# INTEGRATED MULTI-ROLE MICROWAVE ANTENNAS AND PASSIVE CIRCUITS

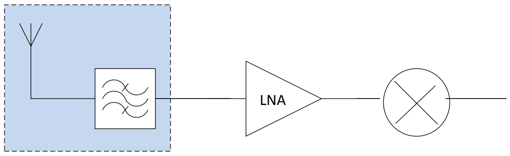
**Yi Wang**

Department of Engineering Science, University of Greenwich (Medway campus), ME4 4TB, U.K.

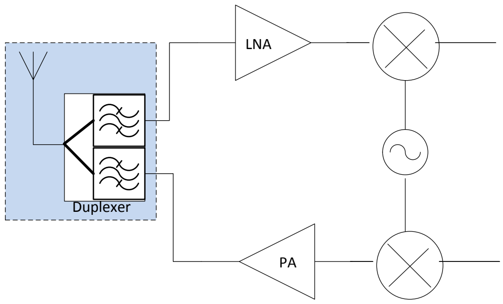
*This paper discusses a relatively new microwave device concept - the so-called multi-role devices where multiple circuit functions are combined and integrated in a single component. This could mean the merge of passive devices such as filters and power dividers, the co-design of passive and active circuits such as filters and amplifiers, or the integration of passive circuits with antennas. In most cases, one of the concerned circuit function is filtering. Various circuit technologies have been developed to absorb the filtering functions into other devices in the RF front ends. Among many potential benefits from the function integration is the circuit miniaturisation. This paper focuses on two technologies that have been in the research front in the past few years: integrated and co-designed filtering antennas and multi-port filtering networks.*

## INTRODUCTION

RF front ends use filters for various purposes from frequency selection, harmonic rejection to interference mitigation. Low insertion loss of the filters is often highly desired. But this is usually a trade off with the size of the filters especially for those based on transmission lines and resonators [1]. High-performance microwave filters are relatively bulky and difficult to be integrated and therefore occupy significant circuit areas. This trade-off also applies to some other important but relatively bulky passive components such as power dividers and couplers as well as antennas. Although the frequency selectivity of the front end largely depends on filters, other constituent components are usually narrow band or band-limited due to the distributed effect of transmission lines. Many antennas are essentially resonators themselves. The narrow-band nature of passives and antennas renders the opportunity for microwave engineers to utilise the frequency-selective responses of traditionally non-filtering components for the purpose of filtering. Existing circuit theories allow this realisation without too much complexity. For instance, the quarter-wavelength transmission lines in many microwave circuits can be substituted for by resonators and their couplings as impedance or admittance inverters [1]. In this background, various circuit technologies have been proposed, researched and developed for multi-role devices, the integration of filtering in other traditionally non-filtering passive, actives devices and antennas in particular. This paper will discuss two types of functionally integrated circuits. They are integrated filtering antennas and multi-port filtering networks concerning filtering power dividers and all-resonator-based multiplexers.

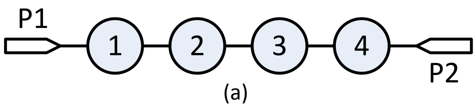



(a)

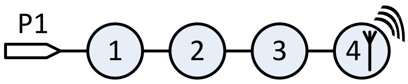



(b)

Figure 1. A receiver (a) and a transceiver (b) front end where its antenna and pre-selection filter or duplexer can be integrated and co-designed.




(a)



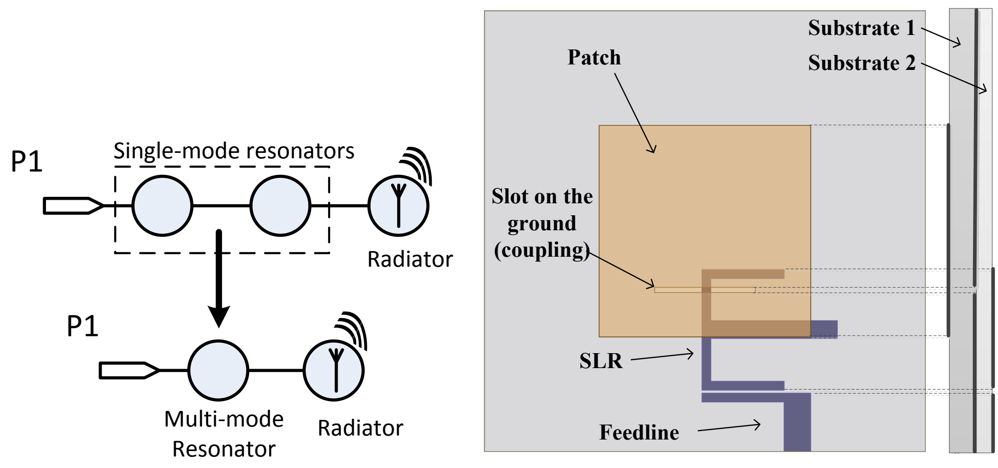

(b)

Figure 2. The approach of seamless integration between a coupled-resonator filter and a resonant antenna. (a) Coupling topology of a coupled-resonator filter; (b) Coupling topology of a filtering antenna that has the same order of filtering characteristics as (a).

# INTEGRATED FILTERING ANTENNAS

As illustrated in Figure 1, when an antenna is followed by a pre-selection filter in a receiver or by a duplexer in a frequency duplexing transceiver front end, an integrated filtering antenna can be used. Instead of referring to the proximity or vertical cascade of an antenna and a filter, which has merit in circuit miniaturisation in its own right, this paper focuses on an approach that seamlessly integrates the filtering and radiation function into an inseparable single device – a filtering antenna. This approach is most applicable to radiation elements that resonate with a narrow bandwidth, such as patch, dipole, monopole, and slot antennas.

Figure 2(a) illustrates the topology of a coupled-resonator filter. As an example, it is a fourth order filter formed of four resonators. It is plausible to replace one or more of the resonators with one or more resonant radiation elements and expect the same order of filtering characteristics from the topology shown in Figure 2(b) while generating radiation at the same time. Indeed, one of the first papers demonstrating this integration method reported a 2nd-order filtering antenna where an L-shaped half-wavelength resonator coupled with a patch antenna through a capacitive gap [2].

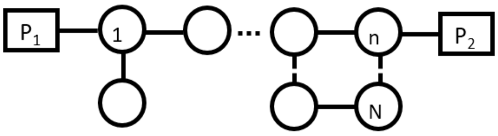



(a) (b)

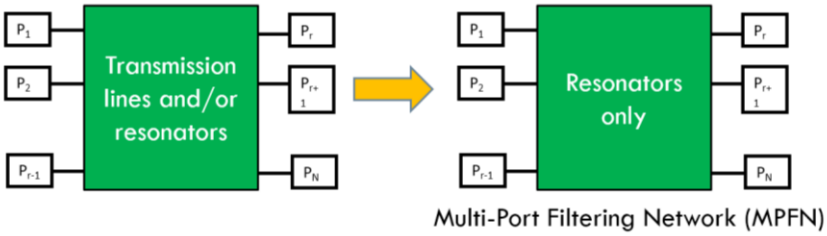
Figure 3. A 3rd-order integrated filtering antenna. (a) Coupling topology; (b) Circuit layout.

In the past few years (the last two years in particular), filtering antennas have attracted a lot of interests from both academia and industry. Many different integration schemes and circuit technologies have been developed. Figure 3 shows a 3rd-order integrated filtering antenna where two poles of the filtering characteristics are from a dual-mode stub-loaded resonator (SLR) and one pole from the resonant patch. The SLR is the E-shaped resonator in Figure 3(b). The SLR is electromagnetically coupled with the patch through a slot on the shared ground plane between the patch and the resonators. The feedline is edge-coupled to the SLR. As can be seen, the coupling techniques, widely used in conventional filter designs, are adopted here in the co-design of the filtering antenna. The resonator becomes an integral and inseparable part of the antenna, serving as the impedance matching circuit. 50-ohm interfaces between the traditionally cascaded filter and antenna are no longer needed. The mismatching and performance degradation issues associated with the cascaded configuration are eliminated. From the reflection response $S_{11}$, a 3rd-order filtering response can be observed [3]. From the gain curve as a function of the frequency, a flat gain response has been achieved across the operation bandwidth with a sharper roll-off at the band edges, as compared with traditional patch antennas. These are some of the typical performance features from an integrated filtering antenna employing electromagnetic couplings.

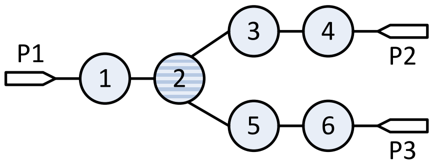
Using the coupled-resonator structures, wideband antennas as well as multiband antennas [4] have been demonstrated. Wideband harmonic suppressed can be achieved [5]. Filtering functions have been integrated not only in antenna elements but also in arrays [6] with single [7] as well as dual [8] polarisations. In terms of antenna types, apart from patches, dipoles [9], slot antennas [10] and dielectric antennas [11] with integrated filtering functions have been reported. An integrated duplex antenna with the combined duplexer and antenna under a tight footprint has also been reported [12].




(a)




(b)




(c)

Figure 4. An illustration of (a) the topology of a two-port coupled-resonator filter; (b) the concept of multi-port filtering network (MPFN). (c) An example 3-port filtering network representing either a two-way filtering power divider or a duplexer/diplexer.

# MULTI-PORT FILTERING NETWORKS

In [13], a filtering antenna array was realised by embedding a fourth-order filtering function in a four-way power divider (the feeding network of the array). Different from traditionally transmission-line based power dividers, the filtering power divider was formed exclusively of coupled resonators. It is essentially a multi-port filtering network. The concept of multi-port filtering network (MPFN) is an extension from the conventional two-port coupled-resonator filters (Figure 4a) to multiple ports (Figure 4b). It has been established that a coupling matrix can be used to represent such a network and relate to S-parameters in a similar way as in two-port filters. The key difference between a MPFN and a filter is the 'junction resonator' (e.g. the resonator-2 in Figure 4c). It is used not only to generate a resonant pole but also to split the signal as is conventionally achieved by a transmission-line junction. This concept has found applications in multi-port signal distribution networks such as power dividers, couplers, and multiplexers. These traditionally transmission-line based passive networks can be implemented solely using resonators through electromagnetic couplings.

One of the circuits that benefits most from the MPFN concept is a multiplexer, a complex passive circuit used to combine multiple channels to share a common antenna. Conventionally between the common antenna and the channel filters, signals are distributed through a hybrid branching network or manifold. Such networks occupy space but do not contribute to the poles of the filter (selectivity). Replacing these networks with a single junction resonator or a cluster of junction resonators [14,15] offers significant potential in circuit miniaturisation and performance enhancement. The MPFN concept has also led to other passive circuits with integrated filtering functions. For instance, replacing the quarter-wavelength transmission-lines in a power divider with inter-coupled resonators could result in an embedded Chebyshev filtering function [16,17]. Figure 4(c) can be used to illustrate such a topology. Similarly, integrated filter-couplers and filter-Butler-matrices [18] have been demonstrated.

# CONCLUSION

The integration of passive devices and antennas enables a single component serving multiple functionalities. Various integration schemes and circuit technologies have been proposed and developed for filtering antennas and multi-port filtering networks. Reduced component count and miniaturised circuit footprint are the direct benefit of the integration. The co-design approach also brings new dimensions of controlling the bandwidth, antenna gain and frequency selectivity. Similar integration and co-design approach can also be applied to active devices such as amplifiers [19]. The integration of the functionality also raises challenges to the design and implementation where new design and synthesis approaches are needed.

# REFERENCES

1 J. S. Hong and M. J. Lancaster, Microstrip Filters for RF/Microwave Applications. New York, NY, USA: Wiley, 2001.

2 C. Lin, S. Chung, “A compact edge-fed filtering microstrip antenna with 0.2 dB equal-ripple response,” in 2009 Eur. Microw. Conf., 29 Sept. - 1 Oct. 2009.

3 C. X. Mao, S. Gao, Y. Wang, “Stub-Loaded Resonator-Fed Filtering Patch Antenna with Improved Bandwidth”, 46th European Microwave Conference, pp. 317-320, 2016.

4 C. Mao, S. Gao, Yi Wang, B. SanzIzquierdo, “A Novel Multi-Band Directional Antenna for Wireless Communications”, IEEE Antennas and Wireless Propagation Letters, 2016. 10.1109/LAWP.2016.2628715

5 C. X. Mao, S. Gao, Yi Wang, Z. Cheng, “Filtering antenna with two-octave harmonic suppression”, IEEE Antennas and Wireless Propagation Letters, 2016. 10.1109/LAWP.2016.2636198

6 C. X. Mao, S. Gao, Y. Wang, F. Qin, Q. Chu, “Multi-Mode Resonator-Fed Dual Polarized Antenna Array with Enhanced Bandwidth and Selectivity”, IEEE Trans. Antenna Propagation, vol. 63, no.

12, pp. 5492-5499, 2015.

7 C. Mao, S. Gao, Y. Wang, B. SanzIzquierdo, Z. Wang, F. Qin, Q. Chu, J. Li, G. Wei, J. Xu, "Dual-Band Patch Antenna with Filtering Performance and Harmonic Suppression", IEEE Trans. Antennas and Propag., vol. 64, no. 9, pp. 4074-4077, Sept. 2016

8 C. X. Mao, S. Gao, Yi Wang, Q. Luo, Q. Chu, "A Shared-Aperture Dual-Band Dual-Polarized Filtering-Antenna-Array with Improved Frequency Response", IEEE Trans. Antennas and Propag., 2017. 10.1109/TAP.2017.2670325

9 A. Eltokhy, Y. Wang, "Integrated Filtering Planar Dipole Antenna Using Edge Coupled Feed", Loughborough Antennas and Propagation Conference, 14-15 November 2016.

10 Y. Yusuf, H. Cheng, X. Gong, "A seamless integration of 3-D vertical filters with highly efficient slot antennas", IEEE Trans. Antennas Propag., 59, (11), pp. 4016–4022, 2011.

11 P. F. Hu, Y. M. Pan, X. Y. Zhang and S. Y. Zheng, "A Compact Filtering Dielectric Resonator Antenna With Wide Bandwidth and High Gain," in *IEEE Transactions on Antennas and Propagation*, vol. 64, no. 8, pp. 3645-3651, Aug. 2016.

12 C. X. Mao, S. Gao, Yi Wang, F. Qin, Q. Chu, "Compact Highly Integrated Planar Duplex-Antenna for Wireless Communications", IEEE Trans. Microwave Theory Tech., vol. 64, no. 7, pp. 2006-2013, 2016.

13 C. X. Mao, S. Gao, Yi Wang, Zheng-Peng Wang, Fan Qin, B. Sanz-Izquierdo, Qing-Xin Chu, "An Integrated Filter-Antenna-Array with High Selectivity and Harmonics Suppression", IEEE Trans. Microwave Theory Tech., vol. 64, no. 6, pp. 1798 – 1805, May 2016.

14 X. Shang, Y. Wang, W. Xia, M. J. Lancaster, "Novel Multiplexer Topologies Based on All-Resonator Structures", IEEE Trans. Microwave Theo. Tech., vol. 61, no. 11, pp. 3838-3845, Nov. 2013.

15 Y. Wu, Y. Wang, E. A. Ogbodo, "Microstrip Wideband Diplexer with Narrow Guard Band Based on All-Resonator Structures", 46th European Microwave Conference 2016.

16 A. Mohammed, Y. Wang, "Four-way Waveguide Power Dividers with Integrated Filtering Function", in the 44th European Microwave Conference, Paris, France, Sept. 2015.

17 Y. Lu, G. Dai, Y. Wang, T. Liu and J. Huang, "Dual-Band Filtering Power Divider with Capacitor-Loaded Central Coupled-Line Resonators", IET Microwaves, Antennas & Propagation, vol. 11, no. 1, pp. 36-41, 2017.

18 V. Tornielli di Crestvolant, P. Iglesias, M. Lancaster, "Advanced Butler Matrices With Integrated Bandpass Filter Functions," IEEE Trans. Microw. Theo. Techn., 2015, 63 (10), pp.3433-3444.

19 K. Chen, X. Liu, W. Chappell, D. Peroulis, "Co-design of power amplifier and narrowband filter using high-Q evanescent-mode cavity resonator as the output matching network", IEEE MTT-S Int. Microw. Symp. Dig., June 2011, pp.1-4.