A compact band selection filter in 0.18- μ m CMOS technology

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Abstract: A compact band selection filter (BSF) is implemented in a 0.18- μ m CMOS technology. The structure consists of a pair of symmetric slow wave anti-coupled line and a shunted transistor. When the transistor is in the off-state, the BSF can work as a low-pass filter. The measured insertion loss is 3 dB, and the return loss is better than 9 dB from DC to 10 GHz. When the transistor is in the on-state, the BSF can work as a bandpass filter. The measured insertion loss is 3 dB, and the return loss is better than 10 dB from 14 to 27 GHz.

Keywords: band selection filter, CMOS, lowpass filter, bandpass filter

Classification: Microwave and millimeter wave devices, circuits, and systems

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1 Introduction

Many standards have been developed for wireless communications that are promising for industrial, scientific, medical and commercial applications. High performance BPF is one of the important components in many microwave/millimeter-wave circuits. To meet the requirements of the selectivity of multi-band or multi-mode RF transceivers, the unwanted signals must be suppressed by multi-band BPFs. Various switchable BPFs are implemented by piezoelectric and pin diode to control their multi-mode resonator [1, 2, 3, 4, 5]. In [1, 2, 3], a dual mode switchable BPF was developed to obtain good selectivity, low insertion loss and high stopband attenuation. To extend the passband bandwidth and the selectivity simultaneously, [5] adopted an open loop structure with pin diodes to switch a narrow-band bandstop filter to a wideband bandpass filter. However, this approach is difficult to implement in CMOS technology because the filter requires large chip area and suffers from high substrate losses in CMOS process. This letter proposes a novel frequency-selecting coupling structure (FSCS) to implement a high selectivity, wide stopband and compact band selection filter. The proposed FSCS is realized by a slow wave anti-coupled line which is realized by a shorted circuit at a shunted transistor. Meanwhile, the adjustment of the capacitance of the input/output feed lines [6] can introduce two transmission zeros (TZs) in the upper stopband which effectively enhances the stopband level and bandwidth.

2 Structure of the band selection filter

Figs. 1 (a) and 1 (b) shows the schematic layout and equivalent circuit model of the proposed BSF, which consists of two sections of the anti-coupled line (L_1 and L_2), four capacitors (C_1 , C_2 , C_3 and C_4) and one transistor M_n . L_1 and L_2 have the characteristic admittances of Y_1 , and Y_2 with electrical lengths of θ_1 and θ_2 , respectively. Assuming that the transistor M_n is an ideal transistor ($C_{off} = 0$ and $R_{on} = 0$). A control voltage V_C is applied to the gate of the transistor M_n . When the $V_C = 0$ V (off-state), the transistor M_n can be modeled as an open-circuited stub ($Z_C = \infty$); the BSF then operates as a low-pass filter. When the $V_C = 1.8$ V (on-state), the transistor M_n can be modeled as a short-circuited stub ($Z_C = 0$); the BSF then operates as a band-pass filter. Since the structure is symmetrical with respect to the plane AB, the commonly used even/odd-mode analysis can be applied to the BSF. For even-mode excitation, the even-mode equivalent circuit is shown in Fig. 1 (c). The input admittance for even-mode can be expressed as (1).

$$Y_{even} = Y_0 \frac{Y_L^e(V_c) + jY_0 \tan \theta_1}{Y_0 + jY_L^e(V_c) \tan \theta_1} \quad (1)$$

where $\theta = \theta_1 = \theta_2$, $Y_0 = Y_1 = Y_2$, Y_0 is the system characteristic impedance, Y_L^e , and Y_{even} are the input admittance looking into the points a, and b, respectively. When $V_c = 0$ V (off-state), $Y_L^e = jY_0 \tan \theta_2$, and when $V_c = 1.8$ V (on-state), $Y_L^e = -jY_0 \cot \theta_2$. The resonance condition is $Y_{even} = 0$,

Fig. 1. (a) Schematic layout. (b) Equivalent circuit of the proposed BSF. (c) Even-mode. (d) Odd-mode.

thus, the resonance frequencies (i.e., $f_{\text{even_on}}$ for on-state, and $f_{\text{even_off}}$ for off-state) can be derived as (2) and (3).

$$f_{even_off} = nc / (2(L_1 + L_2)\sqrt{\epsilon_{re}}) \quad (n = 1, 2, \dots), \quad (2)$$

$$f_{even_on} = (2n - 1)c / (4(L_1 + L_2)\sqrt{\epsilon_{re}}) \quad (n = 1, 2, \dots) \quad (3)$$

where c is the velocity of the light in free space, and ε_{re} is the effective dielectric constant. For odd-mode excitation, there is a voltage null along the symmetrical plane AB, therefore, the input admittance for odd mode shown in Fig. 1 (d) is derived as (4).

$$Y_{odd} = Y_0 \frac{Y_L^o + jY_0 \tan \theta_1}{Y_0 + jY_L^o \tan \theta_1} + j\omega C_2 \quad (4)$$

where $Y_L^o = (-jY_0 \cot \theta_2 + j\omega C_1)$, Y_{odd} and Y_L^o are the input admittances looking into the points a, and b, respectively. Comparing (4) with (1), it indicates that the odd-mode input admittances can be controlled by the C_1 and C_2 . Then, under the resonance condition $Y_{\text{odd}} = 0$, the odd-mode resonance frequency can be extracted as

$$\tan \theta_1 = \frac{Y_0(\omega(C_1 + C_2) - \cot \theta_2)}{\omega^2 C_1 C_2 - Y_0^2}. \quad (5)$$

By solving (5), the odd-mode resonance frequency can be tuned by adjusting the electric length θ_1 , θ_2 with the parameter of the C_1 and C_2 .

3 Filter design

To verify the above results, the circuit-simulator Agilent ADSTM software is employed. In Fig. 1(a), two $\lambda/4$ feed-lines with $50\ \Omega$ characteristic impedances are utilized to feed the proposed BSF. The passband frequencies are mainly determined by the entire length L_1 and L_2 . In our design, the transistor M_n can independently control the BSF. When the M_n is in the off-state, the open-circuited stub is connected. As shown in Fig. 2(a), by changing the capacitance C_1 , the bandwidth of stopband and its level are changing. The increase of the capacitance C_1 increases the stopband level but slightly decreases the bandwidth. In addition, two finite transmission zeros ($f_{Z1'}$, $f_{Z2'}$) can be generated near the passband edge for the harmonics suppression. When the M_n is in the on-state, the short-circuited stub is connected. In Fig. 2(b), the existence of both even- and odd-mode in the resonator results in a bandpass response. At this state, the filter also obtains

Fig. 2. Frequency response of the proposed BSF (a) Effects of the C_1 on the stopband level with $C_2 = 224\text{ fF}$, $C_3 = 0\text{ fF}$. (b) Effects of the C_1 on the bandwidth of passband with $C_2 = 224\text{ fF}$, $C_3 = 0\text{ fF}$. (c) Effects of the C_3 on the stopband enhancement under the f_{Z2} and f_{Z3} with $C_1 = 340\text{ fF}$, $C_2 = 224\text{ fF}$.

two transmission zeros (f_{Z1} , f_{Z2}). Meanwhile, adjusting the capacitance C_1 and C_2 can control the bandwidth of passband.

To improve the rejection level and extend stopband bandwidth, a pair of bypass capacitors C_3 is incorporated into the BSF, which the external capacitive coupling between input/output feed-lines can produce another transmission zero f_{Z3} particularly in the upper side of the stopband. As shown in Fig. 2(c), the stopband bandwidth is controlled by varying the value of C_3 . It has been shown a significant stopband improvement of asymmetric rejection response with high selectivity on the upper side of the passband's skirt, whereas the fundamental even-mode resonant frequency is preserved.

4 Experimental results

The band selection filter was fabricated using tsmc 0.18- μm CMOS 1P6M technology. Fig. 3(a) shows the chip photo of proposed band selection filter whose size is $0.672 \times 0.485 \text{ mm}^2$ including pads. The length of the L_1 and L_2 are $236 \mu\text{m}$, and $175 \mu\text{m}$, respectively. The size of transistor M_n is $480/0.18 \mu\text{m}$ with simulated R_{on} and C_{off} of 2Ω and 0.02 pF . The control voltage V_c for the transistor M_n is varied between 0 and 1.8 V. Figs. 3(b) and 3(c) shows the simulation and measurement results of the band selection filter with $C_1 = 340 \text{ fF}$, $C_2 = 224 \text{ fF}$, and $C_3 = 159 \text{ fF}$. When the transistor M_n operates at off-state, the measured insertion loss is better than 3 dB from DC to 10 GHz, and the return loss is better than 9 dB from DC to 10 GHz. At on-state, the measured insertion loss is less then 3 dB and the

(a)

(b)

Fig. 3. Measured and simulated result of the reflection and insertion losses (a) Chip photo. (b) Transistor M_n operates in the off state. (c) Transistor M_n operates in the on state.

return loss is greater than 10 dB over the passband range of 14 to 27 GHz. The transmission zeroes are located at 8 GHz and 32 GHz, respectively. As can be observed in Fig. 3(b) and Fig. 3(c), the rejection of these two bands is higher than 17 dB.

5 Conclusion

A compact slow wave anti-coupled line with loaded a shunted transistor is presented for a band selection filter. The LPF and BPF can be reconfigured by switching the on/off state of a transistor which presents either open or short termination of condition. Meanwhile, two reconfigurable TZs can be produced for wide passband operation and wide stopband with good rejection level. Beside, the cross-coupled capacitance can improve the upper side passband selectivity and stopband bandwidth. The proposed filter features of compact size and good passband/stopband performance which is attractive to the UWB and other wireless communication applications.

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