[0005] Filtering relatively high frequency radio frequency signals and meeting stringent filtering specifications can be difficult. Accordingly, improved filters are desired to filter relatively high frequency signals and meet performance specifications.

SUMMARY

[0006] Without limiting the scope of the claims, some prominent features of this disclosure will now be briefly described.

[0007] In one aspect, there is provided hybrid acoustic LC filter with harmonic suppression, the hybrid acoustic LC filter comprising:

a first hybrid passive/acoustic filter configured to filter a radio frequency signal, the first hybrid passive/acoustic filter including at least a first acoustic resonator in parallel with a first inductor, the first acoustic resonator and first inductor in series with a second inductor and a second acoustic resonator in series with a third inductor, and at least a first non-acoustic passive component having at least a first capacitor in parallel with a fourth inductor, the first capacitor and fourth inductor further connected in parallel with the first and second acoustic resonators, and a second non-acoustic passive component having at least a second capacitor in parallel with a fifth inductor, the second capacitor and fifth inductor further connected in parallel with the first acoustic resonator; and a non-acoustic LC filter cascaded with the first hybrid passive/acoustic filter, the non-acoustic LC filter configured to suppress a harmonic of the radio frequency signal, the non-acoustic LC filter including a first LC resonant circuit connected to a series LC tank, a second LC resonant circuit connected to the series LC tank, and a first bridge capacitor coupled to an input and the series LC tank, and a second bridge capacitor coupled to the first LC resonant circuit and the series LC tank. In an aspect, there is provided multiplexer comprising:

a first filter configured to filter a radio frequency signal, the first filter including a hybrid passive/acoustic filter and a non-acoustic LC filter cascaded with the hybrid passive/acoustic filter, the hybrid passive/acoustic filter including at least a first acoustic resonator in parallel with a first inductor, the first acoustic resonator and the first inductor in series with a second inductor and a second acoustic resonator in series with a third inductor, and at least a first non-acoustic passive component having at least a first capacitor in parallel with a fourth inductor, the first capacitor and the fourth inductor connected in parallel with the first and second acoustic resonators, a second non-acoustic passive component having at least a second capacitor in parallel with a fifth inductor, the second capacitor and the fifth inductor further connected in parallel with the first acoustic resonator, and the non-acoustic LC filter configured to suppress a harmonic of the radio frequency signal, the non-acoustic LC filter including a first LC resonant circuit connected to a series LC tank, a second LC resonant circuit connected to the series LC tank, and a first bridge capacitor coupled to an input and the series LC tank, and a second bridge capacitor coupled to the first LC resonant circuit and the series LC tank; and a second filter coupled to the first filter at a common node. In on aspect, there is provided a wireless communication device comprising:

a radio frequency front end including a filter configured to filter a radio frequency signal, the filter including a hybrid passive/acoustic filter and a non-acoustic LC filter cascaded with the hybrid passive/acoustic filter, the hybrid passive/acoustic filter including at least a first acoustic resonator in parallel with a first inductor, the first acoustic resonator and first inductor in series with a second inductor and a second acoustic resonator in series with a third inductor, and at least a first non-acoustic passive component having at least a first capacitor in parallel with a fourth inductor, the first capacitor and fourth inductor further connected in parallel with the first and second acoustic resonators, a second non-acoustic passive component having at least a second capacitor in parallel with a fifth inductor, the second capacitor and fifth inductor further connected in parallel with the first acoustic resonator, and the non-acoustic LC filter configured to suppress a harmonic of the radio frequency signal, the non-acoustic LC filter including a first LC resonant circuit connected to a series LC tank, a second LC resonant circuit connected to the series LC tank, and a first bridge capacitor coupled to an input and the series LC tank, and a second bridge capacitor coupled to the first LC resonant circuit and the series LC tank; and an antenna in communication with the radio frequency front end, the antenna configured to transmit a filtered version of the radio frequency signal with the harmonic suppressed. One exampleof this disclosure is a cascaded filter for radio frequency filtering. The cascaded filter includes a hybrid acoustic LC filter and a non-acoustic LC filter cascaded with the hybrid acoustic LC filter. The hybrid acoustic LC filter is configured to filter a radio frequency signal. The hybrid acoustic LC filter includes a first acoustic resonator on an acoustic resonator die, a second acoustic resonator, a capacitor external to the acoustic resonator die, and an inductor external to the acoustic resonator die. The non-acoustic LC filter includes an LC circuit.

[0008] The hybrid acoustic LC filter further can further include a second inductor in parallel with the second acoustic resonator, in which the second acoustic resonator is arranged as a shunt resonator in series with the inductor.

[0009] The first acoustic resonator and the second acoustic resonator can be shunt resonators. The capacitor and the inductor can be arranged as an LC tank coupled between the first acoustic resonator and the second acoustic resonator.

[0010] The first acoustic resonator can be coupled to a node in a signal path between the LC circuit and both the inductor and the capacitor.

[0011] The first acoustic resonator and the second acoustic resonator can be bulk acoustic wave resonators. For example, the first acoustic resonator and the second acoustic resonator can be film bulk acoustic wave resonators.

[0012] The LC circuit of the non-acoustic LC filter can include integrated passive devices on an integrated passive device die. The inductor of the hybrid acoustic LC filter can be a surface mount inductor. The inductor of the hybrid acoustic LC filter can include a

1. A hybrid acoustic LC filter with harmonic suppression, the hybrid acoustic LC filter comprising:

a first hybrid passive/acoustic filter configured to filter a radio frequency signal, the first hybrid passive/acoustic filter including at least a first acoustic resonator in parallel with a first inductor, the first acoustic resonator and first inductor in series with a second inductor and a second acoustic resonator in series with a third inductor, and at least a first non-acoustic passive component having at least a first capacitor in parallel with a fourth inductor, the first capacitor and fourth inductor further connected in parallel with the first and second acoustic resonators, and a second non-acoustic passive component having at least a second capacitor in parallel with a fifth inductor, the second capacitor and fifth inductor further connected in parallel with the first acoustic resonator; and

a non-acoustic LC filter cascaded with the first hybrid passive/acoustic filter, the non-acoustic LC filter configured to suppress a harmonic of the radio frequency signal, the non-acoustic LC filter including a first LC resonant circuit connected to a series LC tank, a second LC resonant circuit connected to the series LC tank, and a first bridge capacitor coupled to an input and the series LC tank, and a second bridge capacitor coupled to the first LC resonant circuit and the series LC tank.

2. The hybrid acoustic LC filter of claim 1 wherein the non-acoustic LC filter is a notch filter.

3. The hybrid acoustic LC filter of claim 2 wherein a frequency response of the notch filter has a notch corresponding to a second harmonic of the radio frequency signal.

4. The hybrid acoustic LC filter of claim 2 wherein a frequency response of the notch filter has two notches corresponding to different harmonics of the radio frequency signal.

5. The hybrid acoustic LC filter of claim 1 wherein the non-acoustic LC filter is a low pass filter.

6. The hybrid acoustic LC filter of claim 1 wherein the non-acoustic LC filter includes integrated passive devices of an integrated passive device die.

7. The hybrid acoustic LC filter of claim 1 further comprising a second hybrid passive/acoustic filter with an output connected to the output of the first hybrid passive/acoustic filter at a common node, the first hybrid passive/acoustic filter including a first carrier and the second hybrid passive/acoustic filter including a second carrier to support carrier aggregation at the common node.

8. The hybrid acoustic LC filter of claim 1 wherein at least one of the first and second acoustic resonators include bulk acoustic wave resonators.

9. The hybrid acoustic LC filter of claim 1 wherein the first and second acoustic resonators include a first shunt acoustic resonator and a second shunt acoustic resonator.

10. A multiplexer comprising:

a first filter configured to filter a radio frequency signal, the first filter including a hybrid passive/acoustic filter and a non-acoustic LC filter cascaded with the hybrid passive/acoustic filter, the hybrid passive/acoustic filter including at least a first acoustic resonator in parallel with a first inductor, the first acoustic resonator and the first inductor in series with a second inductor and a second acoustic resonator in series with a third inductor, and at least a first non-acoustic passive component having at least a first capacitor in parallel with a fourth inductor, the first capacitor and the fourth inductor connected in parallel with the first and second acoustic resonators, a second non-acoustic passive component having at least a second capacitor in parallel with a fifth inductor, the second capacitor and the fifth inductor further connected in parallel with the first acoustic resonator, and the non-acoustic LC filter configured to suppress a harmonic of the radio frequency signal, the non-acoustic LC filter including a first LC resonant circuit connected to a series LC tank, a second LC resonant circuit connected to the series LC tank, and a first bridge capacitor coupled to an input and the series LC tank, and a second bridge capacitor coupled to the first LC resonant circuit and the series LC tank; and

a second filter coupled to the first filter at a common node.

11. The multiplexer of claim 10 wherein the second filter includes second acoustic resonators and a second non-acoustic passive component.

12. The multiplexer of claim 11 wherein the first filter is a mid-band filter and the second filter is a high band filter.

13. The multiplexer of claim 12 further comprising a low band filter coupled to the first filter and the second filter at the common node.

14. The multiplexer of claim 10 wherein the non-acoustic LC filter includes integrated passive devices of an integrated passive device die.

15. The multiplexer of claim 10 wherein further comprising a second non-acoustic passive component with a second capacitor and a fifth inductor in series with the first non-acoustic passive component.

16. The multiplexer of claim 10 wherein the acoustic resonators include a first shunt acoustic resonator and a second shunt acoustic resonator.

17. The multiplexer of claim 10 wherein the acoustic resonators include bulk acoustic wave resonators.

18. A wireless communication device comprising:

a radio frequency front end including a filter configured to filter a radio frequency signal, the filter including a hybrid passive/acoustic filter and a non-acoustic LC filter cascaded with the hybrid passive/acoustic filter, the hybrid passive/acoustic filter including at least a first acoustic resonator in parallel with a first inductor, the first acoustic resonator and first inductor in series with a second inductor and a second acoustic resonator in series with a third inductor, and at least a first non-acoustic passive component having at least a first capacitor in parallel with a fourth inductor, the first capacitor and fourth inductor further connected in parallel with the first and second acoustic resonators, a second non-acoustic passive component having at least a second capacitor in parallel with a fifth inductor, the second capacitor and fifth inductor further connected in parallel with the first acoustic resonator, and the non-acoustic LC filter configured to suppress a harmonic of the radio frequency signal, the non-acoustic LC filter including a first LC resonant circuit connected to a series LC tank, a second LC resonant circuit connected to the series LC tank, and a first bridge capacitor coupled to an input and the series LC tank, and a second bridge capacitor coupled to the first LC resonant circuit and the series LC tank; and

an antenna in communication with the radio frequency front end, the antenna configured to transmit a filtered version of the radio frequency signal with the harmonic suppressed.

19. The wireless communication device of claim 18 configured as a mobile phone.

20. The wireless communication device of claim 18 further comprising a baseband processor and a transceiver, the transceiver being in communication with the radio frequency front end and also being in communication with the baseband processor.