A Hybrid Resonator Consisting of a Half-Wavelength Stripline Resonator and a Quarter-Wavelength Coplanar Waveguide Resonator and its Application to a Dual-Band Comb-Line Filter

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Abstract

Presented is a resonator of hybrid structure with two independently controllable frequencies of resonance. The hybrid resonator consists of a half-wavelength stripline resonator which is short-circuited at its both ends and a quarter-wavelength coplanar waveguide resonator nested in the half-wavelength resonator. Numerical analysis with a computational tool for electromagnetic fields clarifies such characteristics of dual-frequency resonance as resonant frequencies depending upon structural parameters and distributions of surface current density at resonance. A typical model is fabricated and its frequency characteristics of resonance are measured. Presented and investigated also is a dual-band comb-line filter consisting of hybrid resonators with stepped-impedance structure introduced.

1. INTRODUCTION

Various types of dual-band bandpass filters have recently been proposed with an increasing demand for such mobile access to Internet as cellular phones or wireless LAN terminals designed to operate in multi-band frequencies[1]-[4]. Some of these are equipped with a pair of resonators with individual resonant frequencies. Others employ single resonators having dual-frequency resonance owing to stepped-impedance structure or so. The former has trouble in miniaturizing the structure; the latter has difficulty in controlling resonant frequencies besides structural complexity.

We propose, in the present paper, a new resonator of hybrid structure with two independently controllable frequencies of resonance. The hybrid structure is composed of a half-wavelength ($\lambda/2$) stripline resonator and a quarter-wavelength ($\lambda/4$) coplanar waveguide resonator nested in the $\lambda/2$ resonator. It is possible to achieve independent control on resonant frequencies as well as miniaturization of the structure in our hybrid resonator because each of the two resonators functions independently.

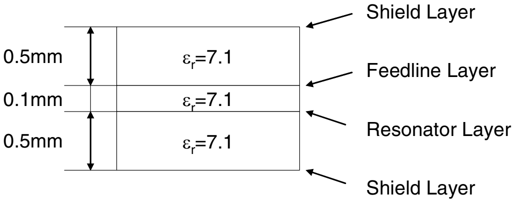
Based on the numerical analysis by the electromagnetic simulator (Sonnet em), we investigate the resonance characteristics as well as distributions of surface current density at resonance. Focusing on the control of resonant frequency, we also study the hybrid resonator with stepped-impedance introduced in the $\lambda/4$ resonator. A typical model has been fabricated on a conductor-backed dielectric substrate and its resonance characteristics have been confirmed by measured data. A comb-line filter consisting of hybrid resonators with stepped-impedance introduced has been proposed and analyzed.

2. RESONATOR OF BASIC TYPE

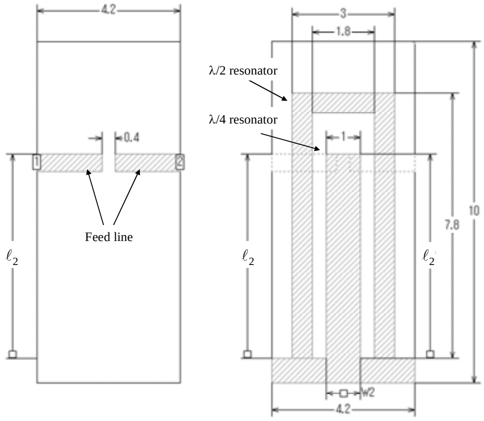
A. Resonance Characteristics based on Simulation

Figure 1 illustrates the configuration of the hybrid resonator we propose in this paper. The cross-sectional view is drawn in Fig. 1(a) and the metallization patterns on the feed-line layer and the resonator layer are shown in Figs. 1(b) and 1(c), respectively. The feed-line layer and the resonator layer are spaced in 0.1mm. The whole structure of volume $4.2 \times 10.0 \times 1.1$ mm^3 with a dielectric constant 7.1 is entirely shielded with perfect conductor. For the purpose of understanding the principle, it is assumed that the dielectric material be lossless. It is also assumed that the conductor thickness be 10μm and its conductivity 6.17×10^7S/m.

As shown in Fig. 1(c), a 17.4mm length of stripline of width w_1=0.6mm is short-circuited at its both ends and is folded in a rectangular shape to pattern the $\lambda/2$ resonator whose dimensions are shown in the figure. The $\lambda/4$ coplanar-waveguide resonator of finite length ℓ_2 and width w_2=1.0mm is nested in the $\lambda/2$ resonator with a space of 0.4mm. The $\lambda/2$ resonator in the present hybrid structure works as ground for the $\lambda/4$ resonator as well, which will be understood from the distributions of surface current density shown later concerning the resonance of the $\lambda/4$ resonator. A 1.9mm length of stripline of width 0.5mm is utilized for feed lines, which are supposed to be placed ℓ_2 away from the short-circuited end of the $\lambda/4$ resonator. This means that a gap feeding over a dielectric substrate with a thickness 0.1mm is applied to the hybrid structure of resonators.



(a) Cross-sectional view



(b) Feed-line layer (c) Resonator layer

Fig. 1: Configuration of the resonator with two frequencies of resonance

First, fixing all the structural parameters of the $\lambda/2$ resonator, we investigate the resonance characteristics of the hybrid structure with the length of the $\lambda/4$ resonator as a parameter. It is supposed that the placement of the feed lines be adjusted around the open end of the $\lambda/4$ resonator so as to realize weak coupling suitable for observing the basic characteristics of resonance.

Figure 2 shows the transmission characteristics (S21) in the frequency region from 1GHz up to 7GHz when ℓ_2 is changed as 5.0mm, 6.0mm, and 7.0mm. We have two frequencies of the fundamental resonance of the $\lambda/2$ resonator and the $\lambda/4$ resonator, indicated in the figure as f_{r2} and f_{r4}, respectively, and the resonance of the first higher order mode of the $\lambda/2$ resonator, $f_{r22}=2f_{r2}$, in this frequency region. Although it is quite a well-known result that the resonant frequency of the $\lambda/4$ resonator comes down with the increasing length of the resonator, yet a significant fact is that the resonant frequencies of the $\lambda/2$ resonator, including the higher order resonance, are not affected significantly by the change of length of the nested $\lambda/4$ resonator.

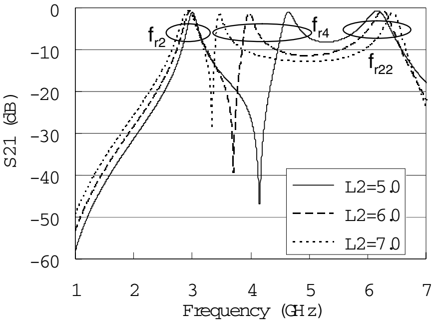
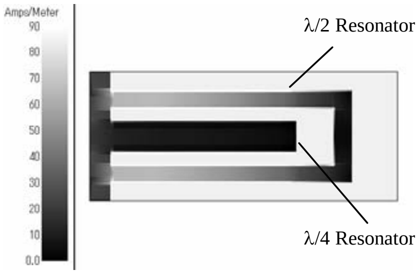
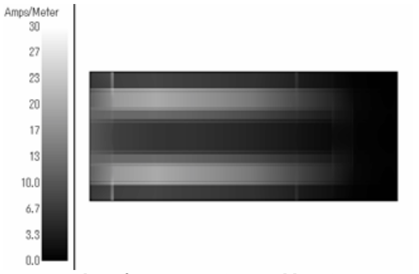


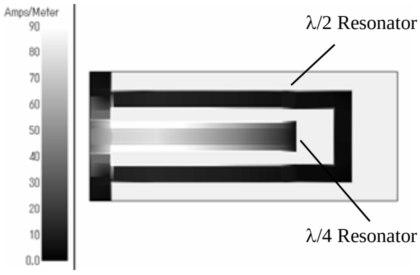
Fig. 2: Resonance characteristics of the resonator shown in Fig. 1 when w_2=0.5mm and ℓ_2=5.0, 6.0, 7.0mm.



(a) f=2.97 GHz ($\lambda/2$ Resonator)



(b) f=2.97 GHz (Ground layer)

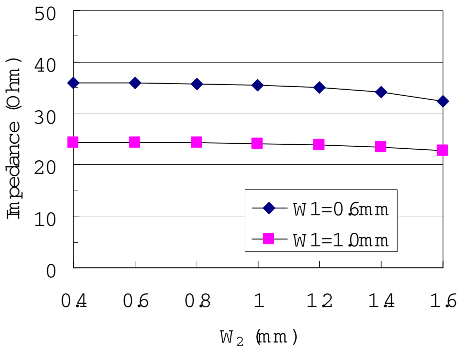


(c) f=3.97 GHz ($\lambda/4$ Resonator)

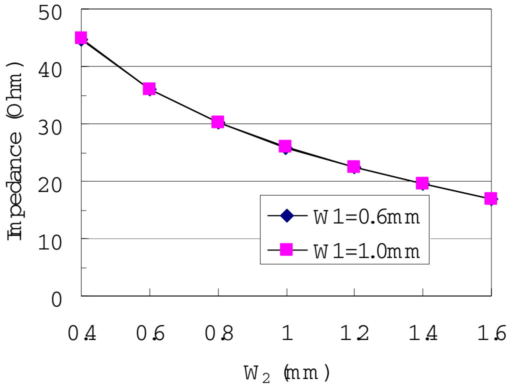
Fig. 3: Current density distribution on the conductor at resonant frequencies when w2=1.0mm and ℓ_2=6.0mm

Secondly, let's observe the distributions of surface current density at the resonance to see how the conductor pattern works. Figure 3 illustrates the distributions of current flow on the conductor at the frequencies of f_{r2} =2.97GHz and f_{r4} =3.97GHz when ℓ_2 =6.0mm. Figures 3(a) and 3(b) reveal that none of significant current on the centre conductor at the resonance of the λ/2 resonator. It is thus understood from these figures that the λ/2 resonator behaves as a stripline resonator with the shield conductor as ground. On the other hand, we can see at the resonance of the λ/4 resonator in Fig. 3(c) a pretty high current density appearing inside the λ/2 resonator. It is hence concluded that the λ/4 resonator functions as a coplanar waveguide resonator with the λ/2 resonator as main ground.

Next, we study the characteristic impedance of transmission line forming the resonators. Figures 4(a) and 4(b) show the characteristic impedance of the stripline and the coplanar waveguide, respectively, as a function of width w_2 of the centre conductor when the width w_1 of the stripline is set to be 0.6mm or 1.0mm with the dimensions of inner side of the rectangle unchanged. The gap g between the centre conductor and the stripline thus becomes narrower with the increase of w_2. Figure 4(a) tells that the characteristic impedance of the stripline keeps constancy up to around w_2 =0.8mm. The characteristic impedance of the coplanar waveguide decreases monotonously with the increase of w_2 in Fig. 4(b), which is considered to be typical behaviour the coplanar waveguide assumes. The results shown in Fig. 4 strongly support the fact that the λ/2 resonator operates free from the influence of the λ/4 resonator.



(a) Stripline patterning the half-wavelength resonator



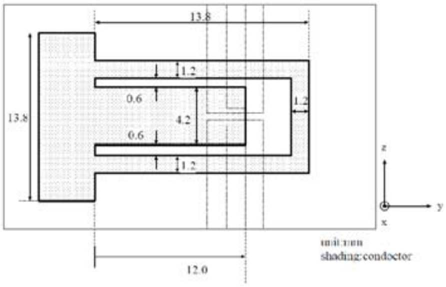
(b) Coplanar waveguide patterning the quarter-wavelength resonator

Fig. 4: Characteristic impedance as a function of w_2.

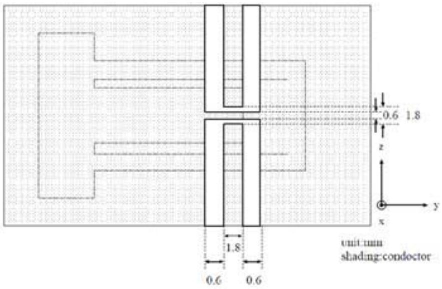
B. Experimental Study

A typical model of the hybrid resonator has been fabricated on a conductor-backed dielectric substrate (ε_r=10.2) of thickness 0.635mm and measured. Figure 5 illustrates the schematic of the fabricated model. In this case, the upper region of the resonator is free space and hence the feed line is a finite length of coplanar waveguide. Fabricating equipment available in our laboratory has forced us to choose such an open structure as Fig. 5 without shield conductor.

Figure 6 shows simulated and measured transmission characteristics. It shows good agreement between simulated and measured results. The characteristics recognized in the figure tell that the present hybrid resonator must be a prospective candidate for compact dual-band bandpass filters.



(a) Resonator



(b) Feed line

Unit [mm]

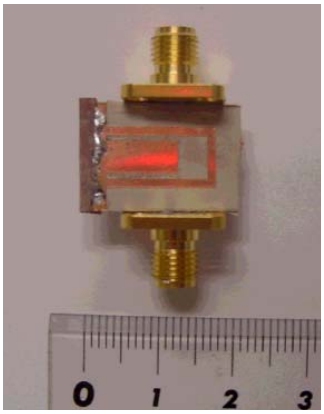

(c) Photograph of the resonator

Fig. 5: schematic of the fabricated model

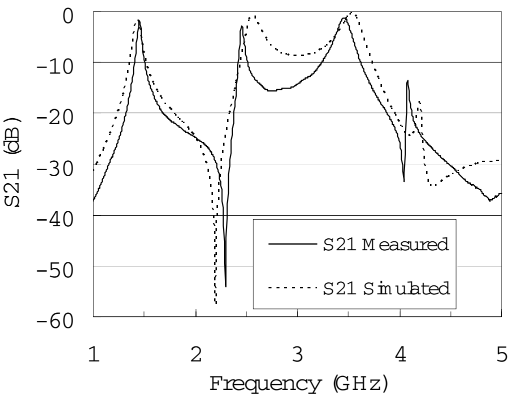


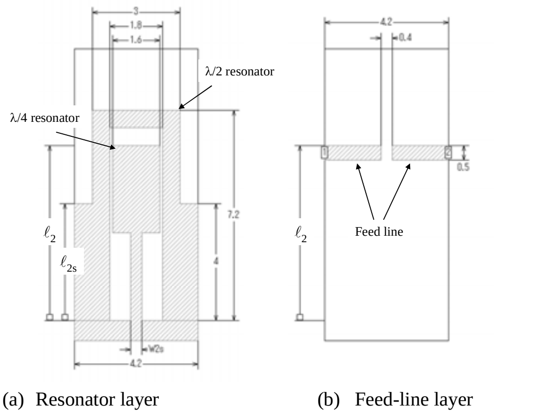
Fig.6 Measured and simulated results

3. STEPPED-IMPEDANCE RESONATOR AND ITS APPLICATION TO COMB-LINE FILTER

A. Stepped-Impedance Resonator

In order to improve the transmission characteristics, it is considered that the λ/4 resonator consisting of straight coplanar waveguide is replaced with a stepped-impedance resonator (SIR). It is well-known that resonators with proper stepped-impedance introduced have lowered resonant frequencies. This structural modification is expected to exchange the resonant frequencies of the two resonators.

Figure 7 shows the metallization pattern of the hybrid resonator with an SIR furnished. As shown in Fig. 7(a), the λ/2 resonator of length 8.2mm and of width 0.6mm has a ground elevated by ℓ_{2s}. The resonator with its length reduced has higher resonant frequencies. With a 0.1mm gap, the λ/4 resonator of length 6.0mm and of width 1.6mm is nested in the λ/2 resonator. The λ/4 resonator has its impedance step at the centre of the structure. We investigate the resonance characteristics with varying the width of the high impedance portion w_{2s} as a parameter from 0.4mm to 1.6mm.



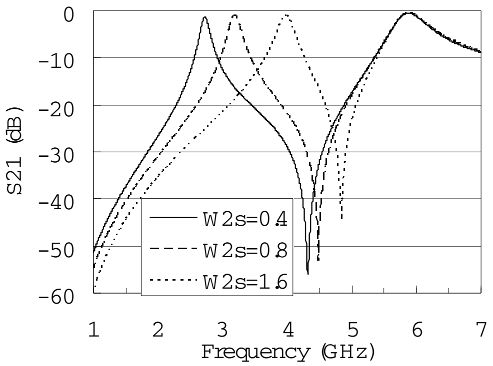
(a) Resonator layer (b) Feed-line layer

Unit [mm]

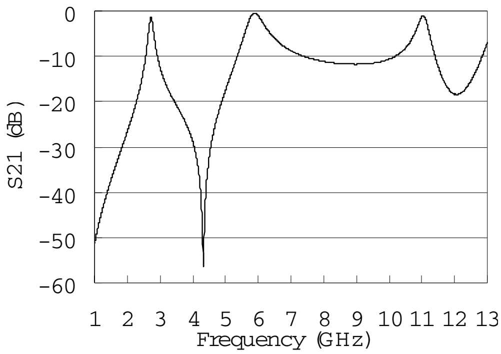
Fig. 7: Metallization pattern of the resonator containing SIR with two frequencies of resonance.

As shown in Fig. 7(b), a 1.9mm length of stripline of width 0.5mm is utilized for feed lines. The feed lines that are supposed to be placed ℓ_2 away from the short-circuited end of the λ/4 resonator are coupled to the resonators through a 0.1mm dielectric layer. The layer configuration of the resonator is same as basic type resonator in Fig.1 (a). A 0.5mm thickness of dielectric layer is overlaid on the resonator layer as well as on the feed-line layer. The whole structure of tri-plate as large as $4.2 \times 10.0 \times 1.1\text{mm}^3$ is supposed to be covered entirely with perfectly conducting shield.

In our simulation, it is assumed that all the conductor patters but the external conducting shield be drawn with silver paste of thickness 10μm; hence a 6.17×10^7S/m of conductivity is taken into consideration. Although we are planning to utilize dielectric substrates with tan $\delta = 0.005$ in our future experiments, we neglect dielectric losses in the present analysis.



(a) Vicinity of dominant resonance



(b) Wide-band response

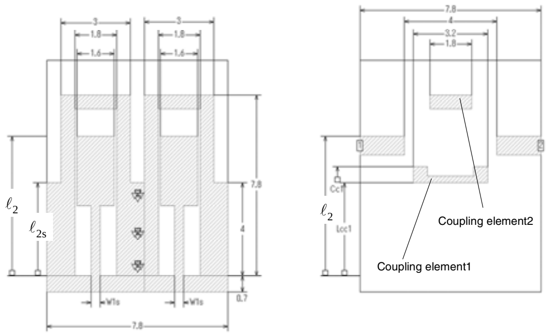
Fig. 8: Resonance characteristics of the resonator shown in Fig.7.

The transmission characteristics are shown in Fig. 8 when w_{2s} is changed as 0.4mm, 0.8mm, and 1.6mm with ℓ_{2s} fixed to be 4.0mm. As shown in Fig. 8(a), the resonant frequency of the λ/4 resonator changes largely in the lower band with an increasing ratio of stepped impedance while that of the λ/2 resonator occupying the higher band remains unchanged for any value of w_{2s}. Figure 8(b) shows the characteristics in a wider frequency range for a typical example of $w_{2s} = 0.4$mm. The hybrid resonator with an SIR furnished has a great advantage that the spurious-free region between the higher band and the nearest resonance of the higher order mode can be extended largely.

B. Dual-Band Comb-Line Filter

A dual-band comb-line filter consisting of two resonators coupled to each other is proposed and analyzed. The metallization pattern is illustrated in Fig. 9. The structure of the resonator is basically the same as Fig. 7. The length of the λ/2 resonator is, however, extended to 9.0mm in order to lower the higher band around 5GHz. The grounding of the conductor between the two resonators is made assured with three via holes to avoid unnecessary resonance. Some spurious resonance would appear without these via holes because of a significant extension of conductor.

Two coupling elements are printed on the feed-line layer to give enough coupling between the resonators. The coupling element 1 works for the λ/4 resonators and the element 2 is for coupling between the λ/2 resonators. The magnitude of coupling between the resonators is controlled by changing C_{c1} for the element 1 and w_3 for the element 2.



(a) Resonator layer (b) Feed-line layer

Fig. 9: Metallization pattern of the comb-line filter consisting of hybrid resonators with SIR introduced.

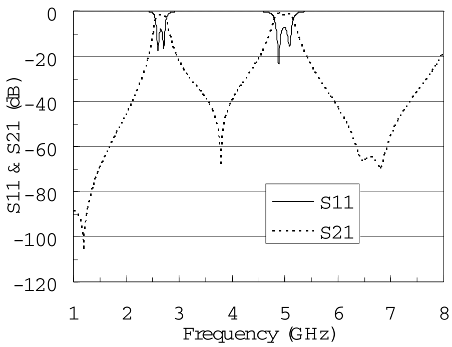
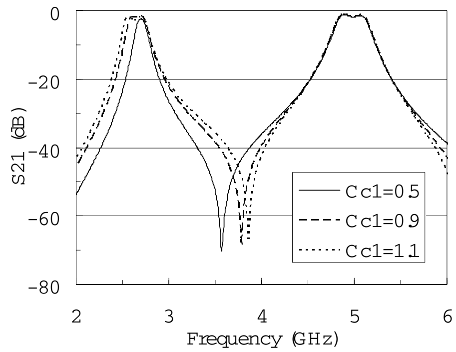


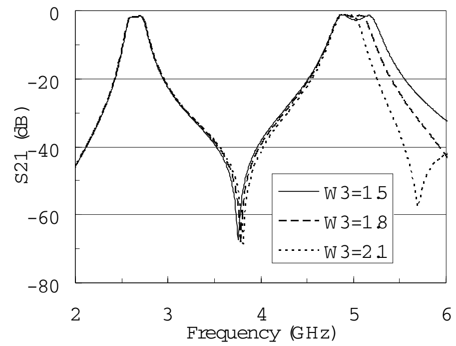
Fig. 10: Filter response of the comb-line filter illustrated in Fig. 9.

The transmission characteristics for a typical example of the dual-band comb-line filter are shown in Fig. 10, where the coupling element 1 overlaps with the λ/4 resonators through an area $0.6 \times 0.9\text{mm}^2$ of conductor while the element 2 does with the λ/2 resonators through an area $0.6 \times 0.6\text{mm}^2$ of conductor. An excellent response suitable for dual-band filters with pass bands at 2.5GHz and 5GHz has been achieved.

Next, the dependence of pass-band characteristics on the coupling elements is studied. Figure 11 shows the transmission characteristics with the dimension of the coupling element as a parameter. In Fig. 11(a), C_{c1} is changed as 0.5mm, 0.9mm, and 1.1mm with w_3 fixed to be 0.9mm while in Fig. 11(b) w_3 is changed as 1.5mm, 1.8mm, and 2.1mm with C_{c1} fixed to be 0.9mm.



(a) C_{c1} is changed as a parameter



(b) w_3 is changed as a parameter

Fig. 11: Filter response of the comb-line filter with the coupling strength as a parameter.

It is easily understood from these results that the pass-band characteristics relating to the pair of λ/4 resonators are under the exclusive control of the coupling element 1 while the coupling element 2 has command of the higher pass band. It should be pointed out that each pass band can be controlled independently with the corresponding coupling element. This is quite a significant feature for filter-designing considerations.

4. CONCLUSIONS

This paper has proposed and studied a new resonator of hybrid structure consisting of a λ/2 stripline resonator folded in a rectangular shape with the short-circuited ends and a λ/4 coplanar waveguide resonator nested in the λ/2 resonator. It has been shown numerically that two resonant frequencies can be controlled independently. As supporting evidences, we have analyzed distributions of surface current density on the resonators and the characteristic impedance of the transmission line forming the resonators. It has been also shown that the spurious-free region between the upper resonant frequency and the nearest resonance of the higher order mode can be extended by introducing a stepped-impedance structure to the λ/4 resonator. A typical model has been fabricated and the basic characteristics of resonance have been confirmed by measured data. Comb-line filters consisting of hybrid resonators with an SIR furnished have been analyzed and good performance suitable for dual-band filters has been achieved.

ACKNOWLEDGEMENT

This work is supported by the Ministry of Internal Affairs and Communications under the grant, "Research and development of fundamental technologies for advanced radio frequency spectrum sharing in mobile communication systems."

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