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REVIEW

A review of centrally loaded multimode microstrip resonators for bandpass filter design

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ABSTRACT

The increasing demand for good performance filters in the field of radio frequency and wireless communication leads to the advancement in the design and development of compact microstrip resonator filters. This paper reviews the development of multimode microstrip resonators in recent decade. Half-wavelength open loop resonator is a well-known design approach for a single-mode resonator design, the half-wavelength line can be centrally loaded with an open-circuited stub, a short-circuited stub or a grounded via to form a dual-mode resonator. For symmetrical resonator structure, the resonant frequencies can be analysed using odd- and even-mode analysis. Triple-mode, quadruple-mode, quintuple-mode resonators are considered for wide bandwidth filters. The multimode resonators, in general, can be designed into filter using three different design methods. The first method uses cross-coupling resonators topology. The second method considers the distribution of the fundamental resonant frequencies of the resonator according to the Chebyshev's insertion loss function. The third approach is to design all fundamental resonant frequencies of the resonator to be located within the 3-dB frequencies. All these three design approaches will be reviewed and discussed in this paper. In addition, a design example using the last approach for a fourth-order bandpass filter using a quadruple-mode resonator is given.

1. Introduction

Many applications in telecommunication and wireless technology required compact radio frequency and microwave bandpass filters. Compact microstrip resonators with superior performance are continuously developed to meet the demands. These microstrip resonators can be classified into single-mode and multimode resonators. The single-mode resonator can be categorised into six sub-classes. They are the half-wavelength resonators, quarter-wavelength resonators, stepped impedance resonators, quarter-wavelength stepped impedance resonators, patch resonators and ring resonators. These single-mode resonators are the basic structure for the theory and design method of the lowpass, highpass, bandpass and bandstop filters [1]. N number of single-mode resonators is required for an N-th order filter. One way of reducing the filter size is to use multimode resonators. If each multimode resonator has N modes, the number of resonators in the filter design is reduced by a factor of N. Thus if the dual-mode resonators ($N=2$) are used, the filter size is halved and so on.

Multimode resonators can also be categorised according to the number of resonant modes. They include the dual-mode resonator, triple-mode resonator, quadruple-mode resonators, quintuple-mode resonators and so on. The following sections summarise the design and development of these multimode resonators, from dual-mode (Section 2) to quintuple-mode (Section 5), with emphasis on centrally loaded open loop resonators in recent decade. Section 6 summarises the different design approaches for these compact multimode resonators. Section 7 gives a design example using a compact quadruple-mode resonator, the simulated and measured results are in good agreement.

2. Dual-mode resonators

As reported by Matsuo et al. [2], conservative dual-mode resonators have the following common design approaches:

1. There must be at least a 90° separation between the input and output ports,
2. The resonator should have a discontinuity/perturbation to generate a reflected wave against an incident wave in the resonator, and

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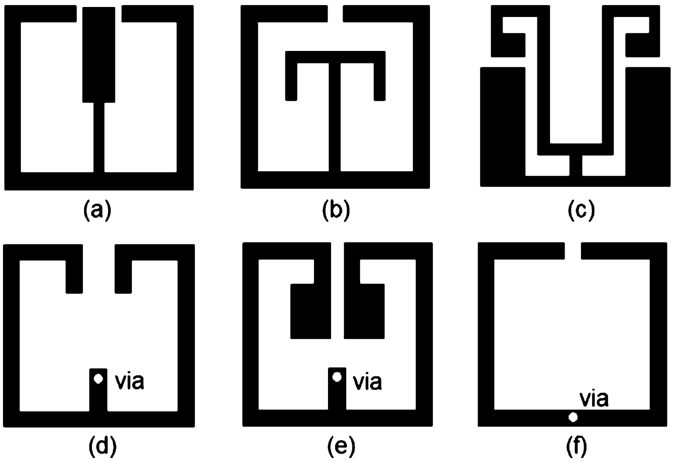

Fig. 1. Open-loop resonators centrally loaded with (a) stepped impedance open-circuited stub [12], (b) T-shaped open-circuited stub [13], (c) Y-shaped open-circuited stub [14], (d) short-circuited stub [16], (e) short-circuited stub [17], and (f) grounding via [19].

3. The resonator must be symmetric.

In a later development, the dual-mode resonators can be further classified into dual-mode patch or ring resonators with perturbation and dual-mode centrally loaded open loop resonators (Fig. 1). Ring or patch resonators can be perturbed by adding stubs or cuts onto the symmetrical plane of the resonators. The most common design is to add open circuited stub(s) on ring resonators with the input and output ports are 90° in separation [3]. This will split the fundamental resonant frequency into two. The ring resonators can be meandered [4] to decrease the size of the filter. Dual-mode ring resonators are designed with defected grounding structure [5] and T-shaped coupling feed structure to improve the stopband response [6,7]. Dual-band filters can be designed by stacking two ring resonators on top of each other using multilayer of substrates [8]. Complement split-ring resonator defected ground structures are implemented on the grounding surface of the dual-mode ring resonator microstrip filter to design a dual-band filter to improve passband selectivity [9]. Dual-mode ring resonator designed with composite-right/left hand transmission lines was proposed by [10].

The basic structure of the dual-mode centrally loaded open-loop resonator is a half-wavelength open loop resonator. The half-wavelength open loop resonator is then centrally loaded with an open-circuited stub, a short-circuited stub or a grounded via (Fig. 1). The centrally loaded element creates a grounding plane along the symmetrical plane of the resonator in odd mode condition, hence splitting the resonant frequency into two. The open-circuited stub has various shapes. They include uniform impedance stubs [11], stepped impedance stubs [12], T-shaped stubs [13], Y-shaped stubs [14], and Q-shaped stubs [15]. The short-circuited elements consist of a uniform impedance stub with grounding via [16,17], a grounding via only [18,19], a resistor with a grounding via at the short-circuited side [20] and others.

The advantages of centrally loaded dual-mode resonators are simple structures and the resonant frequencies can be controlled easily or can be made into tuneable filters [13,16]. The dual-mode resonators also halved the filter footprint. Besides, two of these resonators can be coupled for the design of fourth order bandpass filter [13]. If the filter design requires three resonant frequencies for the formation of the passband, either a dual-mode resonator coupled with a single-mode resonator [11] or a triple-mode resonator can be used for the filter design.

3. Triple-mode resonators

Triple-mode microstrip resonators are categorised into patch or ring resonators with perturbation(s) and centrally loaded open loop resonators (Fig. 2). The patch or ring resonators designs follow the design guidelines as stated by Matsuo et al. [2], similar to the dual-mode resonators. Disc patch resonator with two pairs of etched slots [21] degenerates and perturbs the fundamental mode frequency of the resonator to generate three mode resonant frequencies. Two branch-lines are added to a ring resonator [22] to realise a triple-mode resonator. Three branch-lines are added into a hexagonal-shaped ring resonator. It is then centrally loaded with capacitive stubs to become a triple-mode resonator [23]. A branch-line is added into the square ring resonator [24] to form another triple-mode resonator. This branch-line can be placed in the diagonal of the square ring resonator and two perturbations are introduced to the symmetrical plane of the resonator to form another triple-mode resonator [25].

Two concentric open-loop resonators [26] will produce three mode resonant frequencies. A straight line resonator can be centrally loaded with a patch to become a three-section stepped impedance triple-mode resonator as proposed by [27]. U-shaped three sections stepped impedance resonator can be centrally loaded with two open-circuited T-shaped stubs to form a triple-mode resonator (Fig. 2(a)) [28]. Three sections stepped impedance resonator can be bent into an open-loop resonator. It is then centrally loaded with an open-circuited T-shaped stub and a short-circuited stub (Fig. 2(b)) [29].

L-shaped resonator can be symmetrically loaded with two capacitive radial-line stubs to realise a triple-mode resonator (Fig. 2(c)) [30]. A triple-mode resonator (Fig. 2(d)) using a U-shaped uniform impedance resonator that is centrally loaded with an open-circuited stub and a short-circuited stub is designed by [31]. The open circuited stub in the resonator [31] can be replaced with a radial-line stub to become the triple-mode resonator (Fig. 2(e)) proposed by [32]. This design is proposed for a tri-band filter since three of the resonant frequencies can be controlled separately. The open-loop resonator can be stretched into a straight line and two open-circuited stubs are located at the symmetry plane of the straight line (Fig. 2(f)) as proposed by [33]. The straight line can be replaced with a U-shaped three sections stepped impedance line [34].

Open loop resonator can be centrally loaded with an open-circuited stub and a grounding via to become a triple-mode resonator as proposed by [35]. The open-circuited stub of this triple-mode resonator [35] can be replaced with an open-circuited stepped impedance stub (Fig. 2(g)) as illustrated in [36]. Deng et al. [37–39] researched a series of work on a triple-mode resonator designed using U-shaped resonator centrally loaded with open-circuited T-shaped stub and two short-circuited stubs.

4. Quadruple-mode resonators

Quadruple-mode resonators (Fig. 3) generally can be classified into four categories according to their structures. (i) Coupled-ring resonators [40,41]. The authors in [40] have designed a concentric ring structure which has an inner ring with two open-circuited stubs (Fig. 3(a)). The two periodic stepped impedance concentric rings with two open loop resonators coupled to the outer ring (Fig. 3(b)) are proposed by [41]. (ii) Five-section stepped impedance resonators (Fig. 3(c)) [42]. (iii) Tri-section stepped impedance resonators with embedded stubs (Fig. 3(d)) [43]. (iv) Centrally loaded quadruple-mode resonators. This resonator has the most illustrated examples.