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Analysis of Nonlinear Behavior in Tunable Filters using SAW/BAW Resonators and Variable Capacitors

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1. Introduction

Recently, tunable filters employing SAW/BAW resonators and variable capacitors (VCs) are paid much attention[1-2]. They would make it possible to reduce head acount of discrete compnents such as switches and filters in the radio-frequency (RF) frontend of mobile phones[3]. Although diode-type VCs offer wide tunability, they are expected to exhibit relatively strong non-linearity. On the other hand, micro-electro-mechanical-systems (MEMS) type ones are believed to possess relatively weak non-linearity, however they are physically large.

This paper discusses how non-linearity of diode-type VCs influences the non-linear characteristic of tunable filters.

2. Tunable filter configurations

Fig. 1 shows two configurations of the tunable filter used for the discussion. They employ VCs and SAW/BAW resonators with the capacitance ratio γ of 3.3 achievable using SAW resonators employing Cu-grating/15°YX-$LiNbO_3$ substrate structure[4]. For the configuration (a), the resonance frequencies f_{rs} and f_{rp} of resonators in seires and parellel arms are set to be 1,000 and 860 MHz, respectively, and the shunt capacitoces of these resonators are set to be 1.98 and 6.36 pF. For the configuration (b), f_{rs} and f_{rp} are set to be 900 and 880 MHz, respectively.

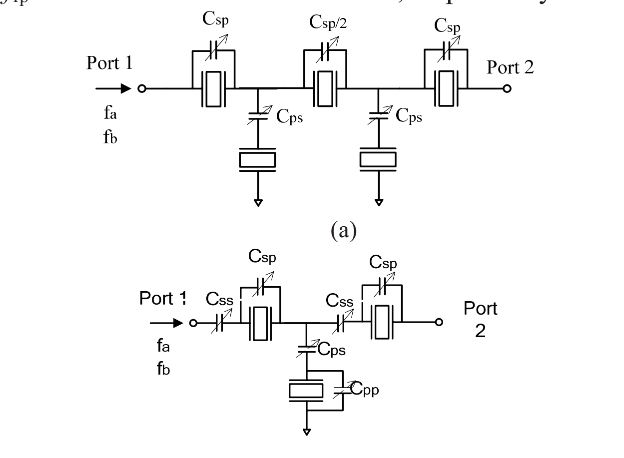

Fig. 1 Filters with one VCs to each resonator, (b) filters with two VCs to each resonator

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We employed Infinion BB831 as diode-type VCs, and analyzed the second-order intermodulation distortion (IMD2) of the filters when two signals signals “a” and “b” are applied to the port “1”. For the analysis, (a) the jammer frequency f_b is fixed, (b) the signal f_a is scanned from 0.7 GHz to 1.2 GHz, and (c) IMD2 output I_{IMD2} with $f=f_a+f_a$ is selectively detected at the port “2”.

In the following analysis, input power I_a and I_b for two signals are fixed at 0 dBm. Note that unless non-linearity is not significant, I_{IMD2} for aribtrary input power can be estimated by the formula $I_{IMD2}=I_2+I_a+I_b$ in decibels, where I_2 is I_{IMD2} calculated for $I_a=I_b=0$ dBm.

3. IMD2 of Tunable Filters

Fig.2 shows f_a dependence of $|S_{21}|$ and I_{IMD2} of the circuit shown in Fig.1(a) . In the figure, solid lines a and b show the results when C_{sp}=1.2 pF and C_{ps}=16 pF, while broken lines c and d show the results when C_{sp}=0.75 pF and C_{ps}=6.6 pF.

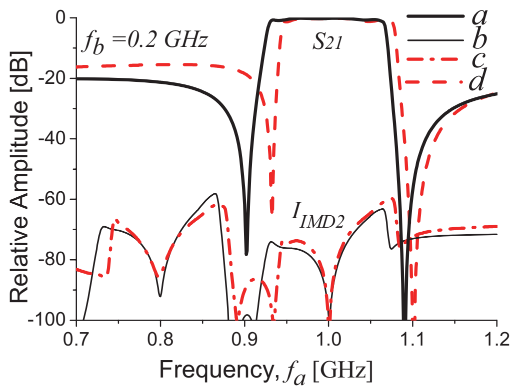

Fig. 2 f_a dependence of $|S_{21}|$ and I_{IMD2} of the circuit shown in Fig. 1(a). Solid lines (a and b): C_{sp}=1.2 pF and C_{ps}=16 pF, and broken lines (c and d): C_{sp}=0.75 pF and C_{ps}=6.6 pF

There are two regions where I_{IMD2} is large. First one is at f_a≈0.8 GHz, where the generated IMD2 signal with $f=f_a+f_b$ can pass through the filter structure with small attenuation. Second one is at f_a≈1.0 GHz, where the input signal with $f=f_a$ can pass through the filter structure with small attenuation.

It is seen that I_{IMD2} at f_a≈1.0 GHz becomes large when f_a approaches to the upper null close to the passband, which is caused by the parallel resonace of resonators in series arms with C_{sp}. This I_{IMD2} behavior is due to the fact that the current flows though C_{sp} takes a maximum value when f_a is close to the upper null but within the passpand. I_{IMD2} at

f_a≈1.0 GHz also becomes large when f_a approaches to the lower null, which is caused by the series resonance of resonators in parallel arms with C_{ps}. This I_{IMD2} behavior is due to the fact that the current flow through C_{ps} takes a maximum value when f_a is close to the lower null but within the passband.

As shown in the figure, with an increase in C_{sp}, the upper null and the I_{IMD2} peak position move downward, and then the peak value slightly decreases. On the other hand, with a decrease in C_{ps}, the lower null and the I_{IMD2} peak position move upward, and the peak value increases slightly. These behaviors might be mainly due to variation of non-linearity generation in VCs with control voltage.

Frequency dependence of I_{IMD2} at f_a≈0.8 GHz looks similar to those at f_a≈1.0 GHz. However, their frequency dependences are occurred by different mechanisms. Namely, non-linear output generated across C_{sp} is almost frequency indepent in this region because f_a and f_b are far from the resonance. Nevertheless, I_{IMD2} becomes large when f_a+f_b approaches to the upper nulls. This is because impedance of the resonators in series arms becomes large for f_a+f_b due to the anti-resonance at the upper null, while admittance of the resonators in parallel arms becomes large for f_a+f_b due to the resonance at the lower null. This results in large non-linear voltage generated across C_{sp} and C_{ps}.

Fig. 3 shows frequency f_a dependence of $|S_{21}|$ and I_{IMD2} in circuit shown in Fig.1 (b). The VC setting is given in Table 1. I_{IMD2} is large when either f_a+f_b or f_a locates in the filter pass band. Comparison of Fig. 3 with Fig. 2 indicates that I_{IMD2} is less frequency dependent within the frequency regions and about

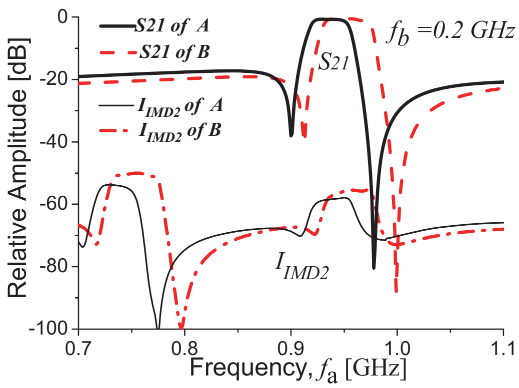

Fig. 3 f_a dependence of $|S_{21}|$ and I_{IMD2} of the circuit shown in Fig.1 (b). Solid lines for setup A, and Broken lines for setup B.

Table 1 VCs setting of filters

	C_{ss} (pF)	C_{sp} (pF)	C_{ps} (pF)	C_{pp} (pF)
Setup A	5.3	1.4	37	12
Setup B	2.6	0.6	17.5	6.6

10~15 dB larger than that generated in the circuit shown in Fig.1 (a). This difference is caused by influence of the non-linear signal generated by C_{ps} and C_{ss}.

Fig. 4 shows variation of I_{IMD2} with Q values Q_s and Q_p of resonators in series and parallel arms, respectively in circuit shown in Fig.1 (b). It is seen that height of the left peak slightly increases with Q_p and that of the right peak does slightly with Q_s. This is explained by the fact that Q_p and Q_s predominantly influence insertion losses at lower and upper passband edges, respectively. Although not shown, variation of I_{IMD2} with Q values is similar to that of the filter transmission characteristics.

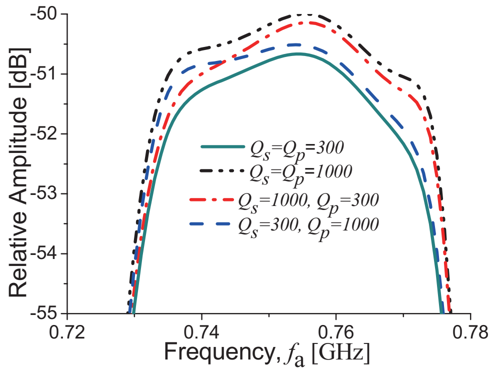

Fig. 4 Q dependence to I_{IMD2}.in the circuit shown in Fig.1 (b) with capacitors value in setup B.

4. Conclusion

The IMD2 characteristic of two types of tunable filters using SAW/BAW Resonators and VCs were simulated. Firstly, we discuss the IMD2 response when one VC is connected to respective resonator. It was shown that the IMD2 become large when the input frequency or generated signal is in the filter pass band. Sencondly, we dicussed the IMD2 response of when VCs are connected in both parallel and series with all of the resonators. This circuit can supply wider tunable range[2], but sustains larger nonlinearity. Finally, It was pointed out that Q values of resonator has scarcely affect on the IMD2 performance of filters.

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