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Circular Patch Filtering Antenna Design Based on Hairpin Bandpass Filter

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***Abstract* - A circular patch filtering antenna (CPFA) is presented based on the Chebyshev hairpin bandpass filter (CHBF) synthesis. The circular patch radiator connected to the last stage of the hairpin resonator using tap technique that can extract the radiation quality of the patch while the feedline connected to the first stage of the resonator using coupling technique that result in the same value between the radiation quality of the patch and the external quality of the filter. The CPFA was designed and simulated to be operated at operating frequency 4.45 GHz with 2.6% fractional bandwidth. The CPFA has also been fabricated and measured. The measurement shows a good agreement with the simulation results.**

Index Terms — Chebyshev filter, filtering antenna, hairpin resonator, circular patch filtering antenna (CPFA) *Index Terms* — Antennas, propagation, EM wave theory, AP-related topics.

1. Introduction

Various methods of miniaturization of Radio Frequency (RF) circuit have been presented. One concept of miniaturization in a RF front-end is the technique of integrating antennas with filters known as filtering antenna, results in a more compact circuit. The concept of a filtering antenna is to insert the filter circuit on the transmission line of the antenna. This technique produces an antenna that has a gain parameter similar to a bandpass filter response.

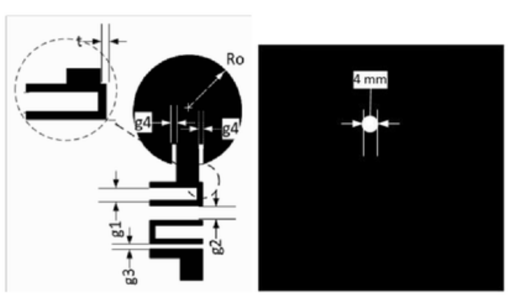
Some antenna filtering design techniques with a single substrate have been exhibited as in [1]–[5]. In [1] implement two of a quarter wavelength line resonator with a pin between the two resonators. Meanwhile [2], [5] insert the T-shape resonator couple to the U patch radiator. An octagonal patch with composite right-left hand and rectangular patch using hairpin resonator are applied in [3], [4]. One of the requirement to design the filtering antenna is to match the external quality factor (Q_{ext}) of the filter with the quality factor radiation (Q_{rad}) in the patch antenna. There are two methods applied for Q_{rad} extraction, the two ports method which is performed in [4] and the single port method as proposed in [6]. The two ports technique has a restriction that the patch antenna must have a symmetry shape, which is not appropriate to be applied to a patch radiator that is asymmetric. And it has not been reported about the design of a circular filtering antenna that has an asymmetry shape with a hairpin resonator.

In this paper, the synthesis of filtering antenna based on the Chebyshev hairpin band-pass filter which implements the combination of coupling and tap technique.

2. Design Process

The basic configuration of the filtering antenna is shown in Fig.1. The filter consists of a circular patch and two hairpin resonators which is connected using the tap technique and the 50 Ω feedline is coupled to the first resonator.

The proposed antenna is designed to operate at resonance frequency 4.45 Ghz with 2.6% fractional bandwidth. The third order CHBF is designed with the 2.6% fractional bandwidth, 0.1 dB ripple at the frequency of 4.45 GHz. The CPFA is fabricated on a single layer Roger Duroid substrate with 1.575 mm thickness and dielectric constant 2.2. All the process of the CPFA design is simulated using CST ®.
Based on a filter theory the filter has Q_{ext} of 39,676 and the coupling coefficient between two resonators ($M_{1,2}$) 0.024. The value of the Q_{ext} must hold the same value with the quality radiation of the patch to obtain a good match between both the radiator (the patch) and the resonator (filter) circuit. With the hairpin arms lengths approximately a quarter wavelength, the distance between the two arms hairpin (g_1) 3 mm and the thickness 1.1 mm result in operation frequency of 4.45 Ghz at the center.



(a) Top (b) Bottom

Fig.1 Proposed filtering antenna dimension with R_o = 12.4 mm, g_1 = 3 mm, g_2 = 3.4 mm, g_3= 1.15 mm, t = 0.85 mm and g_4 = 1.2 mm

The 50 Ω input impedance and the first hairpin resonator filter is coupled fed to the 50 Ω input impedance but the last resonator is tap fed to the circular radiator with 50 Ω inset feed. The hairpin resonator's dimension and the distance between the 50 Ω input impedance and the first stage of the resonator can be adopted to design the CPFA for this distance represents the mutual coupling between them. The design of the radiator initiated by designing a circular patch antenna with radius of 12.4 mm that resonates at the desire frequency. The circular antenna is designed with an inset feed and the CPFA design is based on the dimension of the antenna that replaces the third resonator of the hairpin.

From the result of the Q_{ext} extraction and $M_{1,2}$ coupling hence obtained the distance between 50 Ω feedline to the first resonator of 1.15 mm (g_3) that result in Q_{ext} = 39.676, the gap distance of 3.35 mm (g_2) between two hairpin resonator performs 0.023 coupling coefficient. The 0,85 mm distance of the inset-feed tap to the corner resonator (t) satisfy the Q_{rad} = 39.676 requirement. The Q_{rad} of the patch radiator with the tap technique to connect to the last hairpin resonator is calculated with (1)[7] as follow:

$$t = 2L/\pi \times \{\sin^{-1}\sqrt{[\pi \times Z_o/(2 \times Q_{rad} \times Z_R)]}\}. \quad (1)$$

where L is the length of the hairpin arm, Z_o is the 50 Ω input impedance and Z_r is the impedance of the hairpin which is 111.51 Ω for a thickness 1.1 mm.

3. Result and Discussion

The optimization is performed with g_2 = 3.4 mm and t = 0.85 mm and the addition of a hole on the ground side parallel to the circular patch centre with a radius of 2 mm, the simulation bandwidth widen from 92,1 to 95,4 MHz with frequency range from 4.3904-4.4863 GHz in. The addition of a circular hole on the ground also gives a better returnloss on the S_{11} curve. The realized gain shows a flat response along the bandwidth with a value of 7.2 dBi at its center frequency and declines sharply outside its operating frequency with out-of band rejection of -4.8 dBi.

The simulation result shows a higher gain i.e. 7.2 dBi compare to [1]–[3] and the realized gain response has a flat shape within the bandwidth and decreased sharply to lower than -4 dBi at the out-of-band frequency.

The antenna fabrication was conducted to examine the effectiveness of the simulation. The measurement result shows a good agreement with the simulation as shown in Fig. 2. The measurement operating frequency range from 4.4 - 4.505 GHz with -9.7 dB impedance bandwidth results in a 105 MHz bandwidth (solid black line). The passband bandwidth measurement is shifted 19 MHz to the higher frequency or 0.4% relative to the centre frequency. The returnloss measurement value stays lower than -15 dB in the passband and has two transmission poles.

The realized gain measurement (solid blue line) shows a flat response at the operating band with approximately similar gain compared to the simulation results (dashed blue line). The maximum gain measured 6.4 dBi at 4.5 GHz and decrease sharply at 4.6 GHz to less than -9 dBi. The maximum gain is 0.8 dB lower than the simulation result. At the lower frequency of 4.3 GHz the gain increased sharply from -19 dBi to 2 dBi at 4.4 GHz.

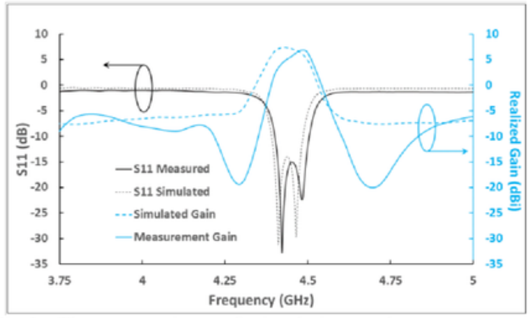


Fig.2. The comparison of simulation and measurement result of the proposed antenna.

4. Conclusion

A CPFA has been designed, simulated and measured. Both simulation and measurement results showed a fairly good agreement. Further refinement is still under study.

Acknowledgment

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