A new Semi-Lumped Microwave Filter Structure

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Abstract

A novel narrow-band microwave filter structure is presented. The merit of this circuit lies in the simplicity of design formulas readily applicable to narrow-band filters. The structure can be realized in planar or uniplanar technology. The design formulas yield good results for bandwidths lower than 10% . Bandpass filter with 4% relative bandwidth at 3GHz was designed with the proposed theory and then implemented in both microstrip and coplanar technologies. Experimental results show good agreement with theoretical predictions.

Introduction

Direct-coupled-resonator band-pass filters in lumped elements [1] have been commonly used as a basic structure for different technologies (see Fig. 1). At low microwave frequencies, it may be possible to realize this structure using semi-lumped elements. Dielectric filled coaxial resonator [2] in stepped impedance form has been used to design a band-pass filter based on capacitive-coupled-resonator structure as presented Figure 1a. Interdigital and gap capacitors fabricated over a dielectric substrate have been used as coupling elements. However, some resonator tuning was necessary after design. Quarter-wavelength coaxial resonators made of high-Q dielectric ceramic [3] have been also used in narrow band filter design. The resonance frequency of each resonator, coupling coefficients between adjacent resonators, and external Q's at both ends were adjusted before assembly. Coupling between adjacent resonators was obtained via apertures.

The objective of the present paper is to design a narrow band filter, using both planar and uniplanar technologies. Due to parasitic coupling between each adjacent resonator, capacitive-coupled resonator filter in Figure 1a can not be directly used. To overcome this problem, resonators can be separated using a section of transmission line with arbitrary characteristic impedance. In this purpose, a new J-inverter shown in Figure 4 is proposed. The line length is calculated in function of its characteristic impedance, filter center frequency, relative bandwidth, and arbitrary capacitance used to calculate the basic structure. The advantages of this structure are:

1. The realization simplicity in microstrip and coplanar technologies.
2. The simplicity to design narrow band filters with any number of resonators.
3. The possibility to control filter realizability.

Coupling capacitors can be fabricated by either MIM or interdigital form in microstrip technology and by series open circuit stubs in coplanar technology. Examples are presented to illustrate the design procedure.

Circuit Description

A capacitive-coupled-resonator filter can be derived from a band-pass filter prototype. Here, only shunt resonators and admittance inverters are used [4] as shown in Figure 2. Many different types of admittance inverters in lumped, semi-lumped and distributed forms are given in [4]. The circuit in Figure 3. is used as a J-inverter to construct capacitive-coupled -resonator filter shown in Figure 1a.

The proposed structure is based on the new J-inverter presented in Figure 4. The inversion property conditions are:

$$J = \frac{\omega_o^2 c^2 z_o^2}{\sqrt{1+\omega_o^2 c^2 z_o^2}} \qquad \text{and} \qquad \phi = \sin^{-1}\frac{1}{\sqrt{1+\omega_o^2 c^2 z_o^2}}$$

The negative shunt capacitance of the J-inverter must be subtracted from positive resonator capacitance to give the net shunt capacitance actually inserted in the circuit. The end coupling capacitances $c_{0,1}$ and $c_{n,n+1}$ are treated in slightly different manner [4].
The proposed inverter has a lower bandwidth as compared

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to the ones that use only lumped elements. This is due to the frequency dependence of the transmission line used, which deteriorates the filter response when used for large bandwidth applications. Good results can be obtained below 10% relative bandwidth.

Due to the negative shunt capacitance of the J-inverter, the resonance frequency of each resonator actually inserted in the circuit is increased. In this case, the traditional lumped to distributed transformation is not valid due to the narrow bandwidth behavior of the J-inverter. A new lumped to distributed transformation is necessary to adapt the performance of the distributed resonator in Figure 5b with the original lumped resonator in Figure 5a. This is done at the center frequency of the filter instead of at the resonance frequency of the lumped resonator. This yields the following relations.

$$\sin 4\pi \frac{l}{\lambda_o} = -4\pi \frac{lA}{\lambda_o B}$$

where

$$A = -Y_o \cot 2\pi \frac{l}{\lambda_o} \quad \text{and} \quad B = Y_o \frac{2\pi l}{\lambda_o \omega_o \sin^2 \frac{2\pi l}{\lambda_o}}$$

and λ_o is the waveguide wavelength at the center frequency of the resonator.

The above equations can be solved graphically. Solutions are the optimum values of characteristic impedance Z_o and resonator length l.

Design examples

A three resonators bandpass filter based on the above structure was designed and realized in planar and uniplanar technologies. The filter specifications are as follows:

Filter response : Chebyshev, .01 dB ripple
Fo : 3 Ghz
B.W : 120 MHz (4 %)

Using an arbitrary capacitance for all resonators in the bandpass filter prototype in Figure 2 in the order of 1.5 pf and 50 ohms series line characteristic impedance for the J-inverter in Fugure 4, the filter parameters are :

$c_{0,1} = c_{3,4} = 0.333$ pf and $c_{1,2} = c_{2,3} = 0.285$ pf

The first and the third resonator parameters are :

Zo = 30.52 ohms and Fo=3.7878 GHz, where the line length is $\lambda/4$ at Fo

Second resonator parameters:

Zo = 30.32 ohms and Fo = 3.7537 GHz

Series line length is 74.94° at 3 GHz

A commercial software [5] was used to simulate the performance of such filter with ideal elements shown in Figure 6. Results are given in Figure 7. Simulations were done for another filter at the same center frequency, but with a bandwidth of 8 % to show the range of operation. Simulation results are given in Figure 8.

The first filter was realized, using coplanar technology with Epsilam dielectric substrate ($\varepsilon r = 10.2$, h = 0.635 mm and tan $\delta = 0.002$). Open circuit stubs are used to insert series capacitances as shown in Figure 9. Simulation and experimental results are shown in Figure 10 and Figure 11, respectively. The measured relative bandwidth is about 4% and I.L is 1.5 dB at the center frequency of 3.105 GHz.

Microstrip multilayer technology [6] was also used to realize the filter. An Alumina substrate with εr=9.9, h=0.635 mm and tan δ =0.0002 was used. Simulation and experimental results are shown in Figure 12 and Figure 13, respectively. In this case, the measured relative bandwidth is about 5% and I.L is 1.8 dB at the center frequency of 2.65 GHz.

For both cases, a center frequency shifting is observed. This is due to the different types of discontinuities that were used. These problems are currently addressed.

Conclusion

A new narrow-band filter structure is proposed. It can be easily implemented in both microstrip and coplanar technologies and closed form expressions can be used for their design. Three-resonators bandpass-filter was designed at 3 GHz and realized in both technologies. This type of filter can be produced at low cost, with low I.L and used in many applications, in particular for radio mobile communications if high-dielectric constant substrates are used.

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(a) Lumped constants, series capacitive coupling

(b) Lumped constants, shunt inductive coupling

Figure 1

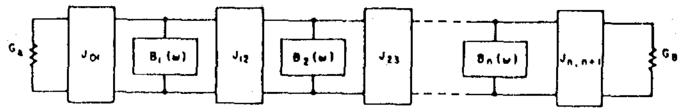

Figure 2 A generalized, bandpass filter circuit using admittance inverters

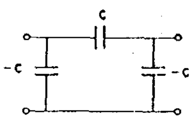

Figure 3 J-Inverter circuit

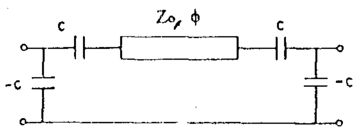

Figure 4 J- Inverter circuit

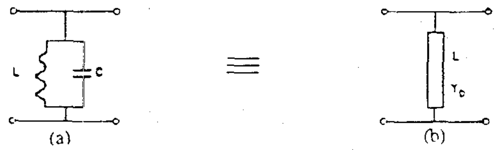

Figure 5. (a) Lumped circuit resonator
(b) Equivalent distributed resonator

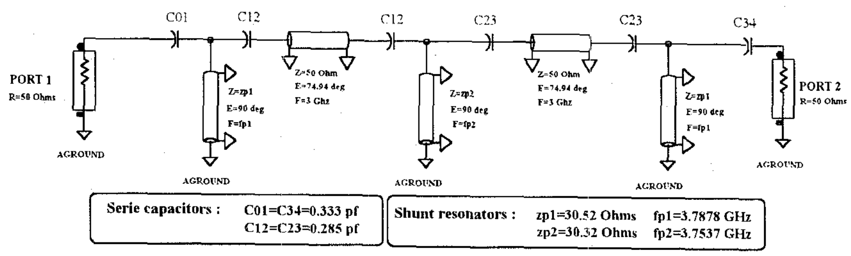

Figure 6 : Ideal elements structure of three resonators bandpass filter

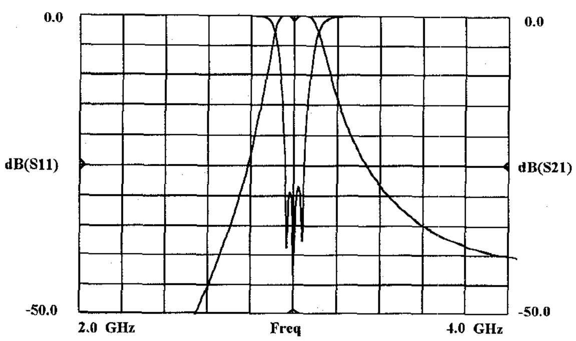

Figure 7 : Simulated response of three resonators bandpass in Figure 6 with 4% relative bandwidth

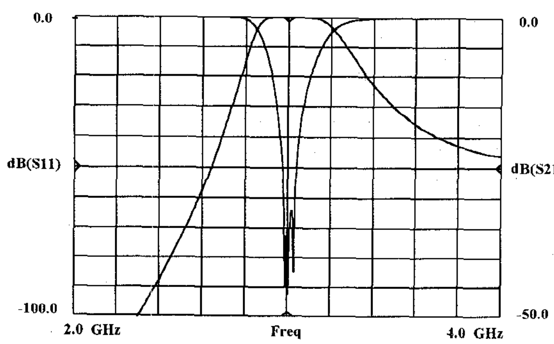

Figure 8 : Simulated response of three resonators bandpass filter with 8% relative bandwidth using ideal elements

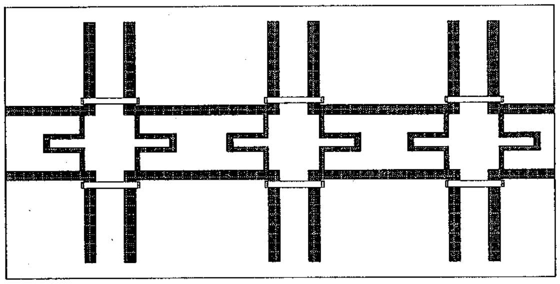

Figure 9 : Layout of the bandpass filter realized in coplanar technology

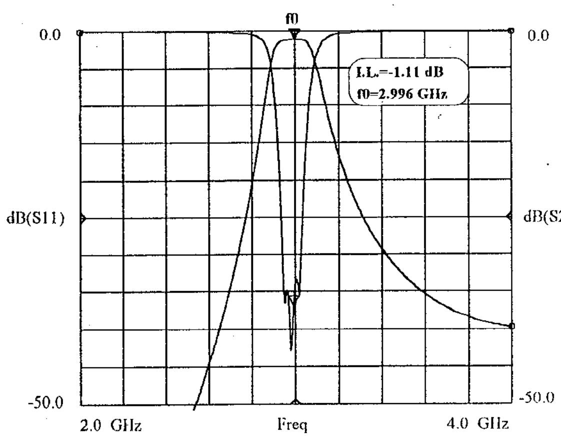

Figure 10 : Simulated response of the filter in coplanar technology

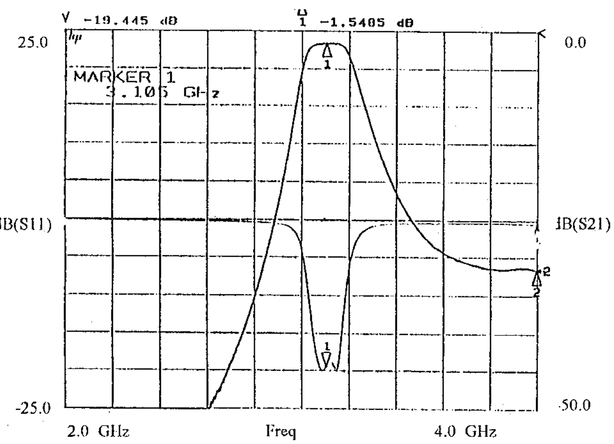

Figure 11 : Measured performance of three resonators filter realized with Epsilam substrate with ε r=10.2 and h=0.635mm using coplanar technology

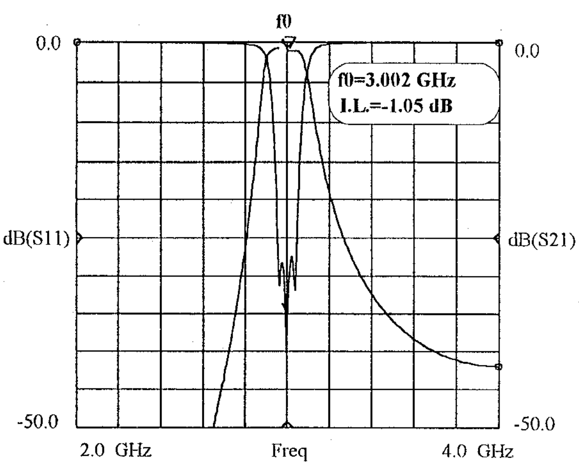

Figure 12 : Simulated response of the filter in microstrip technology

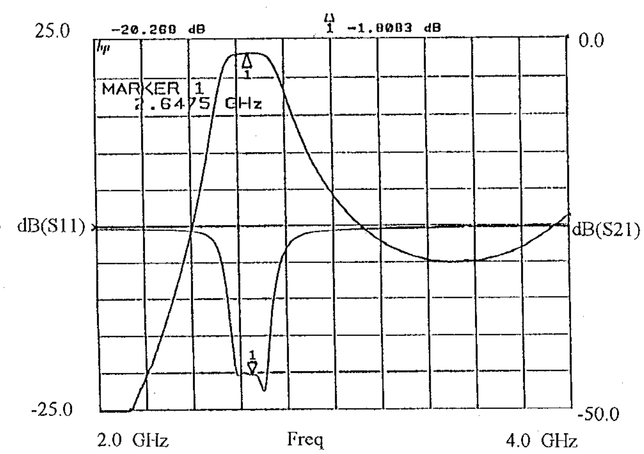

Figure 13 : Measured performance of three resonators filter realized with Alumina substrate with εr=9.9 and h=0.635mm using microstrip technology