Switchable Dual-Band Filter with Hybrid Feeding Structure

Ming-Lin Chuang, Ming-Tien Wu, and Pei-Ru Wu

***Abstract*—This study presents a novel switchable dual-band filter. An original concurrent dual-band filter uses a hybrid feeding structure such that the external quality factors of the two designated bands can be obtained individually. Therefore, there is no need for a dual-band impedance transformer and time-consuming parameter tuning is avoided. Stepped-impedance quarter-wavelength resonators are used to reduce the circuit size. Two types of switching circuit are added to the original concurrent dual-band filter to obtain a switchable dual-band filter. The proposed switchable dual-band filter has four possible operating states and thus the two passbands can be enabled or disabled independently.**

***Index Terms*—Switchable dual-band filter, stepped-impedance resonator, quarter-wavelength resonator.**

I. Introduction

Filters are important in communication systems and equipment. Switchable and tunable filters have become increasingly critical as new complicated and multi-band communication standards have been released. This trend has led to the increasing demand for switchable dual-band or multi-band filters. Switchable dual-band filters contain two major parts. The first one is dual-band filter and the other one is switching mechanism.

The simplest way to realize a switchable dual-band filter is to combine two individual single-band filters [1], [2]. Each single-band filter has an independent switching circuit. Although this type of filters is easy to design, an additional matching or combining circuit and large circuit area are required. To reduce the circuit area, a small number of resonators can be used to construct a dual-band filter. Switchable dual-band filters can be designed using a single set of resonators [3]-[7]. However, most switchable dual-band filters based on this approach is hard to satisfy the bandwidth requirement of both bands simultaneously because these filters do not have suitable structures to meet the required external quality factors and coupling coefficients of both bands simultaneously. The dual-band filters with structures that to meet the required external quality factors and coupling coefficients concurrently may need time-consuming parameter tuning or an additional dual-band impedance transformer. Many of these switchable dual-band filers allow only switching between the two passbands meaning that only one operating band can be used at a time [3], [5]. Some filters can only control the state of a single passband [7].

As commonly used switching mechanism is cascading a dual-band frequency selective bandstop structure controlled by a diode. Another common configuration is connecting diodes to the resonators such that the resonance mode can be destroyed to turn off the required passband.

This study proposes a switchable dual-band filter with four independently controlled states, small size, and arbitrary bandwidths. The filter design is based on dual-band filters with a hybrid feeding structure [8] such that the external quality factors and coupling coefficients of the two bands can be controlled independently without a time-consuming trial-and-error procedure. Two types of diode switching circuits are then added to the concurrent dual-band filters. For lower band controlling, an open-stub switching circuit is added to suppress the lower passband if the lower band is to be disabled. For higher band controlling, diodes are added to the higher-band resonators to change resonance mode such that disabling the higher-passband when the higher band is to be disabled. Both passbands can be turned on or turned off independently.

II. Structure of Switchable Dual-Band Filter with Hybrid Feeding Structure

For the switchable dual-band filter, a concurrent dual-band filter is first designed. The filter adopted in this study is based on the previous work about concurrent dual-band filter design [8]. Fig. 1 shows the coupling scheme of the concurrent dual-band filter consisting of two second-order single-band filters. The lower-band filter has a taped feeding structure and consists of resonators R_{L1} and R_{L2}. The lower-band external quality factors are controlled by the tap position and the coupling coefficient between the two resonators is determined by the coupling length L_L and coupling gap g_L. The higher-band filter has a coupled feeding structure and consists of resonators R_{H1} and R_{H2}. The lower-band external quality factors are controlled by the coupling gap, g_f, between resonator R_{Ln} and R_{Hn}. Resonator R_{Ln} and the feeding line constitute the feeding structure of the higher-band filter, marked as the grey region in Fig. 1. The higher-band coupling coefficient is controlled by coupling length L_H and coupling gap g_H. Therefore, the external quality factors and coupling coefficients of the two bands are determined independently.

In this study, resonators R_{L1} and R_{L2} are stepped-impedance quarter-wavelength resonators in order to reduce the circuit size and move the first spurious frequency to a higher frequency to reduce the effect on the higher band

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response. Resonators R_{H1} and R_{H2} are uniform-impedance quarter-wavelength resonators because they do not affect on the lower-band response.

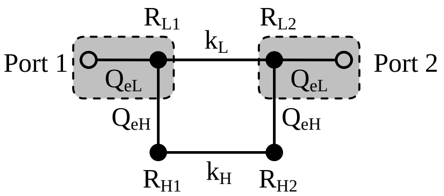

Fig. 1. Coupling scheme of the dual-band filter using hybrid feeding structure.

The above concurrent dual-band filter is modified to become a switchable dual-band filter by adding proper switching circuits, as shown in Fig. 2. To enable or disable the lower passband, a stepped-impedance open stub in conjunction with a PIN diode and its biasing circuit [6] are shunted to the feeding line. The stepped-impedance open stub is designed to have a zero input impedance at the lower band and an infinite input impedance at the higher band. The capacitor connected to port 1 and the capacitor connected to resonator R_{L1} are used to block the DC biasing voltage and retain RF connectivity between resonator R_{L1} and port 1. High impedance resistors provide DC biasing current and retain resonance mode of resonators R_{L1} and R_{L2}. Therefore, if the PIN diode is turned off, the stepped-impedance open stub is disconnected and the filter responses remain the same as those of the original concurrent dual-band filter. When the PIN diode is turned on, the stepped-impedance open stub is connected to the feeding line. At the lower band, the zero input impedance of the open stub grounds the feeding line, blocking the lower passband. At the higher band, the infinite input impedance of the open stub does not affect the feeding line, and thus the higher passband remains the same as that of the original filter.

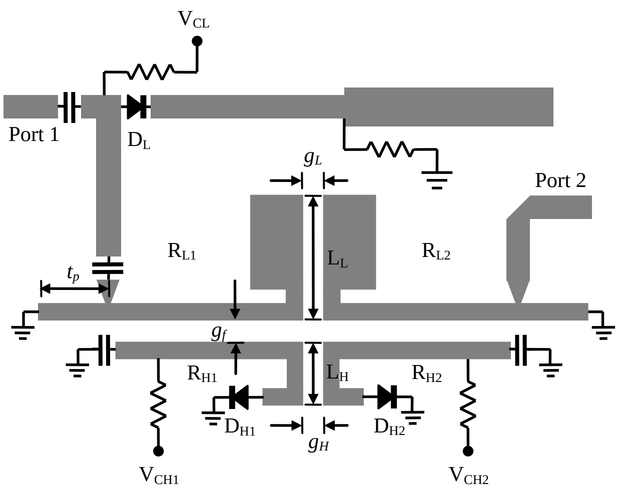

Fig. 2. The proposed switchable dual-band filter using hybrid feeding structure.

The original concurrent dual-band filter has two grounded resonator, namdely R_{H1} and R_{H2}. To enable or disable the higher passband, two grounded PIN diodes are connected to the open-end of resonator R_{H1} and R_{H2}, as shown in Fig. 2. The capacitor connected to the grounded end of resonator R_{H1} and R_{H2} are used to block the DC biasing voltage and retain ground in RF band. High impedance resistors provide DC biasing current and retain resonance mode of resonators R_{H1} and R_{H2}. Because the lower band signal does not pass through the resonators R_{H1} and R_{H2}, this switching circuit only affects the higher passband. When the PIN diode is turned off, resonators R_{H1} and R_{H2} have the same resonance condition as that of the original quarter-wavelength resonator and the higher passband remains that of the same as the original concurrent dual-band filter. When the PIN diode is turn on, resonator R_{H1} and R_{H2} become half-wavelength resonators with two grounded terminals and the resonance frequency becomes twice the original resonance frequency destroying the higher passband. A switchable dual-band filter with two passbands that can be independently controlled is thus obtained.

III. Design Example and Frequency Responses

Based on the above procedure, a switchable Chebyshev dual-band filter with a passband ripple of 0.5 dB is designed in this section. The two designated frequencies are 0.9 and 1.9 GHz. The desired bandwidths of the two bands are 70 MHz and 90 MHz, corresponding to fractional bandwidths of 7.78 % and 4.74 %, respectively. According to traditional single-band filter design theory [9], the required external quality factor and coupling coefficient for the lower band are 18.0379 and 0.0781 and those for the higher band are 29.6177 and 0.0476, respectively.

The filter is designed on a substrate with a dielectric constant of 4.2. The numerical frequency responses are simulated by using Zeland IE3D (now Mentor Graphics HyperLynx). Ideal lumped elements model (i.e., short circuit for forward biased diode and open circuit for reverse biased diode) is applied in simulation. The practical response may degrade due to non-zero resistance and capacitance of forward-biased diodes.

When the diode D_L is reverse-biased (i.e., the stepped-impedance open-stub is disconnected) and diodes D_{H1} and D_{H2} are reverse-biased (i.e., resonator R_{H1} and R_{H2} are quarter-wavelength resonators at the higher passband), the filter remains the concurrent dual-band filter. Figure 3 shows the frequency response of the concurrent dual-band filter.

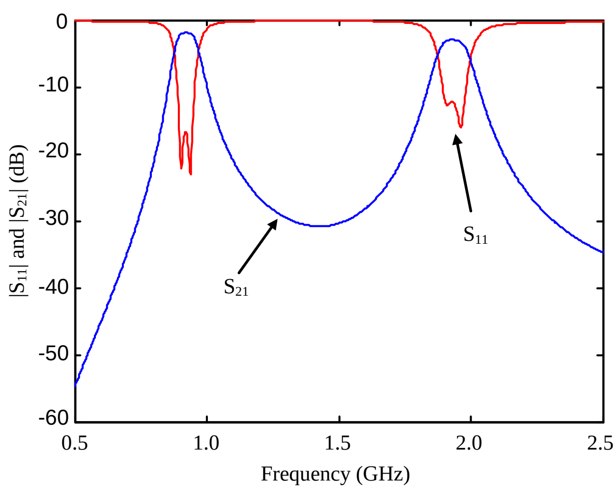

Fig. 3. The simulated frequency response of the proposed switchable dual-band filter with both bands enabled.

When diodes D_L, is forward-biased and diodes D_{H1} and D_{H2} are reverse-biased, the lower passband is suppressed and the filter has only the higher passband. Fig. 4 shows the frequency response of the filter with only the higher passband.

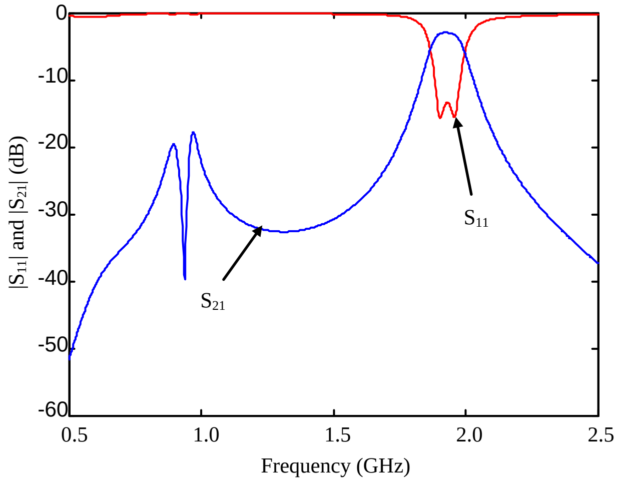

Fig. 4. The simulated frequency response of the proposed switchable dual-band filter with the lower band disabled and the higher band enabled.

When the diode D_L is reverse-biased, and diode D_{H1} or D_{H2} is forward-biased, the higher passband is disabled and the filter has only the lower passband. Fig. 5 displays the frequency responses with only diode D_{H1} turned on and with both diodes D_{H1} and D_{H2} turned on, respectively.

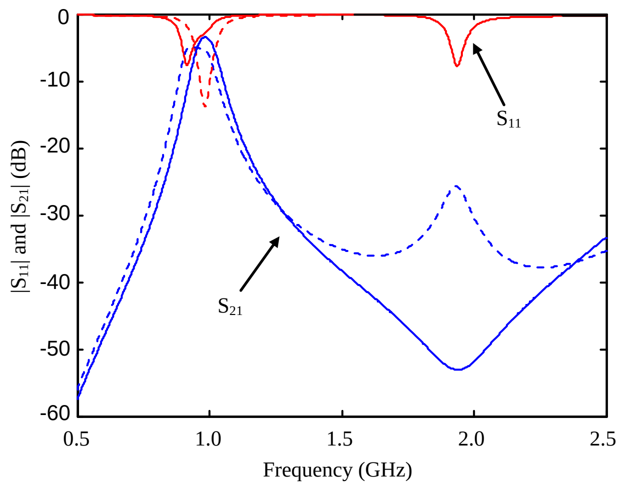

Fig. 5. The simulated frequency response of the proposed switchable dual-band filter with the lower band enabled and the higher band disabled. The solid lines denote diodes D_{H1} and D_{H2} are all turned on, and the dotted lines denote that only one diode is turned on.

The filter has a higher on/off ratio when both diodes are turned off. If only one diode is turned off, the other resonator still resonant at the original frequency, leading to a weak coupling. When diode D_L, D_{H1} and D_{H2} are all forward-biased, the two passbands are disabled and the filter is turned off. Fig. 6 shows the corresponding responses. It is noted that the suppression of the higher passband is better than that of the lower passband. This is due to the lower passband being suppressed but not eliminated by the shunt stub. In contrast, the higher passband disappears because it moves to a higher frequency. The lower-band on/off ratio can be improved by connecting another open stub at the feeding line of port 2.

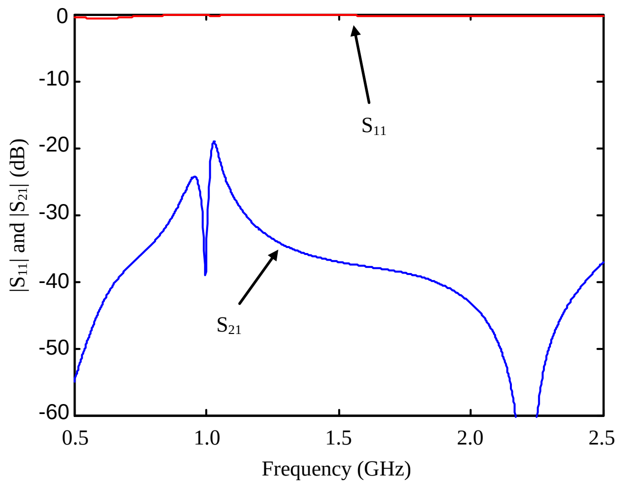

Fig. 6. The simulated frequency response of the proposed switchable dual-band filter with both bands disabled.

The relationships between the diode biasing condition and the filter operating state are listed in Table I. By controlling diode biasing voltages V_{CL}, and V_{CHn}, the two passbands can be enabled or disabled independently.

TABLE I: DIODE BIASING CONDITION AND FILTER OPERATING STATE

Diode D_L	Diode D_{H1} / D_{H2}	Lower band	Higher band
Reversely biased	Forward biased	enabled	enabled
Reversely biased	Reversely biased	enabled	disabled
Forward biased	Forward biased	disabled	enabled
Forward biased	Reversely biased	disabled	disabled

Fig. 5 shows that the lower-passband response degrades when the higher-passband is disabled. This may due to the strong coupling between the lower-band resonators and the higher-band resonators with two grounded terminals.

IV. Improved Configuration

To improve the lower band response when the higher band is disabled, the filter is modified as shown in Fig. 7. In this configuration, the higher band resonator is open at one end and the other end is connected to ground by a PIN diode. Compared to Fig. 2, this configuration does not require additional capacitors to isolate DC biasing voltage and the grounded end of the higher-band resonators.

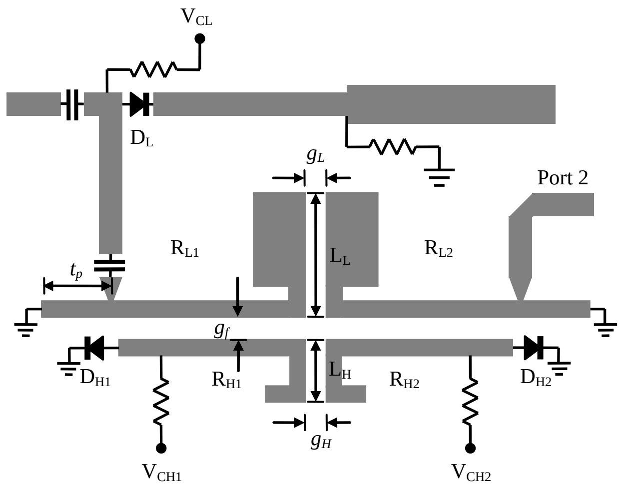

Fig. 7. Improved switchable dual-band filter using hybrid feeding structure.

The switching mechanism is described as follow. When the PIN diode is turned on, resonators R_{H1} and R_{H2} have the same resonance condition as that of the original quarter-wavelength resonator and the higher passband remains that of the same as the original concurrent dual-band filter. When the PIN diode is turn off, resonator R_{H1} and R_{H2} become traditional open-ended half-wavelength resonators and the resonance frequency becomes twice the resonance frequency of the quarter-wavelength resonator and destroys the higher passband. This switchable dual-band filter also has two independently controlled passbands.

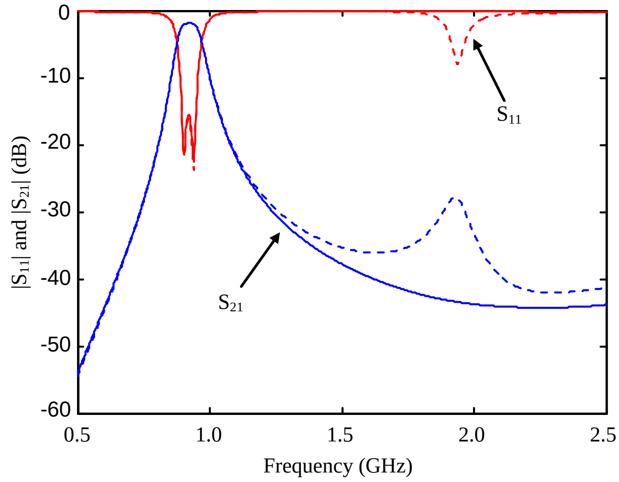

Fig. 8. The simulated frequency response of the proposed switchable dual-band filter with the lower band enabled and the higher band disabled. The solid lines denote diodes D_{H1} and D_{H2} are all turned off, and the dotted lines denote that only one diode is turned off.

Fig. 8 shows the frequency response of the switchable filter with reverse-biased diodes D_{L1} and D_{L2} which disconnect the two open-stubs, and reverse-biased diode D_{H1} and D_{H2} which change the resonance frequency resonators R_{H1} and R_{H2}. Obviously, two reverse-biased diodes produce a better suppression of higher passband. Compared to Fig. 5, the lower passband response is improved obviously when the higher passband is disabled. Figure 9 shows the frequency response of the switchable filter with reverse-biased diodes D_{L1}, D_{L2}, D_{H1}, and D_{H2} which disable the two passbands simultaneously. Table II lists the relationship between the diode biasing condition and the filter operating state.

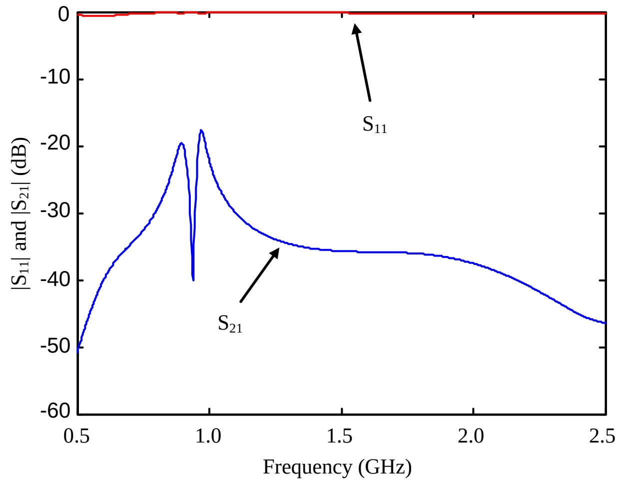

Fig. 9. The simulated frequency response of the proposed switchable dual-band filter with both bands disabled.

TABLE II: DIODE BIASING CONDITION AND FILTER OPERATING STATE OF IMPROVED CONFIGURATION

Diode D_L	Diode D_{H1} / D_{H2}	Lower band	Higher band
Reversely biased	Reversely biased	enabled	enabled
Reversely biased	Forward biased	enabled	disabled
Forward biased	Reversely biased	disabled	enabled
Forward biased	Forward biased	disabled	disabled

V. CONCLUSION

This study proposed a compact switchable dual-band filter with four independent operating states. The original concurrent dual-band filter uses a hybrid feeding structure and can be designed easily without time-consuming parameter tuning to meet the required external quality factors and coupling coefficients for both bands simultaneously. The concurrent dual-band filter is then modified to become a switchable dual-band filter by adding two types of switching circuits. The two passbands can be turned on or turned off independently. The simulated results validate the proposed structure.

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