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Microstrip Dual-Band Bandpass Filter Fed with Lumped Capacitors

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Abstract

This paper presents a method of designing microstrip dual-band bandpass filter fed with lumped capacitors. Unlike the tapping or coupling feeding structures, the lumped capacitors could make the external quality factors have suitable values in two different pass bands. Thus no impedance transformers are needed when designing dual-band bandpass filter fed with lumped capacitors. An example of this kind of filter is designed, fabricated and measured. The measured results accord well with the simulated results, showing validity of the proposed method.

Index Terms: Dual band, bandpass filter, capacitor.

1. Introduction

Because of the rapid development of modern wireless and mobile communication systems, multi-band microwave devices have attracted gradually increased attentions. Among these devices, dual-band bandpass filters (BPFs) are essential ones which have already been used in so many applications [1-4]. There are several methods to design dual-band bandpass filters. A direct method is to compose a dual-band BPF with two distinctive BPFs which operate at different frequency bands respectively [5]. Another method is to have dual-band responses by constructing suitable coupling matrix. The coupling matrix can be obtained by direct optimization [6-7] or by frequency transformation [8]. The third method is to use dual-frequency resonators, such as stepped- impedance resonators [9], embedded resonators [10-11], stub loaded resonators [12-13]. Since the two frequency responses are all dependent on the same physical structures, tuning one frequency band may affect the other frequency band.

For example, if determined filter structures have suitable external quality factors at one frequency band, they

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usually can't have suitable external quality factors at the other frequency band. If the higher center frequency is two times the lower center frequency, impedance transformers could be used to have suitable external quality factors at two frequency bands [14]. However, the impedance transformers will make the size of the whole filter become larger.

In this paper, lumped capacitors are used as feeding structures instead of tapping lines or coupling structures. Choosing high quality lumped capacitor, the variation of the capacitor value in a wide frequency band (for example, below 10GHz) could be negligible. Helped by these feeding capacitors, the required external quality factors could be easily obtained in two pass bands, no impedance transformers are needed. Unlike the method presented in [15], the method here is associated with coupling coefficients, which may ease the design process starting from coupling coefficieints. A dual-band filter fed with lumped capacitors is designed, fabricated and measured. The measured and simulated results exhibit excellent agreement, validating the proposed method.

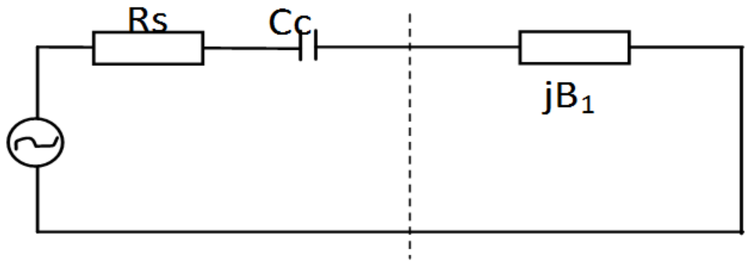

Fig.1. A transmission line resonator fed with lumped capacitor.

2. Filter Design

Fig. 1 shows the equivalent circuit of an open ended transmission line resonator fed with lumped capacitor. C_c is the lumped feeding capacitor, R_s is the source resistor, the component jB_1 is used to denote the transmission line resonator with susceptance given below,

$$jB_1 = jY_0 \tan \beta z \tag{1}$$

where Y_0 is characteristic conductance of the transmission line resonator, B_1 is the susceptance component of the input admittance of the resonator, z is the physical length of the transmission line resonator.

To facilitate calculation of the external quality factor, Fig. 1 could be transformed into Fig. 2.

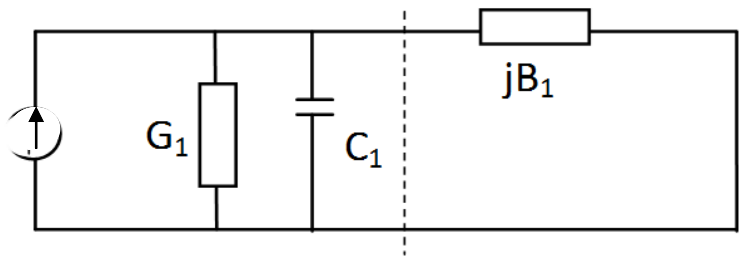

Fig.2. A transformation of Fig. 1.

As showing in Fig. 2, the series connected circuit of R_s and C_c are transformed into shunt connected circuit composed by G_1 and C_1, where

$$G_1 = \frac{R_s \omega^2 C_c^2}{1 + (R_s \omega C_c)^2} \tag{2}$$

$$C_1 = \frac{C_c}{1 + (R_s \omega C_c)^2} \tag{3}$$

the total susceptance at the feeding point could be given below,

$$B = \omega C_1 + Y_0 \tan \beta z \tag{4}$$

Letting B equal to zero at desired frequency, ω_1 ,the physical length z could be determined from equation (4). The external quality factor could also be determined as below [16],

$$Q_e(\omega_1) = \left. \frac{\omega}{2G_1} \frac{\partial B}{\partial \omega} \right|_{\omega=\omega_1} \tag{5}$$

With the knowledge of z, the harmonic frequencies of circuit in Fig. 2 could be determined. The first harmonic frequency is the usually used one, here denotes it as ω_2 . Then the external quality factor at ω_2 could be determined,

$$Q_e(\omega_2) = \left. \frac{\omega}{2G_1} \frac{\partial B}{\partial \omega} \right|_{\omega=\omega_2} \tag{6}$$

Given desired external quality factors at two different frequency bands, with the help of equations (4), (5) and (6), C_c and Y_0 could be determined. That means through properly tuning feeding capacitor and the characteristic conductance Y_0, the desired external quality factors at two different bands could be obtained, and no impedance transformer is needed.

Another important issue in the filter design is obtaining proper internal coupling coefficients between the resonators. When suitable coupling coefficients are obtained in one frequency band, the coupling coefficients in other band are usually not suited. For transmission line resonator filter, it is possible to maintain coupling coefficient in one frequency band, and vary the coupling coefficient in the other band. A simple way is tuning the characteristic impedance Z_0 of the transmission line. However, it should be mentioned that the tuned coupling coefficient could just vary in a certain value range. If a desired coupling coefficient is out of the value range, it could not be obtained simply by tuning the characteristic impedance. A tuning example with hairpin shaped uniform transmission line resonators is given in Fig. 3.

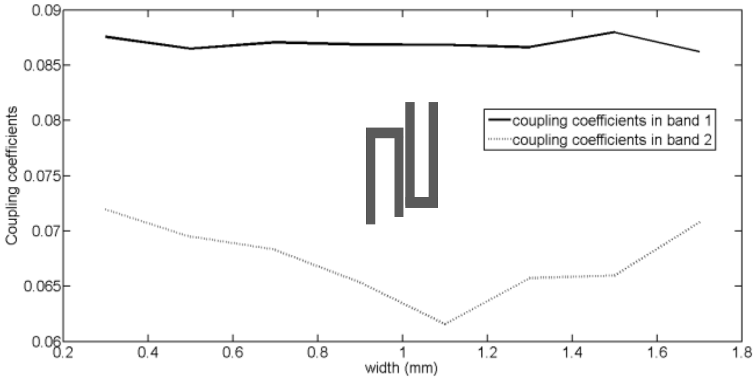

Fig.3. Coupling coefficients in two frequency bands.

The substrate in the example is Rogers RO3003, thickness of the substrate is 20mil. Since variation of transmission line width denotes the variation of characteristic impedance, the transmission line width is used as the independent value in the figure. From Fig. 3, it could be seen that though the coupling coefficient is almost maintained unchanged in one frequency band, the coupling coefficient could vary in a certain range in the other frequency band. To achieve a relative larger value range of the coupling coefficient, non-uniform transmission line resonators may be preferred, for example, the stepped impedance resonators (SIRs). Thus more structural parameters could be adjusted to achieve suitable coupling coefficient's value range. However, if the desired coupling coefficient is far away from the value range, the design of dual-band bandpass filter may fail with the method presented in this paper.

3. Design Example

To validate the design method presented above, an example of dual-band bandpass filter with order three is given. Since the filter works at two bands, the filter coupling topology could be given as below,

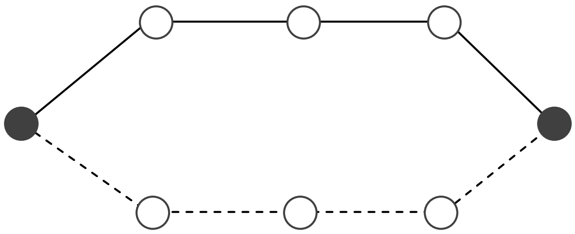

Fig.4. Coupling topology of the dual-band bandpass filter ('●' represents Source or Load, '○' represents resonator, '—' represents coupling in frequency band 1, '- - -' represents coupling in frequency band 2).

Fundamental frequency band of the filter is in the 1.7GHz band, the second frequency band is in the 3.4GHz band. The used normalized external quality factors and normalized coupling coefficients are given below,

$$\text{band1}: \quad q_{e1} = q_{e2} = 0.4403, \quad m_{12} = m_{23} = 1.8133$$

$$\text{band2}: \quad q'_{e1} = q'_{e2} = 0.3953, \quad m'_{12} = m'_{23} = 2.04$$

According to these parameters, a microstrip dual-band bandpass filter is simulated, fabricated and measured. The relative permittivity of the substrate used in the filter is 3.0, the thickness of the substrate is 20mil. After solving the non-linear equations from (4) to (6), the feeding capacitor and characteristic conductance are determined as 0.9pF and 0.017S. Based on these parameters, a proper physical structure of the dual-band filter could be obtained which satisfies the coupling matrix in (7-8). Simulated performances of the dual-band bandpass filter are then given out.

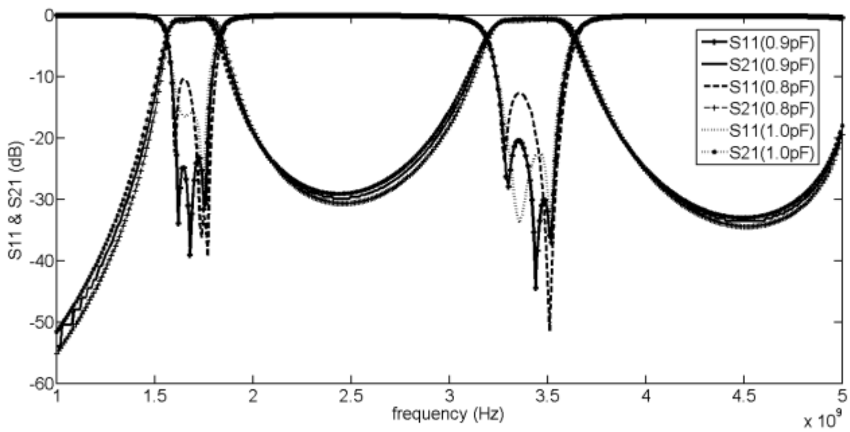

Fig.5. Simulated performances of the dual-band bandpass filter with feeding capacitors' value altered

Fig. 5 gives the simulated performances of the filter with values of the feeding capacitors altered. Since tolerance of the used capacitors with value of 0.9 pF is ±0.1 pF [17], the Fig. 5 is adequate to know the performances of the filter even the real capacitor value is deviated from the 0.9pF. From Fig. 5 it could also be seen that simulated performances at both frequency bands are really good with suitable feeding capacitors.

After approved by the simulations, the designed filter is then fabricated under standard printed circuit board (PCB) process. Then Agilent PNA 5230C is used to measure the fabricated filter. The measured and simulated responses are given in Fig. 6.

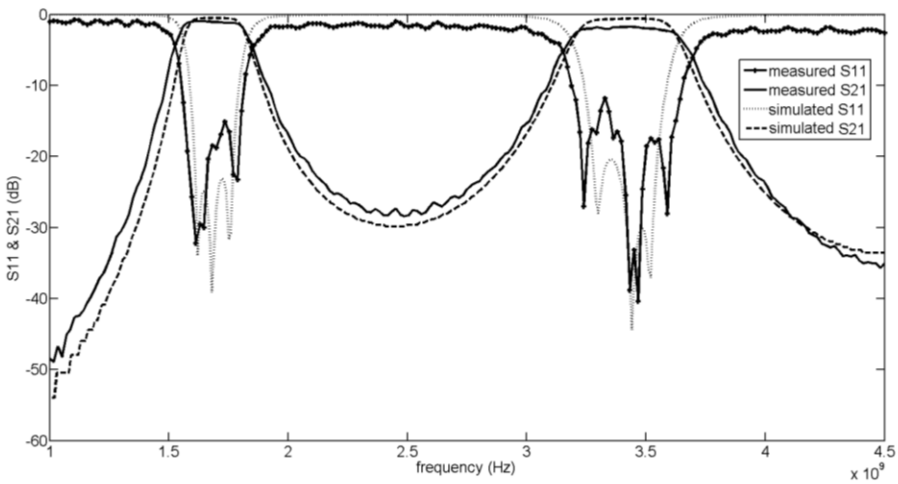

Fig.6. Measured and simulated performances of the dual-band bandpass filter.

It could be clearly seen from Fig. 6 that the measured responses accord well with the simulated responses. The measured S_{11} responses in two frequency bands are both lower than -10dB, and lower than -15dB in most part of the two bands, ensuring good S_{21} performances in two bands. Unlike the filters with tapping feeding lines, this capacitors fed filter has no transmission zeros near the pass bands, so signal suppression level near the pass bands is not so good. The S_{21} between the two pass bands is larger than -30dB. Fig. 7 gives the structure and photo of the fabricated filter, it could be clearly seen that the feeding structures of this dual-band bandpass filter is so simple and compact.

4. Conclusions

A method of designing microstrip dual-band bandpass filter is presented in this paper. Through solving non-linear equations, the parameters needed in the filter design, value of the feeding capacitor C_c and characteristic conductance Y_0, could be determined. Dual-band bandpass filters are then could be designed based on these parameters. A distinct merit of this method is that no complex impedance transformers are needed in the filter to maintain suitable external quality factors at two frequency bands. But since lumped capacitors used in the filter, the effects of the value derivation of the capacitors on the filter should be considered. If order of the filter is larger than two, internal coupling coefficients should also be considered prior to the detailed simulations, because suitable coefficients should be maintained in two frequency bands with the same physical structures. Tuning characteristic impedance of transmission line resonator could maintain coupling coefficients in one frequency band while varying coupling coefficients in the other band. But this way is only feasible when the coupling coefficients are in certain value ranges. An example of the dual-band bandpass filter fed with lumped capacitors is also presented. The measured responses accord well with the simulated responses, validating the proposed method.

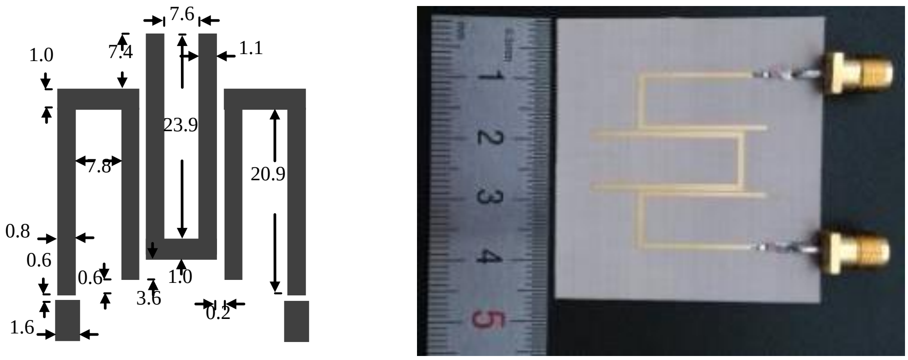

Fig.7. Structure(unit:mm) and photo of the fabricated filter.

Acknowledgements

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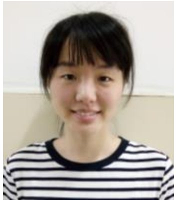

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