Dual-Mode Microstrip Triangular Patch Resonators and Filters

Jia-Sheng Hong and Shuzhou Li

Department of Electrical, Electronic and Computer Engineering, Heriot-Watt University, Edinburgh EH14 4AS, UK

Abstract — **Dual-mode operation of microstrip triangular patch resonators has been investigated. It has been found theoretically that the dual modes can result from the rotation and superposition of a fundamental mode. The characteristics of the dual modes and their mode splitting are described. The application of this new type of dual mode microstrip patch resonator in the design of microwave planar filter is presented. A two-pole and one four-pole filters of this type are demonstrated at the first time. Both theoretical and experimental results are presented. Advantages of using this type of filter are not only its lower loss and higher capability of power handling, but also its compact size and natural circuit topology for implementing filters.**

I. INTRODUCTION

Microstrip filters have found wide applications in many RF/microwave circuits and systems. This is particularly driven by rapidly growing wireless communications, emerging high temperature superconducting (HTS) and micromachining technologies [1]-[7]. In general, microstrip bandpass filters may be designed using single or dual-mode resonators. Dual-mode microstrip 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 configuration [6]-[11].

Several types of dual-mode microstrip resonators have been used, including the circular ring [8], the meander loop [9], the circular disk and the square patch [10]-[11]. The 1D transmission line dual-mode resonators such as rings and loops are smaller in size than the 2D patch dual-mode resonators such as circular disks and square patches. However, the line-based resonators generally suffer from higher conductor loss and lower power handling capability. Therefore, the patch resonators appear more attractive for bandpass filter applications where low insertion loss and high power handling are of primary concern [12]-[15]. In addition, at millimeter waves the size may not be the issue and the use of patch resonators can also ease the fabrication.

However, so far only few dual-mode microstrip patch resonators, i.e. square and circular patches have been available for the filter design. Although microstrip filters using triangular patch resonators have been reported recently [15], each of the triangular patches operates merely with a single mode at a certain frequency band. The triangular patch is an interesting element. It would be desirable to see if the dual-mode operation of a microstrip triangular patch is possible, and hence to offer alternative dual-mode microstrip filter designs. In this paper, we report the results of a primary investigation into these issues. The theoretical solutions have been found to confirm the dual-mode operation of an equilateral triangular microstrip patch resonator. The characteristics of two degenerate modes are described. It will also be addressed how to perturb the two modes for the coupling. Two novel dual-mode microstrip bandpass filters of this type are at the first time demonstrated theoretically and experimentally.

II. DEGENERATE MODES

Fig.1 shows the geometry of an equilateral triangular microstrip patch resonator. Using a waveguide cavity mode with magnetic wall on the sides, the fields within the resonator can be expanded by TM^z modes

$$\begin{aligned} E_z &= A_{m,n,l}T(x,y) \\ H_x &= \frac{j}{\omega\mu_0}\frac{\delta E_z}{\delta y} \\ H_y &= \frac{-j}{\omega\mu_0}\frac{\delta E_z}{\delta x} \\ H_z &= E_x = E_y = 0 \end{aligned} \tag{1}$$

where z is perpendicular to the ground plane. $T(x,y)$ is an eigenfunction, which can be found in [16]. $A_{m,n,l}$ is a reference amplitude where the indexes m, n and l satisfy $m+n+l=0$. However, only single-mode fields can be found from (1) along. To predict the dual-mode operation of a fundamental mode ($m=1, n=0, l=-1$), we found that another set of the fields that are expanded in a rotated coordinate system (X', Y', Z) as indicated in Fig. 1 would be required, i.e.,

$$E_z' = A_{m,n,l} T(x', y') \quad (2)$$

The magnetic field can be derived in the same manner as (1). According the principle of superposition, we notice that the field

$$E_z - E_z' \quad (3)$$

can also be a solution of the electric field. The superposition can be applied to the magnetic field as well. A computer program was written and used to compute the field patterns. It has then found that the equilateral triangular patch resonator exhibits a pair of degenerate modes at the fundamental resonant frequency. The computed current distributions of the degenerate modes of interest are depicted in Fig. 2, where Fig. 2(a) is obtained from (1) while Fig. 2(b) from (3).

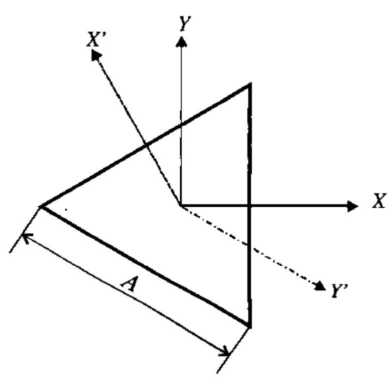

Fig. 1. Equilateral triangular microstrip patch geometry.

Having identified the pair of degenerate modes of interest, a small cut is introduced, as Fig. 3 shows, to control the coupling between the two modes for the dual mode operation. Fig. 4 illustrates the frequency characteristics of mode splitting for different cuts, which are simulated using a full-wave EM simulator [17]. In the simulation, the unperturbed equilateral triangular microstrip patch resonator has an equal side of a = 15 mm. The substrate used in the simulation has a relative dielectric constant of 10.8 and a thickness of 1.27 mm.

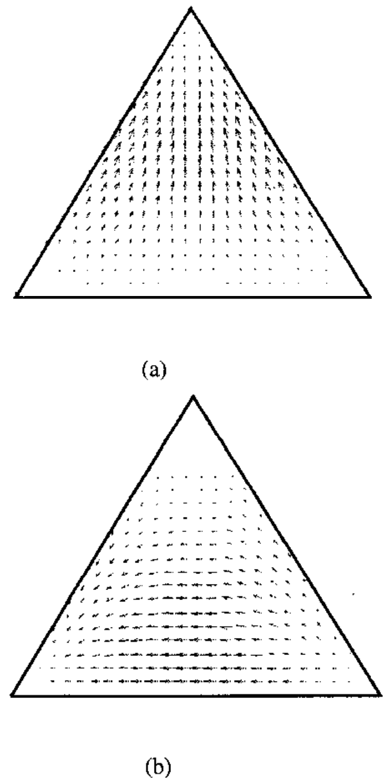

Fig. 2. Computed current distributions of a pair of degenerate modes.

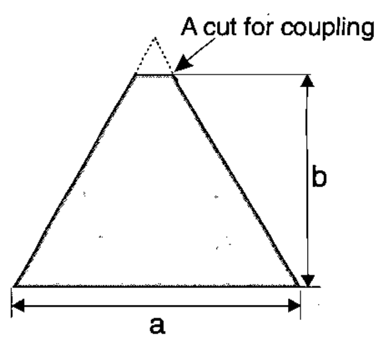

Fig. 3. Mode perturbation with a small cut on a triangular microstrip patch resonator.

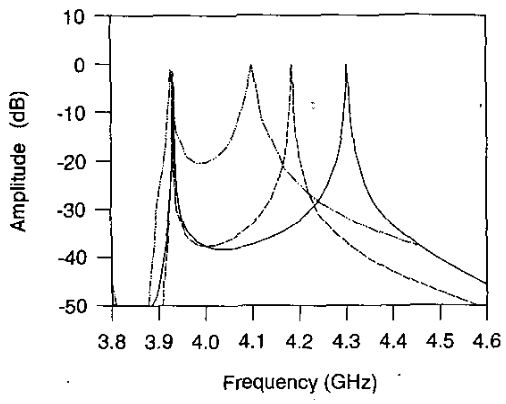

Fig. 4. Characteristics of mode splitting for a = 15 mm in Fig.3. (Dotted line: b = 11.75 mm. Broken line: b = 11.25 mm. Full line: b = 10.75 mm.)

From Fig. 4 we can see that the larger the cut (the smaller the dimension b), the wider is the mode splitting. It is noticeable that the mode splitting is asymmetrical, with one resonant frequency almost unchanged. This is because the cut does not make the same perturbation of the two modes.

III. DUAL-MODE BANDPASS FILTERS

To demonstrate the application of the proposed dual-mode microstrip triangular patch resonator, two-pole bandpass filters with a single microstrip triangular patch resonator were investigated first. This allows us to identify input/output (I/O) coupling structures. An I/O coupling structure with coupled lines has been developed. Fig. 5 demonstrates the layout and the simulated performance of a developed dual-mode microstrip bandpass filter of this type. The simulated performance, obtained using the full-wave EM simulator [17], shows the typical two-pole bandpass filtering characteristic. The filter exhibits a fractional bandwidth of 5% at 4.1GHz. The microstrip triangular patch resonator used has a size of a = 15 mm on a 1.27mm thick dielectric substrate with a relative dielectric constant of 10.8. The experiments were also carried out to confirm the dual-mode operation of this type of filter.

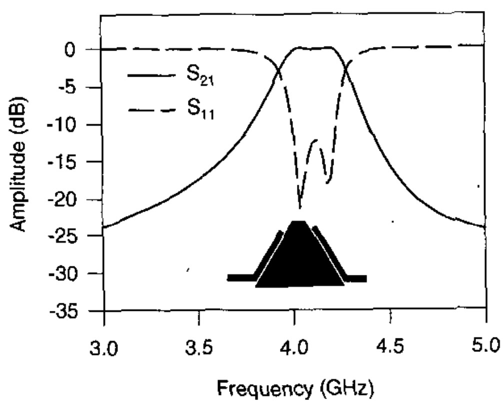

Fig. 5. The layout and performance of a two-pole dual-mode microstrip triangular patch resonator filter.

After the success in demonstrating the two-pole dual-mode microstrip triangular patch resonator filter, we have further developed multi-pole filters. Fig. 6 shows a photograph of a fabricated 4-pole filter of this type on a RT/Duriod substrate with a relative constant of 10.8 and a thickness of 1.27 mm. The filter consists of two dual-mode microstrip triangular patch resonators in a very simple cascaded coupling structure. The filter was designed using the tool of full-wave EM simulation [17]. The measured frequency responses of the filter are plotted in Fig. 7, which were obtained using an HP8720 network analyzer. The filter shows a very good performance with a measured insertion loss of ~2.3dB at a midband frequency of 4.01 GHz.

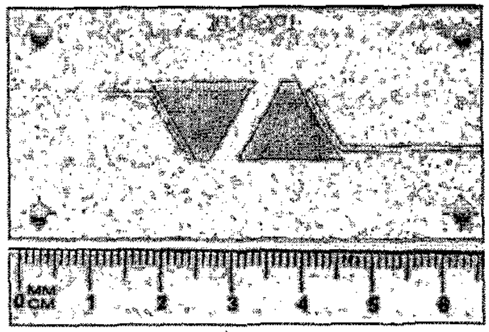

Fig. 6. Photograph of a fabricated four-pole dual-mode microstrip triangular patch resonator filter.

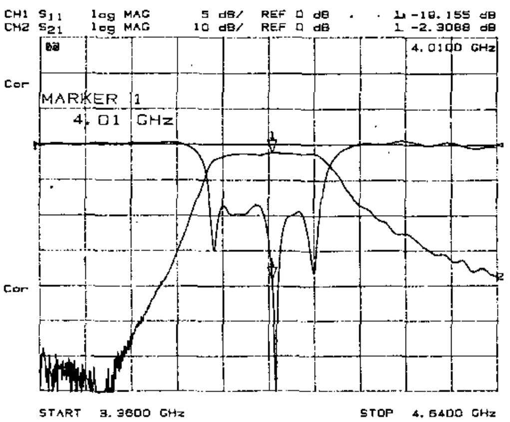

Fig. 7. Measured performance of the four-pole dual-mode microstrip triangular patch resonator filter of Fig. 6.

IV. CONCLUSION

We have investigated the dual-mode operation of microstrip triangular patch resonators and their applications in realizing dual-mode microwave planar filters. We have presented at the first time the theoretical solutions of a pair of degenerate modes of an equilateral patch resonator. It has been found that the degenerate modes can result from the rotation and superposition of a fundamental mode. The characteristics of the dual modes and their mode splitting have been described. We have also demonstrated at the first time two dual-mode microstrip triangular patch resonator filters. It has been shown that the use of triangular patch resonator not only offers an alternative to circular and square patch resonators for implementing dual-mode filters, but also results in a compact size and simple coupling topology in a cascaded form. It is expected that this type of filter will be very attractive for developing planar microwave filters with low loss and high power handling. It will also be promising for applications of high temperature superconductor, RF MEMS and LTCC technologies.

REFERENCES

[1] Y. Toutain, J. –P. Coupez, and C. Person, "Microstrip miniaturized loop-filters with high out-of-band rejection for future 3G mobile terminals", 2001 IEEE MTT-S Digest, pp. 1589-1592.

[2] P.Blondy, A.R.Brown, D.Cros and G.M.Rebeiz, "Low loss micromachined filters for millimeter-wave telecommunication systems", 1998 IEEE MTT-S, Digest, pp.1181-1184.

[3] C. Y. Ng, M. Chongcheawchanman, M. S. Aftanasar, I. D. Robertson, and J. Minalgiene, "X-band microstrip bandpass filter using photoimageable thick-film materials", 2002 IEEE MTT-S, Digest, 2002,pp.2209-2212.

[4] W. Hattori, T. Yoshitake, and K. Takahashi, "An HTS 21-pole microstrip filter for IMT-2000 base stations with steep attenuation", Applied Superconductivity, IEEE Transactions on , Volume: 11 Issue: 1 Part: 2 , March 2001 pp.4091-4094.

[5] G. L. Matthaei, "Narrow-band, band-pass filters with zig-zag, hairpin-comb resonators", 2002 IEEE MTT-S, Digest, 2002 pp.1931-1934.

[6] K. F. Raihn, G. L. Hey-Shipton, "Folded dual-mode HTS microstrip band pass filter", 2002 IEEE MTT-S Digest, pp.1959-1962.

[7] J. -S. Hong M. J. Lancaster, *Microstrip Filters for RF/Microwave Applications*, John Wiley & Sons, INC., New York, 2001.

[8] I. Wolff, "Microstrip bandpass filter using degenerate modes of a microstrip ring resonator", Electronics Letters, Vol. 8, No. 12, June 1972, pp. 302-303.

[9] J. -S. Hong M. J. Lancaster, "Microstrip bandpass filter using degenerate modes of a novel meander loop resonator", IEEE Microwave and Guided Wave Letters, Vol. 5, No. 11, November 1995, pp.371-372.

[10] J. A. Curitis and S. J. Fiedziuszko, "Miniature dual mode microstrip filters', IEEE MTT-S Dig., 1991, pp.443-446.

[11] R. R. Mansour, "Design of superconductive multiplexers using single-mode and dual-mode filters", IEEE Trans., 1994, MTT-42, pp.1411-1418.

[12] R.R.Mansour, B Jolley, S.Ye, F.S.Thomson and V.Dokas, "On the power handling capability of high temperature superconductive filters", IEEE Trans, MTT-44, pp.1322-1338, 1996.

[13] Z.-Y. Shen, C.Wilker, P.Pang and C.Carter, "High-power HTS planar filters with novel back-side coupling, " IEEE Trans., MTT-44, pp.984-986, 1996.

[14] M.A.Hein, et.al.,"High-power high-Q YB_aC_uO disk resonator filter", Applied Superconductivity 1997 (Proceedings of EUCAS 1997), pp.319-322.

[15] J. –S. Hong and M. J. Lancaster, "Microstrip triangular patch resonators filters", 2000 IEEE MTT-S Digest, pp.331-334.

[16] J.Helszajn and D.S.James, "Planar triangular resonstors with magnetic walls", IEEE Trans., MTT-26, pp.95-100, no.2, Feb. 1978.

[17] *em*, Sonnet Software, Inc., 2001, Version 7.0.