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Planar Differential Filtenna for Communications

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Abstract—This letter presents a novel differential filtenna for microwave systems at 2.4 GHz on planar technology. This filtenna exhibits 5% bandwidth with a 3-pole Chebyshev response. The filtenna uses a square patch as radiating element combined with $\lambda/2$ resonators. Experimental and simulated results are presented with good agreement. Moreover, the experimental common and differential mode radiation patterns are presented showing an attenuation greater than 15 dB for the common mode.

1. INTRODUCTION

In recent years, the integration of antennas and filters (Filtennas) in one single module has been suggested to reduce circuit size [1–4]. In order to achieve maximum miniaturization, the antenna radiators are used as filter resonators, hence reducing resonant elements, baluns and interconnections [3–7]. In addition, modern communications systems require common-mode (CM) noise immunity, caused by cross talk and electromagnetic interference (EMI). Crosstalk is generated by the coupling of lines within the circuit, whereas EMI is caused by external electromagnetic energy coupled to the system [8–10]. Differential circuits, including filtennas, are a well-known technique to increase immunity to these effects [11–15]. In [16], a 2-pole filtering antenna is presented; however, no experimental CM and DM radiation patterns are shown. In [17] a 4-element differential filtenna array is introduced, where they experimentally demonstrate CM radiation attenuation. Nevertheless, these two proposals utilize multiple layers increasing manufacturing difficulties, especially for system on chip packages where most components should ideally be manufactured in the same photo-lithographic process [18].

In this letter, a novel differential filtenna centered at 2.4 GHz is presented with a 3-pole filtering response. This design is manufactured on a single layer, which reduces manufacturing difficulties and facilitates the integrability of system on chip components. In addition, simulated and experimental return losses (S_{11d}) are presented with good agreement. In order to measure the DM and CM radiation patterns, the structure is connected to a 180° hybrid coupler. It is shown that there is a 15 dB CM suppression. Table 1 shows a comparison of this work with the available literature.

2. DIFFERENTIAL FILTER DESIGN

The first step is to design a Chebyshev filter centered at 2.4 GHz with a fractional bandwidth (5%) and ripple of 0.2 dB. An RT/duroid 5880 substrate of 3.175 mm and permittivity $\varepsilon_r = 2.2$ is chosen.

From [19] we obtain the Low Pass Prototype g values as follows:

$$g_0 = g_4 = 1$$
$$g_1 = g_3 = 1.5963$$
$$g_2 = 1.0967$$

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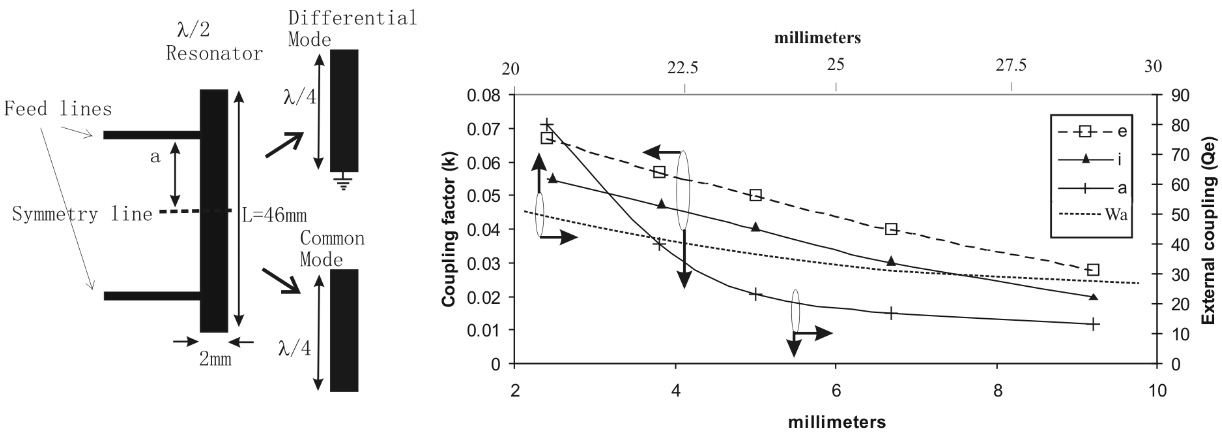
From [20] the required coupling coefficients k_{ij} and the external coupling factor can be calculated using Eqs. (1) and (2)

$$Qe = \frac{g_1}{FBW} \tag{1}$$

$$k_{ij} = \frac{FBW}{\sqrt{g_i g_{i+1}}} \tag{2}$$

In our case we calculate $Q_e = 30.1$ and $k_{12} = k_{23} = 0.04$.

The resonators measure half-wavelength at the resonant frequency. Their principle of operation is shown in Fig. 1(a), where two parallel lines are used for feeding the circuit. Therefore, for a differential signal an electric wall is forced along the symmetry line, generating a shorted $\lambda/4$ resonator. For a common mode signal, a magnetic wall along the symmetry line is created, hence, no band-pass can be excited at the center frequency [21].



(a) (b)

Figure 1. (a) Coupled resonator showing differential and common mode operations; (b) simulated mutual coupling, external Q and radiation Q values.

In order to synthesize the filter dimensions, a full wave simulator is used [22] following the procedure presented in [20]. To extract Q_e, a tap coupling is utilized, and the distance a is changed (Fig. 1(a)). From Eq. (3) Q_e is calculated. It is necessary to point out that differential lines are used to feed the resonators as shown in [23].

$$Qe = \frac{fo}{\Delta f} \tag{3}$$

where f_o is the center frequency, and Δf is the 3 dB bandwidth.

Figure 1(b) shows the extracted external coupling versus distance a. In our case, for $Q_e = 30$, the distance needs to be $a = 4.5$ mm.

For the mutual coupling (k_{12}), Fig. 2(a) shows the simulation results, where two resonators are weakly coupled to the differential feeding lines. From this figure, e is changed, and with Eq. (4) we extract parameter k_{ij}. The required distance for $k_{12} = 0.04$ is $e = 6.7$ mm.

$$k_{ij} = \frac{f2^2 - f1^2}{f2^2 + f1^2} \tag{4}$$

where f_1 and f_2 are the resonant frequencies.

3. ANTENNA DESIGN

Once the filter is designed, the last filter resonator is replaced by a square patch antenna. The antenna is excited at its fundamental TM_{010} mode, for which $L_a = \lambda_g/2$ that is 40 mm at 2.4 GHz (Fig. 2(b)).

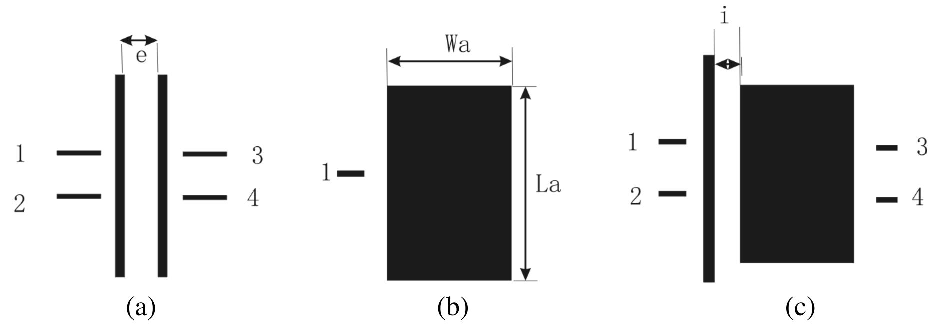


Figure 2. (a) Coupled resonators to calculate k_{12}; (b) Simulated square patch to obtain W_a dimension; and (c) patch antenna coupled to resonator to calculate k_{23}.

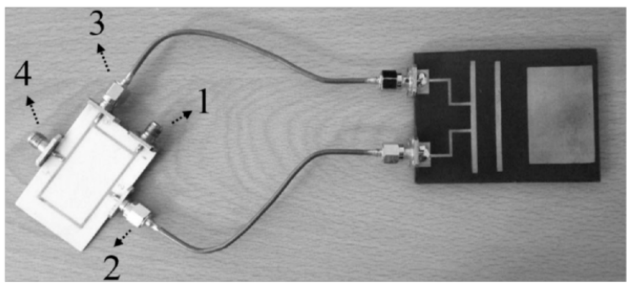


Figure 3. Fabricated filtenna connected to hybrid coupler.

Moreover, to choose W_a, the condition that the radiation quality factor (Q_r) should be equal to the external Q (Q_e) must be satisfied for proper matching [5]. By using a full wave simulator [22], a single square patch antenna is simulated (Fig. 2(b)) with $L_a = 40$ mm and changing W_a. By solving Eq. (3), we obtain the Q value, which is plotted in Fig. 1(b). From this figure, it is found that when $W_a = 26$ mm, we get $Q_r = 30$. Subsequently, we obtain the mutual coupling by simulating the structure presented in Fig. 2(c) and solving Eq. (4). The simulated results are shown in Fig. 1(b). For $k_{23} = 0.04$, we get $i = 5$ mm. The final filtenna is implemented on an RT/duroid 5880 substrate using conventional photolithography (Fig. 3).

4. EXPERIMENTAL A ND SIMULATED RESULTS

The filtenna is simulated in a full wave simulator [22]. To extract the differential S parameters from a two port network, the mix-parameters procedure shown in [23] is utilized. The experimental measurements are performed with a vector network analyzer [24]. In order to measure the differential mode parameters, the filtenna is connected to a 180 hybrid coupler as shown in Fig. 3, where port 1 excites the common mode and port 4 the differential mode. Ports 2 and 3 are the hybrid outputs connected to the filtenna. Fig. 4 shows the simulated and experimental return losses in differential mode (S_{11d}). The experimental center frequency is 2.39 GHz, whereas the simulation gives 2.41 GHz. Both responses have a 5% FBW for an attenuation greater than 15 dB. The experimental mismatches are thought due to material tolerances and manufacturing errors. In addition, it is important to highlight that no tuning was performed on the filter for measurements. Fig. 5 shows E and H planes radiation patterns at 2.41 GHz in polarization. As can be seen, for the E and H planes the CM pattern provides a 15 dB attenuation compared to the DM mode. Table 1 compares the performance of the proposed filtenna with some relevant reported structures. As can be seen, this work presents a single layer filtenna with a competitive common mode radiation attenuation.

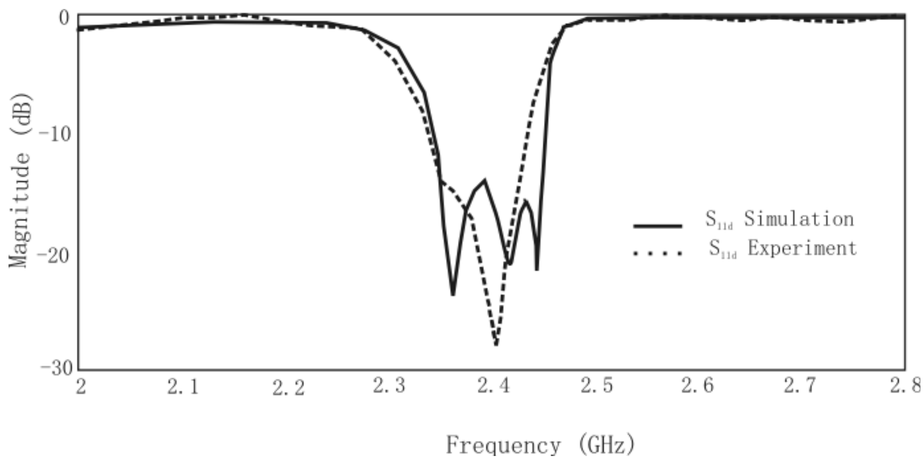


Figure 4. Simulated and experimental return losses of filtenna.

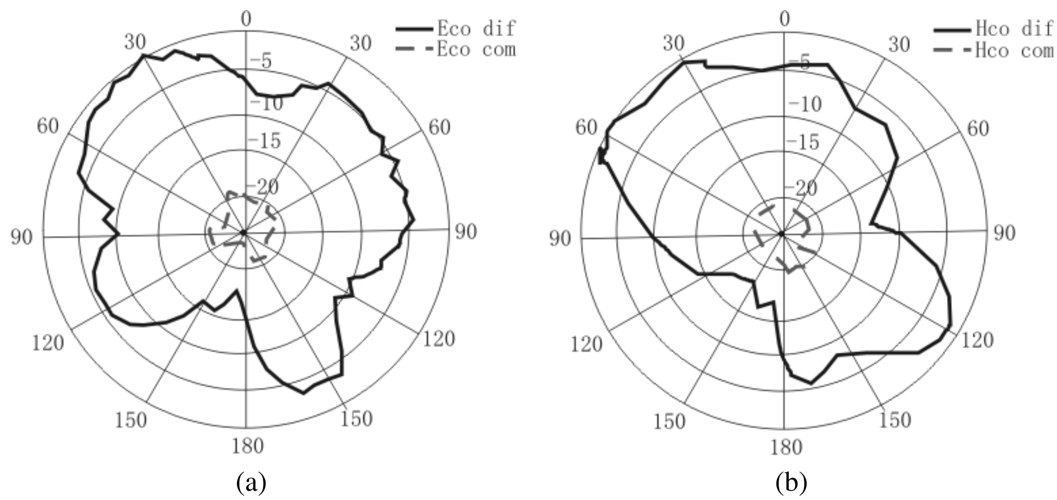


Figure 5. Experimental Co-polarized radiation patterns in E and H planes for differential and common modes.

Table 1. Performance comparison with the available literature.

Reference	Differential	Multilayer	Fractional Bandwith	$\lvert S_{11d}\rvert >$	CM radiation attenuation
[3]	Yes	Yes	2.5%	15 dB	NA
[4]	Yes	Yes	21.00%	NA	NA
[5]	No	No	3.5%	20 dB	NA
[6]	No	No	16%	25 dB	NA
[7]	No	No	2%	12 dB	NA
[16]	Yes	Yes	2.50%	12 dB	NA
[17]	Yes	Yes	3.00%	13 dB	15 dB
This work	Yes	No	5.00%	15 dB	15 dB

5. CONCLUSIONS

In this letter, we demonstrate the implementation of a novel planar differential filtenna with high common mode noise suppression. The structure is fabricated on a single layer, which reduces manufacturing difficulties and facilitates integration with on chip components. Moreover, the experimental and simulated return losses show good agreement. S_{11d} is greater than 15 dB throughout the desired 5% fractional bandwidth. In addition, we experimentally present both CM and DM radiation patterns, where a 15 dB suppression is achieved for the CM mode.

REFERENCES

1. Tseng, Y.-C., P.-Y. Weng, and T.-L. Wu, "Compact wideband balanced filter for eliminating radio-frequency interference on differentially-fed antennas," *2015 IEEE International Symposium on Electromagnetic Compatibility (EMC)*, 1521–1526, IEEE, 2015.
2. Colín-Beltrán, E., A. Corona-Chávez, T. Itoh, and J. E. Mendoza-Torres, "Circular aperture slot antenna with common-mode rejection filter based on defected ground structures for broad band," *IEEE Transactions on Antennas and Propagation*, Vol. 61, No. 5, 2425-31, May 2013.
3. Li, L. and G. Liu, "A differential microstrip antenna with filtering response," *IEEE Antennas and Wireless Propagation Letters*, Vol. 15, 1983-6, 2016.
4. Cavallo, D., S. Savoia, G. Gerini, A. Neto, and V. Galdi, "Design of a low-profile printed array of loaded dipoles with inherent frequency selectivity properties," *Proceedings of the 5th European Conference on Antennas and Propagation (EUCAP)*, 807–811, IEEE, 2011.
5. Mansour, G., M. J. Lancaster, P. S. Hall, P. Gardner, and E. Nugoolcharoenlap, "Design of filtering microstrip antenna using filter synthesis approach," *Progress In Electromagnetics Research*, Vol. 145, 59–67, 2014.
6. Wu, W.-J., Y.-Z. Yin, S.-L. Zuo, Z.-Y. Zhang, and J.-J. Xie, "A new compact filter-antenna for modern wireless communication systems," *IEEE Antennas and Wireless Propagation Letters*, Vol. 10, 1131–1134, 2011.
7. Escobar, A. H., J. A. V. Tirado, J. C. C. Gómez, J. M. Mateu, E. R. Cantenys, and J. L. V. González, "Filtenna integration achieving ideal Chebyshev return losses," *Radioengineering*, Vol. 23, No. 1, 362–368, 2014.
8. G.-Shiue, G.-H., J.-H. Shiu, and P.-W. Chiu, "Analysis and design of crosstalk noise reduction for coupled striplines inserted guard trace with an open-stub on time-domain in high-speed digital circuits," *IEEE Transactions on Components, Packaging and Manufacturing Technology*, Vol. 1, No. 10, 1573–1582, 2011.
9. Kaur, M., S. Kakar, and D. Mandal, "Electromagnetic interference," *Proc. 3rd Int. Conf. Electronics Computer Technology*, Vol. 4, 1–5, Apr. 2011.
10. Bogatin, E., *Signal Integrity-Simplified ser. Modern Semiconductor Design Series*, Englewood Cliffs, Prentice Hall, NJ, USA, 2004.
11. Li, X. B., M. J. Zhao, Z. H. Wu, and B. Li, "A high-linearity fully-differential mixer," *Proceedings of the International Conference of Electron Devices and Solid-State Circuits (EDSSC)*, 1–2, 2011.
12. Zeng, H. Y., G. M. Wang, D. Z. Wei, and Y. W. Wang, "Planar diplexer using composite right-/left-handed transmission line under balanced condition," *Electron Lett.*, Vol. 48, 104–106, 2012.
13. Wadefalk, N., P.S. Kildal, and H. Zirath, "A low noise integrated 0.3–16 GHz differential amplifier for balanced ultra wideband antennas," *Proceedings of the IEEE Compound Semiconductor Integrated Circuit Symposium (CSICS)*, 1–4, 2010.
14. Arbelaez, N. A., C. J. L. Olvera, P. J. A. Escobar, and C. A. Corona, "A novel via-free microstrip balanced-to-balanced diplexer for narrow-band applications," *Microwave and Optical Technology Letters*, Vol. 57, No. 3, 567-70, Mar. 1, 2015.
15. Arbelaez-Nieto, A., A. Corona-Chavez, J. L. Olvera-Cervantes, and C. E. Saavedra, "Active CMOS differential filter with +3.5 dBm IP 1 dB and +12.3 dBm IIP 3," *Microwave Conference (LAMC), IEEE MTT-S Latin America*, 1–3, IEEE, Dec. 12, 2016.

16. Li, L. and G. Liu, "A differential microstrip antenna with filtering response," *IEEE Antennas and Wireless Propagation Letters*, Vol. 15, 2016.
17. Hu, H.-T., F.-C. Chen, J.-F. Qian, and Q.-X. Chu, "A differential filtering microstrip antenna array with intrinsic common-mode rejection," *IEEE Transactions on Antennas and Propagation*, Vol. 65, No. 12, Dec. 2017.
18. Chen, X., B. Li, M. Zhang, and X.-Q. Sheng, "A novel deferentially fed microstrip integrated-antenna-filter," *IEEE International Conference on Microwave Technology and Computational Electromagnetics*, 134–136, 2013.
19. Matthaei, G. L., L. Young, and E. M. Jones, "Design of microwave filters, impedance-matching networks, and coupling structures," Vol. 2, Stanford Research Inst Menlo Park CA, 1963.
20. Hong, J. S. and M. J. Lancaster, *Microstrip Filters for RF/Microwave Applications*, John Wiley & Sons, Apr. 7, 2004.
21. Alonso, C.-C., J. L. Olvera-Cervantes, and C. E. Saavedra, "Balanced filter with parallel resonances for very wide band common mode rejection," *Journal of Electromagnetic Waves and Applications*, Vol. 29, No. 8, 1060–1067, 2015.
22. Sonnet EM Full-Wave Simulator, v. 11.54, Sonnet Software Inc., NY, USA.
23. Arbelaez-Nieto, A., E. Cruz-Perez, J. L. Olvera-Cervantes, A. Corona-Chavez, and H. Lobato-Morales, "The perfect balance-a design procedure for balanced bandpass filters [application notes]," *IEEE Microwave Magazine*, Vol. 16, No. 10, 54–65, USA, Nov. 2015.
24. Keysight Fieldfox N9917A.