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Compact microwave devices on a flexible substrate

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Abstract

This paper presents compact designs of microwave devices on a flexible substrate. Flexible substrates allow you to design conformal devices and reduce the dimensions of common printed designs. We show the layouts of a compact bandpass filter and a directional coupler produced with this technology and evaluate its effect on the resulting characteristics of devices. In addition to the simulation results, experimental parameters of device prototypes are shown.

1 Introduction

Filters are essential for all kinds of RF devices: IoT nodes, cellular communication, satellite networks, etc. Bandpass filters (BPF) are the most common filters from all filter classes, as they determine the selectivity of the receiving device (for example, selectivity on the adjacent channel). The main function of the BPF is to ensure signal transmission in a certain frequency band and suppress signals outside this band. Many researchers wrote about different filters design, such as hairpin filter, filter on coupled lines, stub filter, etc. Printed directional couplers are widely used in beamforming circuits to split input power between its arms with some ratio. The operating frequency determines the size of the device and the area it occupies - the lower the frequency, the larger the occupied area. In this regard, it is often necessary to look for structural and technological methods to reduce the dimensions of such devices. Today in the IEEE Xplore you can find a large number of works related to the miniaturization of microwave devices, for example [1–13]. In this article, we will present a study of two microwave devices made using flexible substrates [14], [15].

2 Layout

All devices were designed using polyimide film AP9151R with a height of 125 μm, $\varepsilon = 3.4$ and $\tan \delta = 0.004$. The center frequency of the filter is 1 GHz. The input and output impedance is 50 Ohms. Fig. 1 show the layout of the proposed filter.

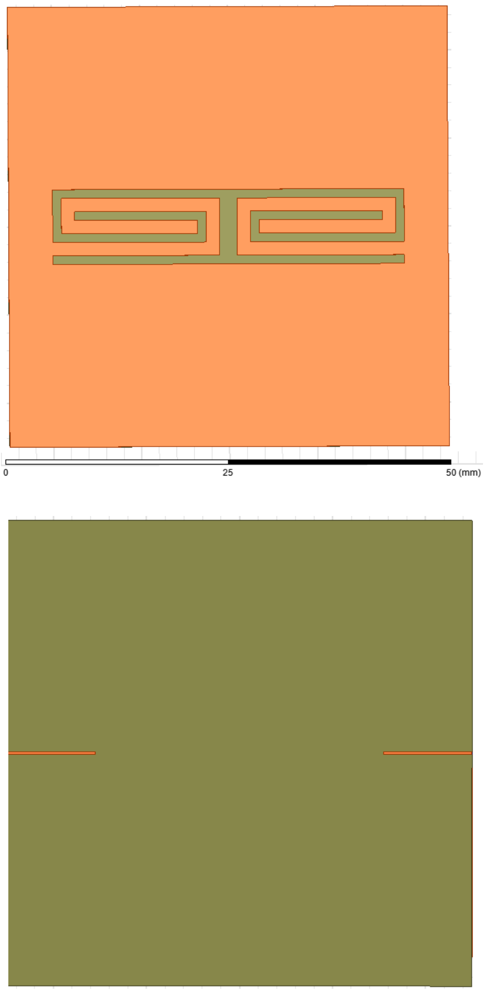

Figure 1. Top and bottom side of the bandpass filter.

The design consists of two half-wavelength segments of the transmission line twisted in a spiral. These spirals implement two identical coupled resonators of the filter. To obtain the best matching on the filter input, it is necessary to choose the location of the input and output paths. Input lines and resonators are on opposite sides of the substrate. Due to this configuration, it is possible to obtain a filter that occupies a small area on the substrate. The principle of operation of such a filter is the same as that of any other band-pass filter. In the passband, the filter resistance has a purely active input and output resistance, respectively equal to the resistance of the generator and the load. In the stopband, the filter has capacitive or inductive impedance and reflects power. The frequency response of the filter obtained after electrodynamic analysis in the specialized software ANSYS HFSS is shown in Fig. 2.

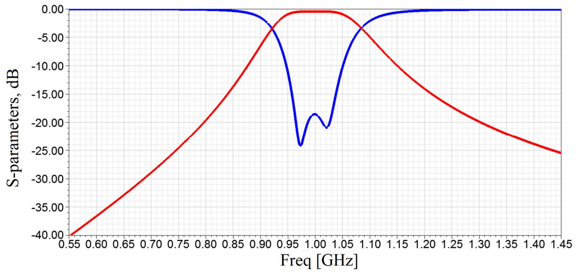

Figure 2. Frequency response of a bandpass filter.

The obtained characteristics showed that the filter with rectangular spirals operates at a central frequency of 1 GHz. The bandwidth, defined as 3 dB of the minimum loss level, is 164 MHz (FBW 16.4%). The minimum loss in the passband is -0.47 dB. The reflection coefficient at the center frequency is -18.5 dB. The area of such a device is 50 x 50 = 2500 mm^2. Fig. 3 presents the layout of a compact branch-line coupler. It was developed in the AWR Design Environment for a central frequency of 2 GHz and on the same substrate as the filter. The area of the compact coupler is 10.65 x 7 = 74.55 mm^2. For comparison, the standard design of such a coupler occupies an area of 23.1 x 23.1 = 533.61 mm2 - this is 86% more than the compact design. Fig. 4 shows the characteristics of coupler.

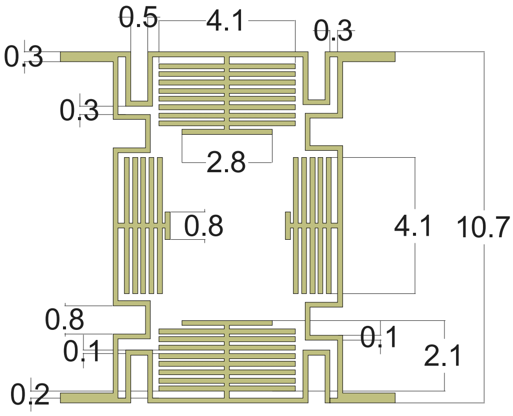

Figure 3. Compact coupler design.

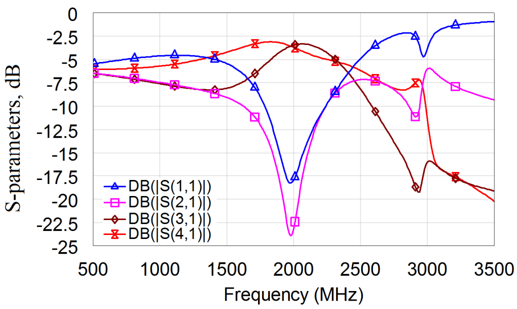

Figure 4. Frequency characteristics of a compact coupler.

According to the results obtained, it is clear that the maximum isolation level is at a frequency of 2 GHz. The bandwidth calculated by the decoupling level of -20 dB is 116 MHz. Miniaturization has led to amplitude imbalance, which resulted in a very narrow frequency band.

3 Parameter Measurement

Prototypes of the devices (Fig. 5, 7) under consideration were produced to test the performance. We obtained frequency responses of the manufactured devices using a high-precision vector network analyzer Rohde & Schwarz ZVA & 24 (Fig. 6, 8).

Figure 5. Top and bottom side of the bandpass filter.

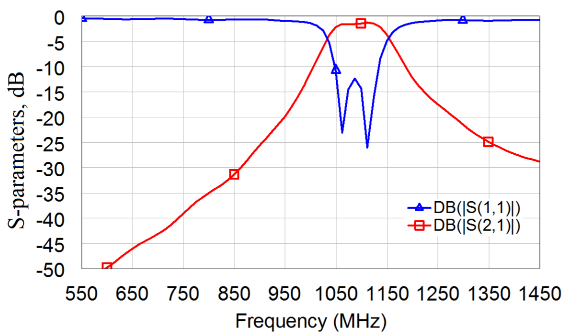

Figure 6. S-parameters from the frequency.

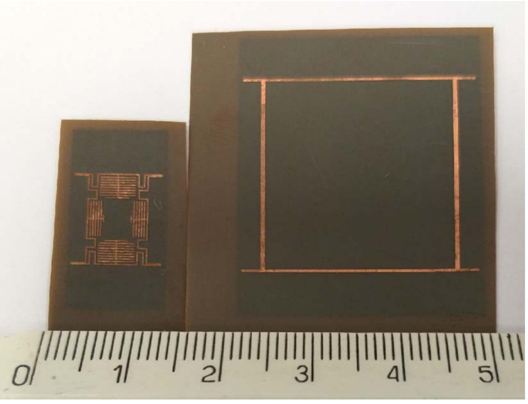

Figure 7. Compact coupler topology.

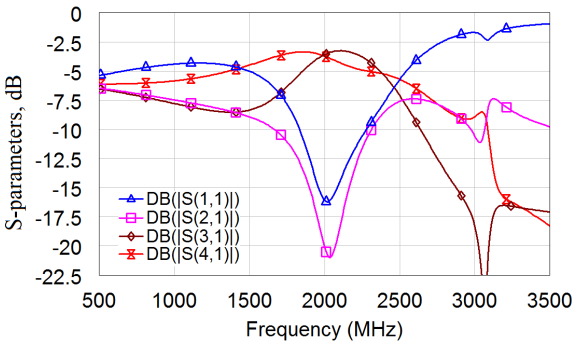

Figure 8. Measured frequency characteristics of a compact coupler.

The center frequency of the filter prototypes is 1090 MHz and the bandwidth is 122 MHz (FBW 11%). The minimum loss in the band is -1.56 dB and the reflection coefficient at the center frequency is -13.5 dB. The coupler operates at a frequency of 2040 MHz. The bandwidth calculated by the decoupling level of -20 dB is 80 MHz. Due to the phase and amplitude imbalance of the manufactured device the operating frequency band is even narrower than that of the simulated one.

4 Conclusions

The designs of compact microwave devices on flexible substrate are investigated. Spiral resonators on a flexible substrate were used to design a bandpass filter with a central frequency of 1090 MHz and a FBW of 11%. The area of such a device is 50 x 50 = 2500 mm2. In addition, we designed a compact coupler, whose area is 86% less than that of a standard coupler, but the bandwidth is rather small (80 MHz).

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7 References

1. C.-Y. Hung, M.-H. Weng, S.-W. Lan, and C.-Y. Huang, “Design of a Wide-Stopband Bandpass Filter by Using Different Feeding Positions of the I/O Ports,” Journal of Electromagnetic Waves and Applications, vol. 26, no. 1, pp. 12–23, Jan. 2012, doi: 10.1163/156939312798954919.

2. S. Vegesna and M. A. Saed, “Compact Two-Layer Microstrip Bandpass Filters Using Broadside-Coupled Resonators,” Progress In Electromagnetics Research, vol. 37, pp. 81–102, 2012, doi: 10.2528/PIERB11101708.

3. J.-Q. Liu, J.-Y. Jin, and J. L.-W. Li, “A Miniature Bandpass filter with split ring resonator and asymmetrical coupled lines,” in 2013 International Conference on Communications, Circuits and Systems (ICCCAS), Chengdu, China, 2013, pp. 425–427, doi: 10.1109/ICCCAS.2013.6765373.

4. V. Rathore, S. Awasthi, and A. Biswas, “Design of compact dual-band bandpass filter using frequency transformation and its implementation with Split Ring Resonator Dual-band bandpass filter using SRR,” in 2014 44th European Microwave Conference, Rome, 2014, pp. 949–952, doi: 10.1109/EuMC.2014.6986593.

5. A. K. Horestani, M. Duran-Sindreu, J. Naqui, C. Fumeaux, and F. Martin, “Coplanar Waveguides Loaded with S-Shaped Split-Ring Resonators: Modeling and Application to Compact Microwave Filters,” Antennas Wirel. Propag. Lett., vol. 13, pp. 1349–1352, 2014, doi: 10.1109/LAWP.2014.2337913.

6. B. A. Belyaev, A. M. Serzhantov, Ya. F. Bal’va, An. A. Leksikov, and R. G. Galeev, “A new design of a miniature filter on microstrip resonators with an interdigital structure of conductors,” Tech. Phys. Lett., vol. 41, no. 5, pp. 504–507, May 2015, doi: 10.1134/S1063785015050193.

7. S.-R. Wu, K.-W. Hsu, and W.-H. Tu, “Compact wide-stopband microstrip bandpass filter-based on stub-loaded stepped-impedance resonators,” IET Microwaves, Antennas & Propagation, vol. 6, no. 13, pp. 1422–1428, Oct. 2012, doi: 10.1049/iet-map.2012.0257.

8. S. A. Khodenkov and B. A. Belyaev, “Microstrip broadband filters based on the multimode resonator,” in 2014 24th International Crimean Conference Microwave & Telecommunication Technology, Sevastopol, Ukraine, 2014, pp. 574–575, doi: 10.1109/CRMICO.2014.6959533.

9. Young-Hoon Chun and Jia-Sheng Hong, “Design of a compact broadband branch-line hybrid,” in IEEE MTT-S International Microwave Symposium Digest, 2005., Long Beach, CA, USA, 2005, pp. 997–1000, doi: 10.1109/MWSYM.2005.1516833.

10. W.-L. Chang, T.-Y. Huang, T.-M. Shen, B.-C. Chen, and R.-B. Wu, “Design of Compact Branch-Line Coupler with Coupled Resonators,” in 2007 Asia-Pacific Microwave Conference, Bangkok, Thailand, 2007, pp. 1–4, doi: 10.1109/APMC.2007.4555113.

11. V. K. Velidim and A. Bhattacharya, “Miniaturized Planar 90° Hybrid Coupler with Unchanged Bandwidth Using Single Characteristic Impedance Line,” in 2008 China-Japan Joint Microwave Conference, Shanghai, China, 2008, pp. 396–399, doi: 10.1109/CJMW.2008.4772454.

12. Shry-Sann Liao, Pou-Tou Sun, Nien-Chung Chin, and Jen-Tee Peng, “A novel compact-size branch-line coupler,” IEEE Microw. Wireless Compon. Lett., vol. 15, no. 9, pp. 588–590, Sep. 2005, doi: 10.1109/LMWC.2005.855378.

13. Jianzhong Gu and Xiaowei Sun, “Miniaturization and harmonic suppression rat-race coupler using C-SCMRC resonators with distributive equivalent circuit,” IEEE Microw. Wireless Compon. Lett., vol. 15, no. 12, pp. 880–882, Dec. 2005, doi: 10.1109/LMWC.2005.859980.

14. D. A. Letavin, “Compact microstrip three-loop coupler,” in 2017 International Applied Computational Electromagnetics Society Symposium - Italy (ACES), Florence, 2017, pp. 1–2, doi: 10.23919/ROPACES.2017.7916036.

15. D. A. Letavin and V. A. Chechetkin, “Miniature microwave bandpass filter with two circular spiral resonators,” in 2016 International Conference on Advances in Computing, Communications and Informatics (ICACCI), Jaipur, India, 2016, pp. 2315–2317, doi: 10.1109/ICACCI.2016.7732399.