, the proposed DRA achieve a wider impedance bandwidth with a third order filtering \( S_{11} \) response. Filtering response of the DRA not only improves the impedance characteristics also enhance the radiation performance such as fairly flat gain over the operating band, sharp roll-off beyond passband. The filtering DRA operate from 3.00 GHz to 3.45 GHz with \( S_{11} \) almost 0 dB at the stop-band ensuring superior filtering performance. Also a smooth gain response of almost 5 dBi within a passband with a radiation null at 3.74 GHz has been achieved. With the high demand for low interfering signal we believe that the proposed design has a huge aspect in wireless communication, especially for a WiMAX router.

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6. References