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Multiple Notch Filter Using On-Die BAW MIM Cap

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MULTIPLE NOTCH FILTER USING ON-DIE BAW MIM CAP

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I. INTRODUCTION

Qorvo has increasingly focused on antennaplexer modules, which often require very large passbands, and in some cases still require steep skirts. When a very large passband with a steep transition is required the solution is often an acoustic notch filter. When a notch filter is multiplexed with other filter bands, there are typically rejection requirements at all other filter band frequencies to create isolation between the ports and keep multiplexing loss low. This typically requires one notch filter per reject band, this can be acoustic for steep transition requirements or simple an LC tank circuit if requirements are less stringent. This need drives up cost and consumes precious space on highly integrated modules, especially as the level of multiplexing increases. In order to increase integration, for additional rejections not requiring acoustic notches it is proposed that additional notches can be incorporated on a single acoustic die.

II. DISCUSSION

This invention relates to notch filters and increasing integration by incorporating capacitance elements on the acoustic die. Previously on-die capacitors have been described as a way to modify the coupling coefficient of individual resonators or as a matching element on bulk acoustic wave (BAW) bandpass filters [1], however, there has been no known mention of the application for a multi-notch filter as described here. This application is likely to become very valuable as antennaplexer integration increases in terms of both size constraints and the number of filter bands multiplexed in a single module.

The invention will be described in the context which it was developed, based on the needs of an existing antennaplexer solution. Simulated performance for the module with spec lines is shown in Figure 1. First, the steep transition from 1dB loss at 1518MHz to 20dB rejection at 1559MHz requires an acoustic solution. The required low-mid-band (LMB) cell passband of 1100-1518MHz corresponds to a fractional bandwidth of roughly 32%, which would be very difficult to achieve with an acoustic bandpass filter. The best solution in this case is a notch filter, however, the additional rejections at 2.4GHz and 5GHz require additional notch filter elements. Since there is no need for a steep transition, a simple LC tank circuit can be used. Typically, this would require two additional SMDs for the two capacitors, however, there is often very little free space for this many additional SMDs in highly integrated modules. Incorporating these capacitors on-die allows increased integration such that the module can fit within the desired footprint while still maintaining high performance.

The die implementation of the first dual-notch BAW filter is shown in Figure 2. In this implementation, the two series acoustic resonators create the L1 notch at 1559-1606MHz where steep transitions are needed on the lower side. The capacitor electrodes are formed by two pre-existing process layers, the bottom electrode layer (also used for interconnects), and the highest metal reflector layer (R4). The uppermost reflector layer (R5) is SiO2 and forms the dielectric of the MIM capacitor. It is possible for this capacitor embodiment to be placed under resonators which requires no or minimal additional die space but given the aniti-parallel resonator splits used here it is not advisable implemented for this particular die. Figure 1 illustrates a simulated in-module LMB cell path with spec lines and topology describing how the rejections are created. The passband is 1100-1518MHz, with rejection specs at 1559-1606MHz, 2403-2481MHz, and 5150-5925Mhz. These rejections correspond to the L1, 2.4GHz Wi-Fi and 5GHz Wi-Fi bands that are multiplexed with the cell band to form the quadplexer.

Figure 2 illustrates a die-only simulation of first implementation of dual-notch die. This die implements the topology shown in Figure 1 with two series acoustic resonators creating the rejection at 1575MHz and the capacitor creating the rejection at 2450MHz. The capacitor is created using two pre-existing layers in the die, the bottom electrode layer and the uppermost metal reflector layer. Note that the rejection in-module achieves deeper rejection with steeper skirts due to the effects of the acoustic Wi-Fi bandpass filter impedance.

Figure 3 illustrates a module simulation (black) and measurement (red) for first sample build down-selected variant. The 10 parts shown are not cherry picked and no outliers had to be removed. The only significant differences are related to higher frequency acoustic modes that are not included in simulation. These measurements verify the approach is manufacturable and can be easily designed and implemented using Qorvo's standard design tools and process.

Figure 4 illustrates simulation and measurement details highlighting LMB cell path defined by the dual notch filter with passband (top-left), acoustic reject band for L1 frequencies (top-right), and LC reject band for WiFi frequencies (bottom. Both the acoustic and LC reject bands show good rejection and reasonable variation. Figure 5 illustrates simulation and measurement details highlighting other bands impacted by the dual notch filter. The WiFi passband (top) shows reasonable loss facilitated by high rejection from the dual notch filter. The L1 passband (bottom-left) difference in loss is related to a difference in simulated and measured Q and k2e, and is not related to the notch filter as verified in standalone measurements. The 5GHz WiFi passband avoids loading and blocks high frequency acoustic mode impacts using a related approach with a notch and bandpass integrated in a single IPD. Figure 6 illustrates simulated and measured results showing wideband results for other bands

Other Embodiments

The MIM capacitor can also be implemented in other ways in addition to the reflector MIM capacitor described. One known option is with the passivation layer (SiN) which has also been previously described and is a released Qorvo process, but possibly not discussed in public literature. The passivation layer MIM capacitor is likely achievable in many other technologies. This is also applicable to bandpass filters and other types of die. This project also created a notch/bandpass two-in-one die using Global Foundries IPD process.This is particularly applicable to BAW technology, since SAW technology can create multiple acoustic notches on the same die simply by varying the electrode pitch. This is not as practical or manufacturable in BAW since different frequencies require different layer thicknesses, thus the need for a workaround of using an LC tank to create additional notches.

The R5MIM reflector MIM capacitor is particularly applicable to solidly mounted resonators (SMR) since the layers needed are already included. It would be more difficult, but it’s conceivable that something similar could be done between the bottom electrode of a film bulk acoustic resonator (FBAR) and a metallized bottom of the air cavity.

Acronyms

BAW – Bulk Acoustic Wave
SAW – Surface Acoustic Wave
SMR – Solidly Mounted Resonator
FBAR – Film Bulk Acoustic Resonator
IPD – Integrated Passive Device
MIM Capacitor – Metal-Insulator-Metal Capacitor
SiN – Silicon Nitride
LC – Inductor-Capacitor

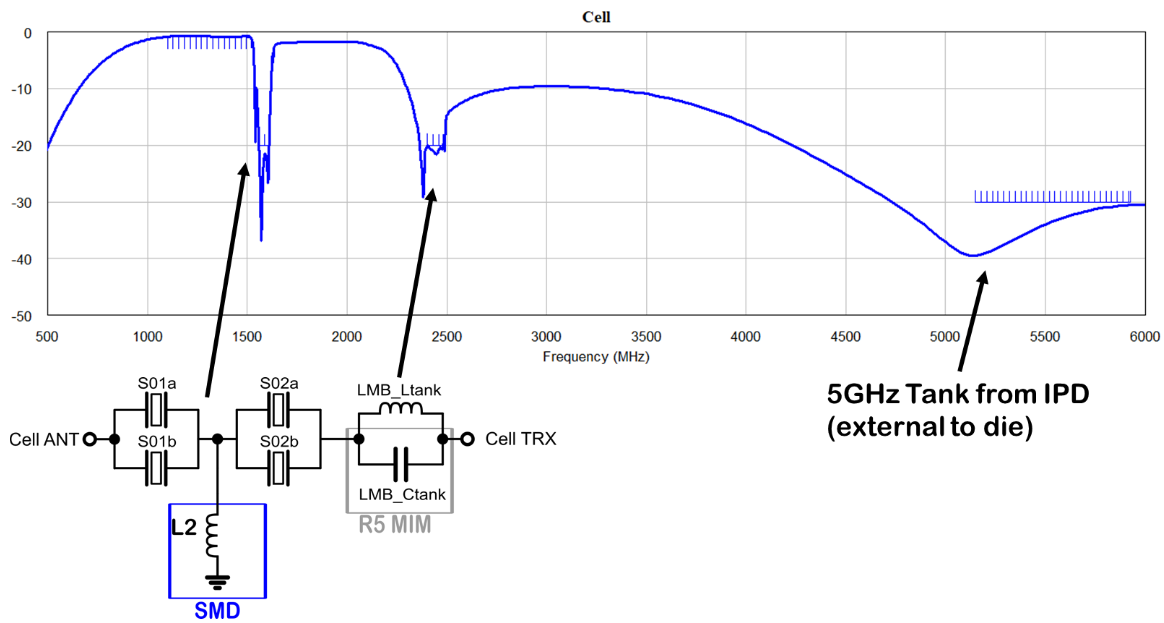

Figure 1

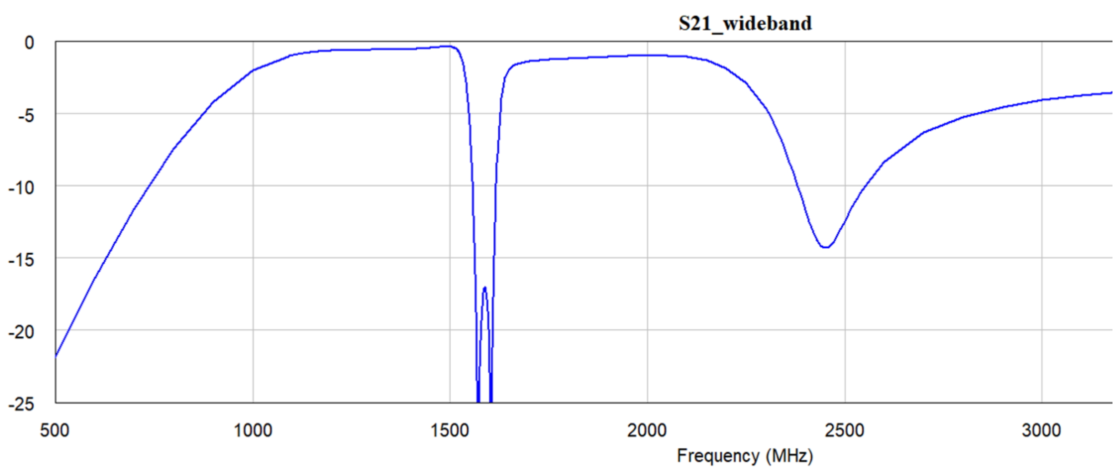

Figure 2

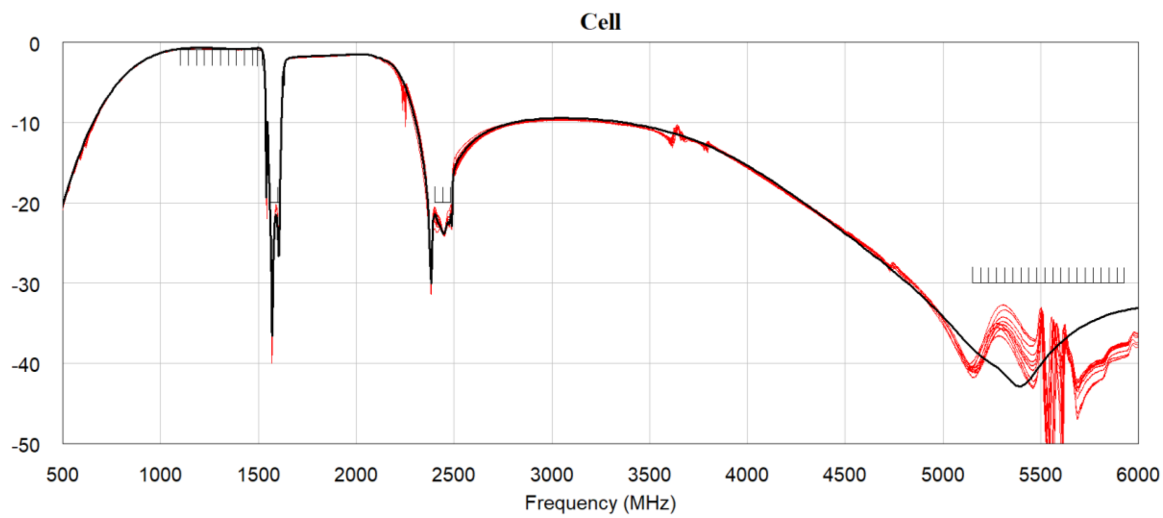
Cell
0
-10
-20
-30
-40
-50
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
Frequency (MHz)

Figure 3

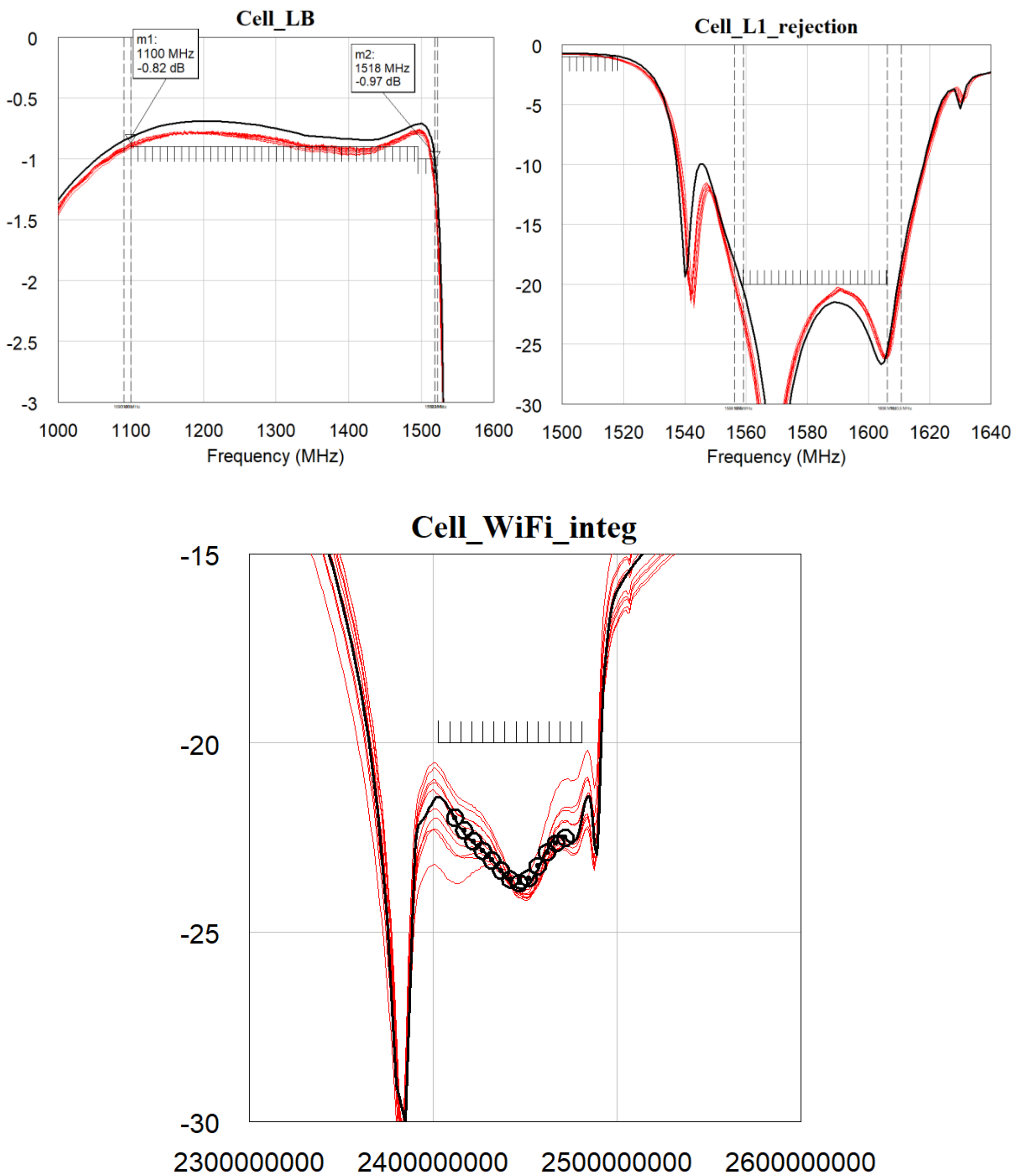
Cell_LB
m1:
1100 MHz
-0.82 dB
m2:
1518 MHz
-0.97 dB
0
-0.5
-1
-1.5
-2
-2.5
-3
1000
1100
1200
1300
1400
1500
1600
Frequency (MHz)
Cell_L1_rejection
0
-5
-10
-15
-20
-25
-30
1500
1520
1540
1560
1580
1600
1620
1640
Frequency (MHz)
Cell_WiFi_integ
-15
-20
-25
-30
2300000000
2400000000
2500000000
2600000000

Figure 4

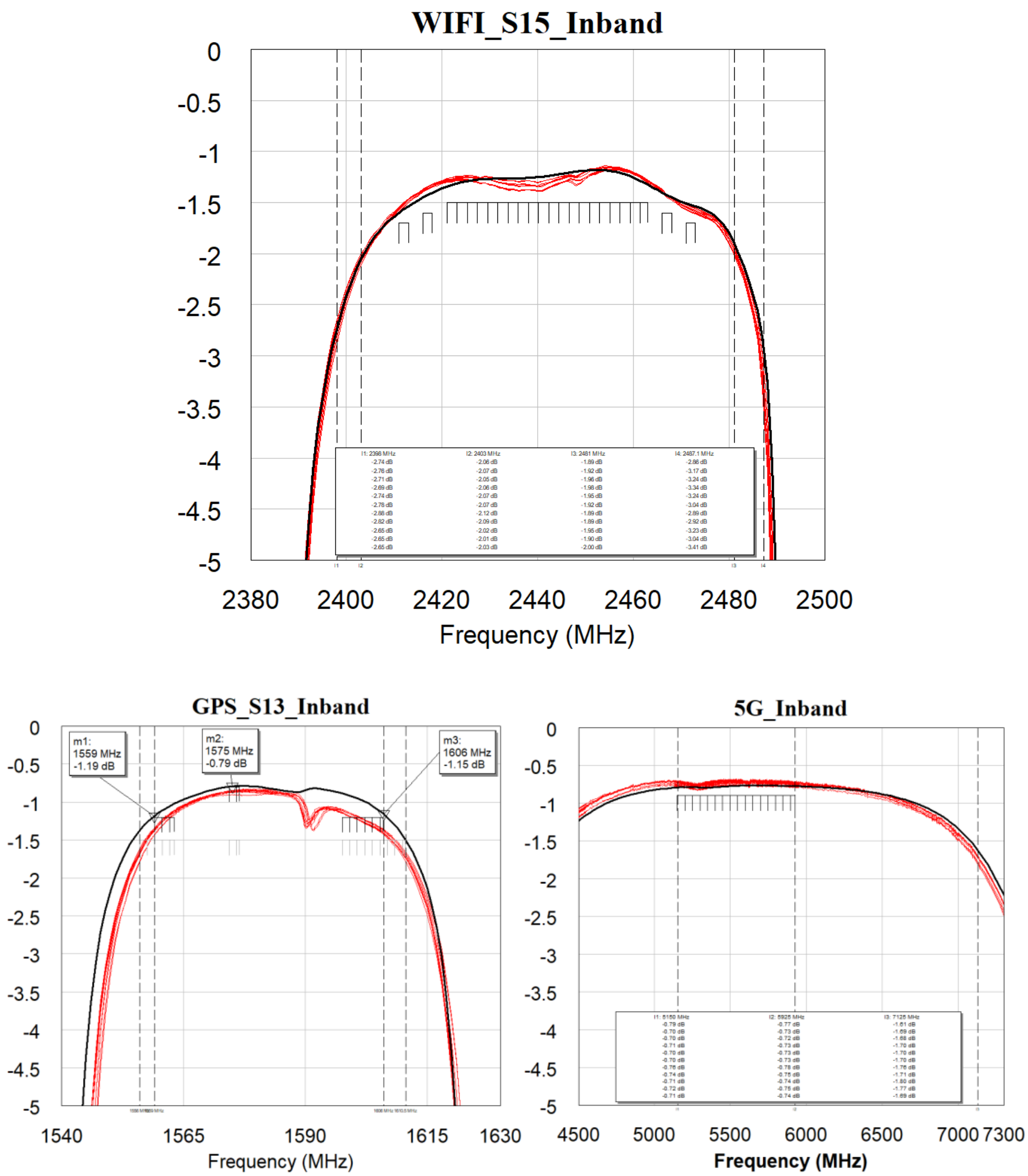
WIFI_S15_Inband
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
-5
2380
2400
2420
2440
2460
2480
2500
Frequency (MHz)
GPS_S13_Inband
m1:
1559 MHz
-1.19 dB
m2:
1575 MHz
-0.79 dB
m3:
1606 MHz
-1.15 dB
1540
1565
1590
1615
1630
Frequency (MHz)
5G_Inband
4500
5000
5500
6000
6500
7000
7300
Frequency (MHz)

Figure 5


GPS_S13_Wideband
Frequency (MHz)
WIFI_S15_Wideband
Frequency (MHz)
5G_Wideband
Frequency (MHz)

Figure 6