NOVEL INTERDIGITAL MICROSTRIP BANDPASS FILTER WITH IMPROVED SPURIOUS RESPONSE

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ABSTRACT

In this paper a novel interdigital bandpass filter with under-coupled quarter-wavelength resonators is proposed. With this new structure, the spurious response up to the 3rd harmonic passband can be suppressed significantly whilst the fundamental passband remains unchanged. Also, this design can take full advantage of the traditional interdigital filter design equations. In order to demonstrate the proposed filter performance, a 3rd-order Butterworth interdigital bandpass filter centered @900MHz with 15% fractional bandwidth was designed and implemented using both the proposed and the conventional structure. From the simulation and experimental results, the proposed filter obtains more than 10 dB suppression in average for the entire upper stopband up to the triple of the midband-frequency value, and also 32 dB suppression of the 3rd harmonic spurious passband.

I. INTRODUCTION

For the microstrip bandpass filters with parallel-coupled half-wavelength resonators, the first/second spurious passband is centered at twice/three-times the midband frequency value due to the unequal even- and odd- mode phase velocity. The most popular approach to this unwanted passband elimination is the use of additional filters through cascading. The main disadvantage is related with the fact that this design requires a larger circuitry space and introduces additional insertion losses. To overcome this problem, several methods based on perturbation of the strip-width, such as, stepped-impedance resonator (SIR) [1], wiggly-line [2, 3] and corrugated structure [4], are employed to tackle the 2nd/3rd harmonic passband suppression for parallel-coupled-line bandpass filters.

In contrast to this parallel-coupled-line bandpass filter, the interdigital bandpass filter [5, 6] consists of an array of quarter-wavelength transmission-line resonators, and is short-circuited to ground at one end and open-circuited at the other end with alternative orientation. This implies that its first spurious passband is centered at about 3 times the midband frequency value [5]. Because of the advantage of having smaller size and no 2nd harmonic-passband when compared with the parallel-coupled-line ones, this microstrip interdigital filter structure is much more widely used in modern communication systems, although, its harmonic-passband suppression capability has not yet been intensively explored. Addressing this intrinsic issue, a novel approach of spurious passband suppression based on under-coupled quarter-wavelength resonators is proposed. The design procedure is very simple and does not require the recalculation of the filter parameters that can be determined from the traditional design equations of the conventional structure.

Besides this introductory section, the fundamental of the proposed filter structure will be introduced in section II. In section III, simulation and experimental results of the proposed filter are presented and compared with that of the conventional interdigital microstrip filter. Finally, the conclusions are drawn in section IV.

II. NOVEL INTERDIGITAL MICROSTRIP BANDPASS FILTER

Conventional microstrip coupled-lines support two quasi-TEM modes, i.e. *even mode* and *odd mode*. As shown in Fig. 1, the microstrip conductors are excited with the same voltage potential in the even mode, and with the opposite voltage potential in the odd mode.

For characterizing the coupled microstrip lines, effective dielectric constants, characteristic impedances and phase velocities for the even- and odd-mode can be obtained, respectively as follows [5-7]:

$$\varepsilon_{re,even} = C_{e(d)} \big/ C_{e(a)} \quad \varepsilon_{re,odd} = C_{o(d)} \big/ C_{o(a)} \tag{1}$$

$$Z_{c,even} = \frac{1}{c\sqrt{C_{e(d)} C_{e(a)}}} \quad Z_{c,odd} = \frac{1}{c\sqrt{C_{o(d)} C_{o(a)}}} \tag{2}$$

$$v_{p,even} = \frac{\omega}{\beta} = \frac{c}{\sqrt{\varepsilon_{re,even}}} \quad v_{p,odd} = \frac{c}{\sqrt{\varepsilon_{re,odd}}} \tag{3}$$

where $C_{e(d)}$ ($C_{o(d)}$) is for the even- (odd-) mode capacitance per unit length with dielectric substrate, whilst $C_{e(a)}$ ($C_{o(a)}$) is for the even- (odd-) mode capacitance with the dielectric substrate replaced by air; and c is the speed of light in free space. ($c \approx 3.0\times10^8 m/s$). As shown in Fig.1, the even-mode capacitance C_e and the odd- mode capacitance C_o can be expressed as:

$$C_e = C_p + C_f + C'_f \tag{4}$$

$$C_o = C_p + C_f + C_{gd} + C_{ga} \tag{5}$$

where C_p denotes the parallel plate capacitance between the strip and the ground plane; C_f is the fringe capacitance for an uncoupled microstrip line; and C'_f is the fringe capacitance having the modification due to the presence of another conductor. In the equation of the odd mode capacitance, C_{gd} and C_{ga} represent the fringe capacitance across the coupling gap in the dielectric and air regions, respectively.

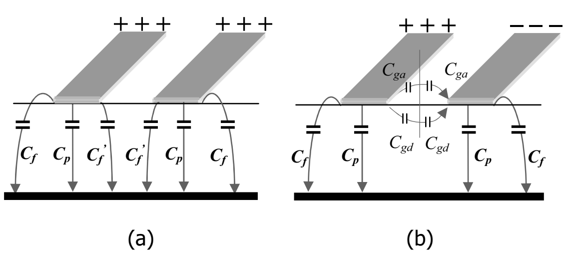


Fig.1 Microstrip coupled lines (a) even mode (b) odd mode.

As there is the air-region fringing capacitance C_{ga} in the odd mode, it can be found that the effective dielectric constant ε_{re} of the odd mode is usually smaller than the even-mode one whilst its phase velocity v_p is always larger. And, it has been reported that the coupled-line microstrip circuit has spurious harmonic passband due to these unequal even- and odd- mode phase velocities. Therefore, the spurious response rejection can be obtained by equalizing the even- and odd mode phase velocities [4, 8].

As depicted in Fig. 2, a new tapped symmetric interdigital bandpass filter based on the under-coupled quarter-wavelength-resonator pair is proposed. This resonator pair is indeed implemented by shifting one of the microstrip conductors by a small distance along the propagation direction.

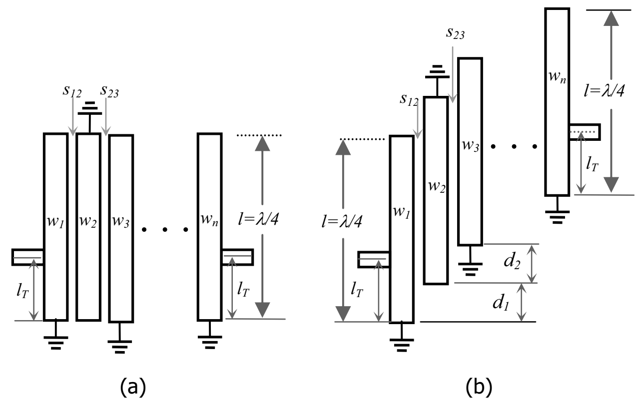


Fig.2 Microstrip interdigital bandpass filter: (a) conventional (b) with under-coupled resonator pair.

With this new filter structure, the conventional interdigital bandpass filter design-method can still be adopted to achieve a fundamental passband response, i.e., the physical parameters l, l_T ,w_i and s_{jk} (where i = 1, 2,…, n; j = 1, 2,…, n-1; k = 2, 3,…, n) are maintained [5, 6]. Then, one of the strips in each pair of adjacent coupled lines is relocated by a distance d_i, (where $1 \le i \le n-1$). With the proposed modification to the conventional interdigital filter structure, the average air-region fringing capacitance C_{ga} per unit length in the odd mode can be reduced. Thus, it is expected that the odd- and even- mode phase-velocities may be equalized at some values of d_i, so as to suppress the spurious response.

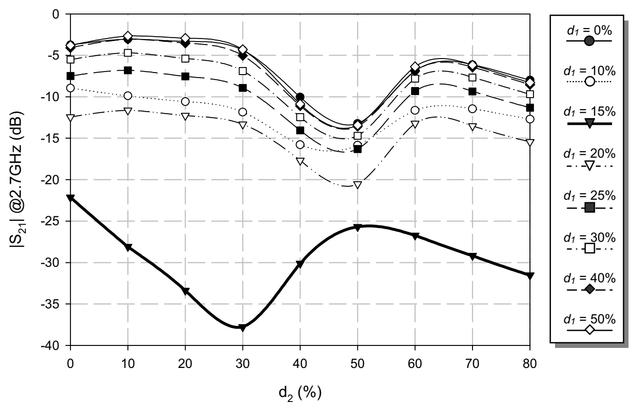
In order to examine the effectiveness of the proposed approach and to design the suitable range for the strip-relocation parameter d_i, a 3rd-order filter centered @900MHz with 15% fractional bandwidth, using the proposed structure, is simulated with different values of d_i, (in terms of the percentage of the strip length, l). The effects of the strip relocation parameters d_1 and d_2 on the $|S_{21}|$ response at the 3rd harmonic frequency and the filter characteristics at the mid-band frequency are depicted in Fig. 3(a) and 3(b), respectively.

For illustration of the effect on the filter mid-band characteristics, subject to various strip-relocation parameters d_1 and d_2, an index A, which is indeed a measure of the difference of the mid-band characteristics between the new structure and the conventional one, it is possible to define:

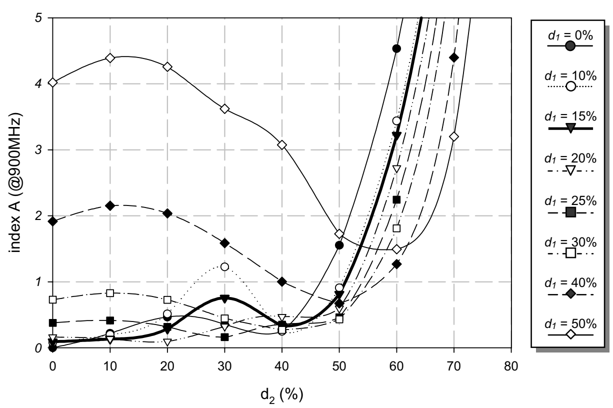
$$A = \sqrt{(1-\frac{|S_{21}|'}{|S_{21}|_O})^2 + (1-\frac{|S_{11}|'}{|S_{11}|_O})^2 + (1-\frac{FBW'}{FBW_O})^2} \tag{6}$$

where $|S_{21}|_o$, $|S_{11}|_o$ and FBW_o are, respectively, the $|S_{21}|$ response, $|S_{11}|$ response and the fractional bandwidth of the conventional structure (i.e. $d_1 = d_2 = 0$), while $|S_{21}|'$, $|S_{11}|'$ and FBW' correspond to the structures modified by various strip-relocation parameters.

As shown in Fig. 3(a), an outstanding attenuation (22dB to 36 dB) can be obtained at the 3rd harmonic frequency when d_1 is 15%. Besides, it is found in Fig. 3(b) that the filter characteristics are significantly altered (A is larger) when d_2 is increased. In order to suppress the spurious response up to the 3rd harmonic spurious passband as well as maintaining the original filter characteristics at the fundamental passband, d_1 is chosen as 15% whilst the d_2 can be selected between 0% to 20%, according to the trade-off between spurious response suppression and filter fundamental passband characteristics.



(a) $|S_{21}|$ at 3 times the mid-band frequency value



(b) Alteration of the filter characteristics at mid-band frequency

Fig.3 Effect of the modification parameters d_1 and d_2. on the fundamental passband characteristics and 3rd harmonic passband suppression.

III. SIMULATIONS AND MEASUREMENTS

To demonstrate the spurious passband suppression capability of the proposed filter structure, especially of the upper stopband up to the 3rd harmonic frequency, a 3rd-order Butterworth bandpass filter centred @900MHz with 15% FBW using both the proposed and the conventional interdigital filter structure is designed and simulated with the MoM-based EM simulation package [9]. These two microstrip filters are implemented on the Roger RO4003 substrate with relative dielectric constant ε_r =3.38 and thickness h=1.524 mm. Conventional interdigital filter layout parameters are evaluated subject to the above specification and the traditional design equations. Based on the analysis in section II, the proposed filter is firstly designed by choosing d_1=15% *and* d_2=10% of strip length. Then, with the built-in optimizer of the EM simulator, an optimal response is achieved when d_1=8.55 mm and d_2= *6.18* mm, for the strip length of *54.37* mm.

Fig. 4 shows the S-parameters simulation of the above filters. It is obvious that the proposed filter has suppressed the spurious response up to the 3rd harmonic passband, and a 25 dB reduction is achieved at the 3rd harmonic frequency. Also, the filter matching is maintained at 20 dB.

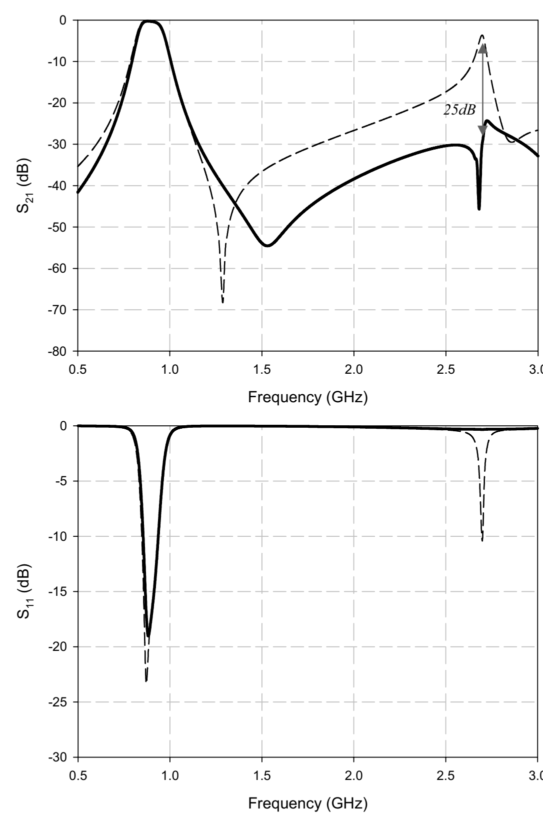


Fig.4 Simulated $|S_{21}|$ and $|S_{11}|$ parameters for a conventional interdigital 3rd order microstrip bandpass filter centered at 900MHz with a 15% FBW (thin dashed line), and for the proposed structure (thick solid line).

In addition, the above two filters were implemented and measured. Their experimental S-parameters are depicted in Fig. 5; where it can be seen that the filter transfer characteristics in the entire upper stopband up to the 3rd harmonic frequency value is reduced to a level lower than -30dB and the 3rd harmonic passband is suppressed by 32 dB. The proposed filter matching is about 12 dB. As such, this confirms the proposed filter feasibility and optimized performance. Fig. 6 shows the photograph of the prototype filter with a dimension of about 70 mm by 30 mm.

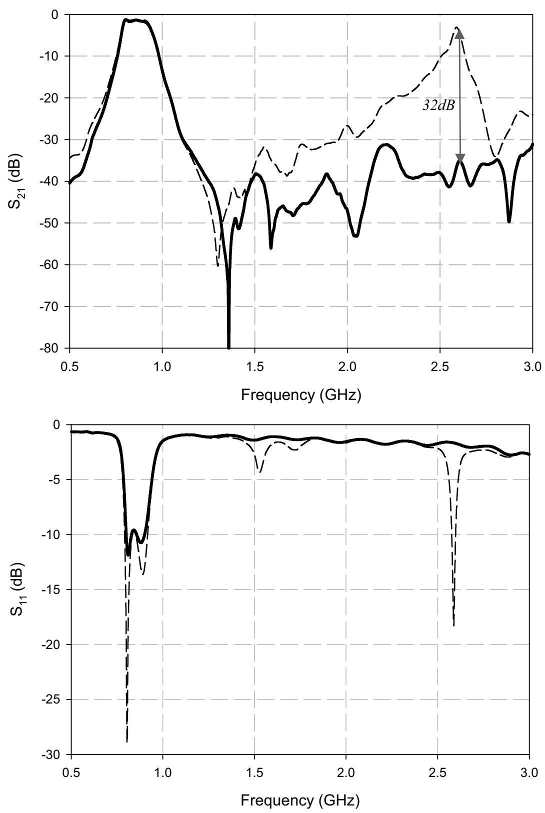


Fig.5 Measured $|S_{21}|$ and $|S_{11}|$ parameters for a conventional interdigital 3rd order microstrip bandpass filter centered at 900MHz with a 15% FBW (thin dashed line), and for the proposed structure (thick solid line).

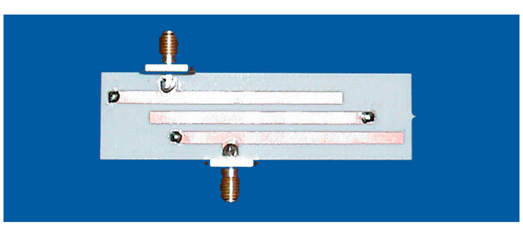


Fig.6 Photograph of the proposed microstrip interdigital filter.

IV. CONCLUSIONS

A novel interdigital microstrip bandpass filter based on under-coupled quarter-wavelength resonator pair has been proposed to suppress the spurious response at the upper stopband. In order to validate this novel filter, two prototype microstrip filters @900MHz with 15% FBW, using the proposed novel and the conventional structures were designed and experimentally characterized. It has been reported that the new filter offers improved spurious response by having the upper stopband up to the 3rd harmonic frequency attenuated by a value close to 30 dB. This new method offers additional flexibility and improved performance in conventional interdigital filter design.

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