MICROSTRIP SLOW-WAVE OPEN-LOOP RESONATOR FILTERS

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ABSTRACT

Microstrip slow-wave open-loop resonators allows various filter configurations including those of elliptic or quasi-elliptic function response to be realised. The filters are not only compact size due to the slow-wave effect, but also have a wider upper stopband resulting from the dispersion effects. These attractive features make the microstrip slow-wave open-loop resonator filters hold promise for mobile communications, superconducting and other applications.

INTRODUCTION

In many applications keeping filter structures to a minimum size and weight is very important. It would seem that planar filter structures which can be fabricated using printed-circuit technologies would be preferred whenever they are available and are suitable because of smaller sizes and lighter weight. Recent advance in high-temperature superconducting (HTS) circuits and microwave monolithic integrated circuits (MMIC) has additionally stimulated the development of various planar filters, especially narrow-band bandpass filters which play an important role in modern communications systems [1-2]. In order to reduce interference by keeping out-of-band signals from reaching a sensitive receiver, a wider upper stopband, including $2f_0$, where f_0 is the midband frequency of a bandpass filter, may also be required. However, many planar bandpass filters which are comprised of half-wavelength resonators have inherently a spurious passband at $2f_0$. A cascaded low-pass filter may be used to suppress the spurious passband at the cost of extra insertion loss and size. Although quarter-wavelength resonator filters have the first spurious passband at $3f_0$, they require short-circuit (grounding) connections with via holes, which is not quite compatible with planar fabrication techniques. Lumped element filters ideally do not have any spurious passband at all, but they suffer from higher loss and poorer power handling capability. Bandpass filters using stepped impedance resonators (SIR) [3] or end-coupled slow-wave resonators [4] are able to control spurious response, but they can only be implemented in few filtering configurations.

In this paper, we introduce a new class of microstrip bandpass filters based on coupled slow-wave open-loop resonators. We show that the use of slow-wave open-loop resonators enable various filters including those of elliptic or quasi-elliptic function response to be designed, that are not only compact size, but that also have a wide upper stopband. Theoretical and experimental results are presented.

SLOW-WAVE OPEN-LOOP RESONATOR

For our purpose let us consider a unit cell of a capacitively loaded periodic transmission line of Fig.1(a), where C is the loaded capacitance; Z_a, β_a and d are the characteristic impedance, the propagation constant and the length of the unloaded line, respectively. Thus the electric length $\theta_a=\beta_a d$. Assume that a standing wave has been excited subject to the boundary conditions $I_1=I_2=0$. The fundamental resonant frequency and the first spurious resonant frequency can be determined from the following eigenequations :

$$\theta_{a0} = 2\tan^{-1}\left(\frac{1}{\pi f_0 Z_a C}\right) \quad (1)$$

$$\theta_{a1} = 2\pi - 2\tan^{-1}(\pi f_1 Z_a C) \quad (2)$$

where the subscripts 0 and 1 indicate the parameters associated with the fundamental and the first spurious resonance, respectively. It can be shown that the resonant frequencies are shifted down as the loading capacitance is increased, indicating the slow-wave effect. However, in addition the ratio of the first spurious resonant frequency to the fundamental one is increased. From the dispersion equation of the periodic transmission line we can find

$$\frac{f_1}{f_0} = 2\frac{v_{p1}}{v_{p0}} \tag{3}$$

where v_{p0} and v_{p1} are the phase velocities of the loaded line at the fundamental and the first spurious resonant frequencies, respectively. If there were no dispersion the phase velocity would be a constant. This is only true for the unloaded line. Hence the increase in ratio of the first spurious resonant frequency to the fundamental one when the capacitive loading is increased attribute to the increase of the dispersion which can be used to design the bandpass filter with a wider upper stopband. It is obvious that based on the circuit model of Fig.1(a) different resonator configurations may be realised. Herein we propose a so-called microstrip slow-wave open-loop resonator, which is composed of a microstrip line with both ends loaded with folded open-stubs as Fig.1(b) shows. The folded arms of open-stubs are not only for increasing the loading capacitance to ground as referred to Fig.1(a), but also for the purpose of interstage or cross couplings. It should be mentioned that the slow-wave open-loop resonator differs from the miniaturised hairpin-resonator [5] primarily in that they are developed from rather different concepts and purposes. The latter is developed from conventional hairpin resonator by increasing capacitance between both ends to reduce the size of the conventional hairpin resonator [5]. The main advantage of microstrip slow-wave open-loop resonator of Fig.1(b) over the previous ones is that various filter structures (Fig.2) can be developed, including canonical filter in Fig.2(d) and cascaded quadruplet (CQ) filter in Fig.2(e) which exhibit elliptic or quasi-elliptic function response.

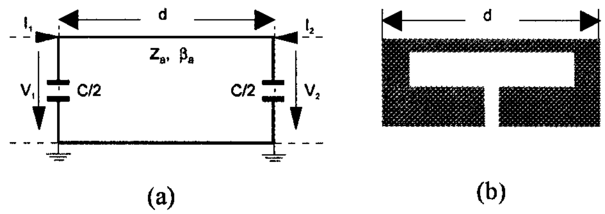

Figure 1: (a) A circuit model for slow-wave resonator. (b) Microstrip slow-wave open-loop resonator.

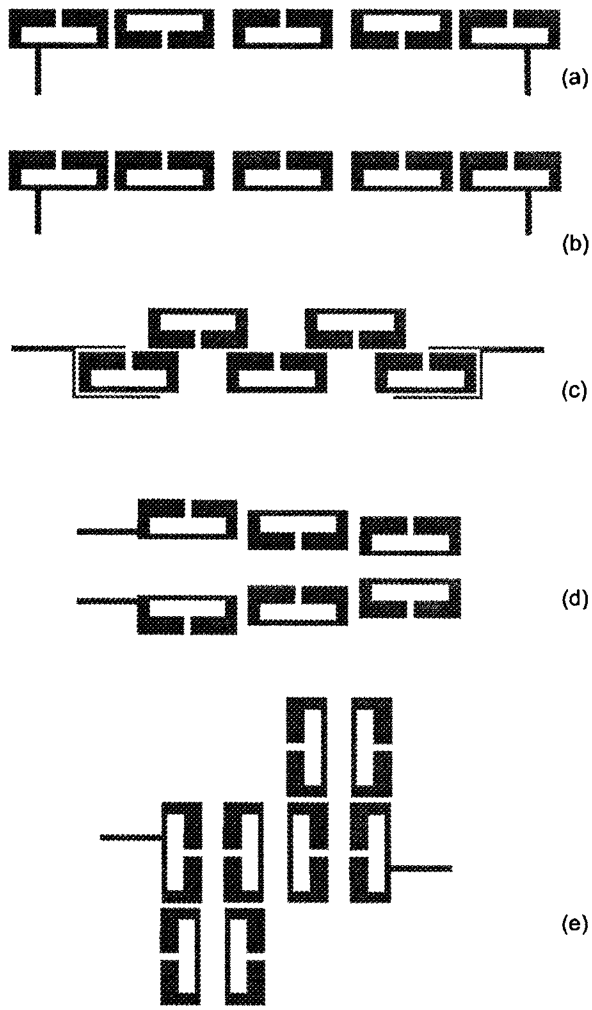

Figure 2: Some filter structures realised using microstrip slow-wave open-loop resonators. (a), (b) and (c) Direct coupling filters. (d) Canonical filter. (e) Cascaded quadruplet (CQ) filter.

FILTER DESIGN EXAMPLES

For our demonstration we will focus on two examples of narrowband microstrip slow-wave open-loop resonator filters. The first one is 5-pole filter with overlapped coupled slow-wave open-loop resonators as

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Fig.2 (c) shows. This filter was originally developed to meet the following specifications for an instrumentation application :

Centre Frequency :	1335 MHz	
3dB Bandwidth :	30 MHz	
Passband Loss :	3dB Max.	
Min. stopband rejection :	D.C. to 1253 MHz	60dB
	1457 to 2650 MHz	60dB
	2650 to 3100 MHz	30dB
60dB Bandwidth :	200 MHz Max.	

As can be seen a wide upper stopband including $2f_o$ is required and at least 30dB rejection at $2f_0$ is needed. The filter design was based on the knowledge of couplings between adjacent resonators. We used a full-wave EM simulator [6] to determine coupling coefficients. Fig.3 (a) shows the computed coupling coefficient against different overlapped length *d* for a fixed coupling gap *s*, where the size of the resonator is 16mm by 6.5mm on a substrate with a relative dielectric constant of 10.8 and a thickness of 1.27mm. One can see that the coupling almost increases linearly with the overlapped length. It can also be shown that for a fixed *d* reducing or increasing coupling gap *s* increases or decreases the coupling. From the filter configuration of Fig.2(c) one might expect the cross coupling between non-adjacent resonators. We investigated this issue and found that the cross coupling between non-adjacent resonators is quite small when the separation between them is larger than 2 mm as Fig.3(b) shows. This, however, suggests that the filter configuration of Fig.2(b) would be more suitable for very narrow-band realisation which requires very weak coupling between resonators. Having characterised the couplings we designed the filter with the aid of the EM simulator. The filter was then fabricated on a RT/Duroid substrate. The size of this 5-pole filter is about $0.70\lambda_{go}$ by $0.15\lambda_{go}$, where λ_{go} is the guided wavelength of a 50Ω line on the substrate at the midband frequency. Fig.4 shows experimental results, which represent the first design iteration. The top of Fig.4 gives the details of the passband while the bottom shows the wideband response. Except for a slight deviation in the centre frequency and bandwidth, the filter had a midband loss less than 3dB and exhibited the excellent stopband rejection. It can be seen that more than 50 dB rejection at $2f_o$ has been achieved.

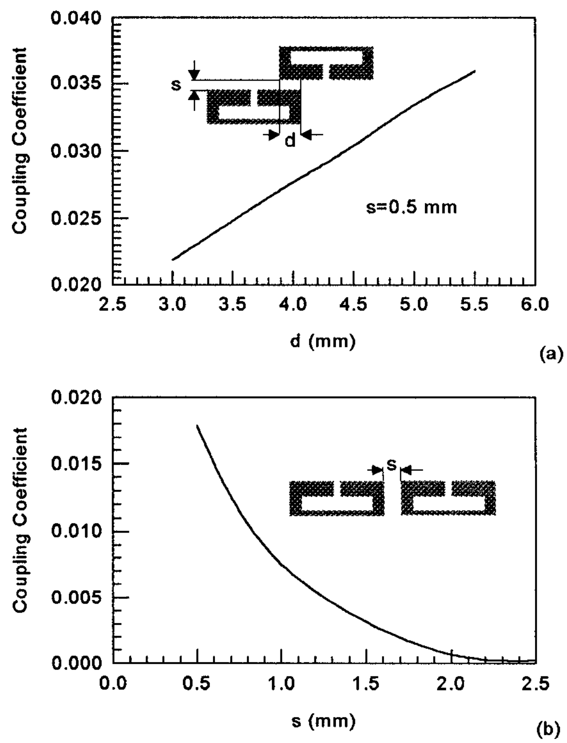

Figure 3: Modelled coupling coefficients of (a) overlapped coupled and (b) end-coupled resonators.

The second trial microstrip slow-wave open-loop resonator filter is that of 4-pole CQ [7] filter of Fig.2(e). It should be noticed that in this case the CQ filter structure is the same as the canonical one of Fig.2(d). The filter was designed and fabricated on a RT/Duroid 6010 substrate with a relative dielectric constant of 10.8 and a thickness of 1.27mm. In this case the size of the filter amounts only to $0.18\lambda_{go}$ by $0.36\lambda_{go}$. Fig.5 shows the measured filter performance, where the two transmission zeros which are the typical elliptic function response can clearly be observed. The asymmetry in zero locations may attribute to the detuning in couplings. The fraction bandwidth is 4% at 1.3 GHz. The minimum passband loss was approximately 2.7dB. As can also be seen the filter exhibited a wide upper stopband with a rejection better than 40dB up to about 3.4 GHz.

CONCLUSIONS

We have proposed a new class of planar microwave bandpass filters using microstrip slow-wave open-loop resonators. It has been demonstrated that the use of the microstrip slow-wave open-loop resonators allows various filter configurations including those of elliptic or quasi-elliptic function response to be realised that are not only compact size due to the slow-wave effect, but that also have a wider upper stopband resulted from the dispersion effect. It can be seen that the microstrip slow-wave open-loop resonator filters hold promise for mobile communications, HTS and other applications.

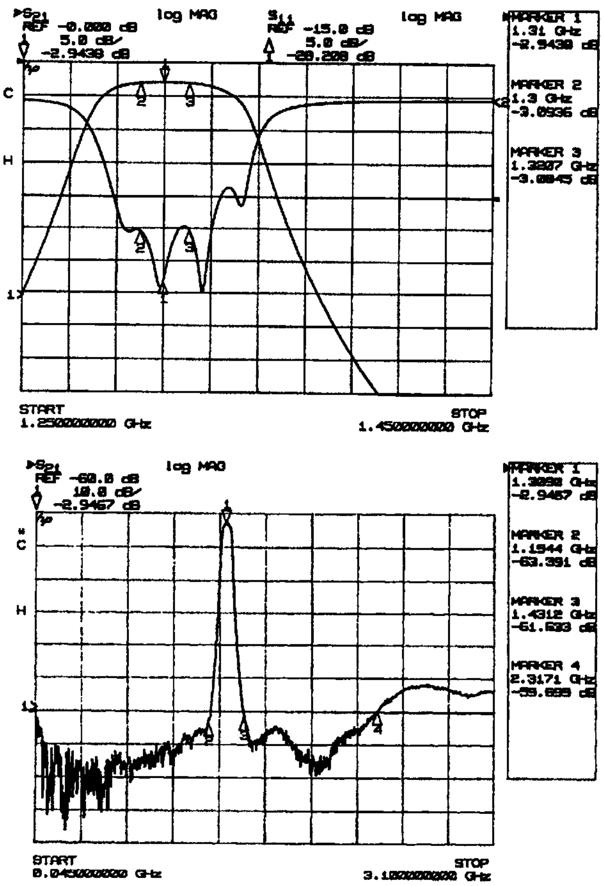

Figure 4: Measured filter performance for a 5-pole filter.

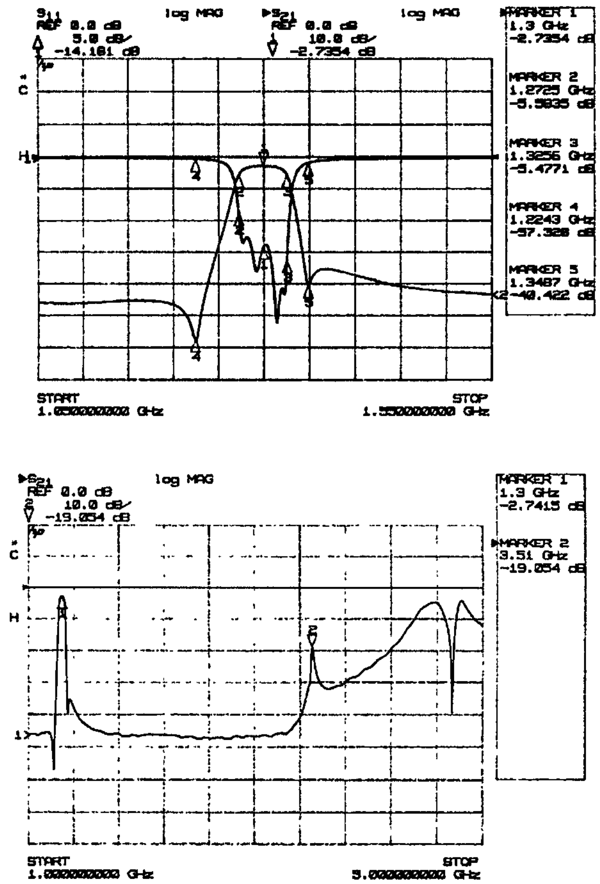

Figure 5: Measured filter performance for a 4-pole filter with elliptic function response. The top is the details of passband response while the bottom shows the spurious response.

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