FILTER INCLUDING TWO TYPES OF ACOUSTIC WAVE RESONATORS

CROSS REFERENCE TO PRIORITY APPLICATION

[0001] This application claims the benefit of priority of U.S. Provisional Patent Application No. 62/656,857, filed April 12, 2018 and titled "FILTER INCLUDING TWO TYPES OF ACOUSTIC WAVE RESONATORS," the disclosure of which is hereby incorporated by reference in its entirety herein.

BACKGROUND

Technical Field

[0002] Embodiments of this disclosure relate to acoustic wave filters.

Description of Related Technology

[0003] An acoustic wave filter can include a plurality of resonators arranged to filter a radio frequency signal. Example acoustic wave filters include surface acoustic wave (SAW) filters and bulk acoustic wave (BAW) filters. A film bulk acoustic resonator (FBAR) filter is an example of a BAW filter. An acoustic wave filter can be arranged to filter a radio frequency (RF) signal.

[0004] Acoustic wave filters can be implemented in radio frequency electronic systems. For instance, filters in a radio frequency front end of a mobile phone can include acoustic wave filters. Two acoustic wave filters can be arranged as a duplexer.

SUMMARY ~~OF CERTAIN INVENTIVE ASPECTS~~

[0005] The innovations described in the ~~claims~~ disclosure each have several embodiments ~~aspects~~, no single one of which is solely responsible for its desirable attributes. Without limiting the scope of the claims, some prominent features of this disclosure will now be briefly described.

[0006] In one aspect, there is an acoustic wave device comprising:
at least first and second transmit filters each including a first stage in communication with an input of a final stage, the first stage including bulk acoustic wave resonators but not surface wave acoustic resonators, the final stage having at least a series surface acoustic wave resonator but not bulk acoustic wave resonators, an output of the final stage coupled to a common node;
first and second receive filters, the first receive filter including a first plurality of surface acoustic wave resonators, the second receive filter including a second plurality of surface acoustic wave resonators, inputs of the first and second receive filters coupled to outputs of the first and second transmit filters at the common node, the first and second transmit filters and the first and second receive filters included in a multiplexer; and
a first loop circuit including a third plurality of surface acoustic wave resonators coupled to an output of the first receive filter and an input of the first transmit filter, the first loop circuit configured to generate and apply a first anti-phase signal at the input of the transmit filter to a target signal at a first particular frequency; and
a second loop circuit including a fourth plurality of surface acoustic wave resonators coupled to the

common node and the input of the first transmit filter, the second loop circuit configured to generate and separately apply a second anti-phase signal at the input of the transmit filter to the target signal at a second particular frequency. In an aspect, there is a method of processing a radio frequency signal, the method comprising: filtering at least a first transmit radio frequency signal with a first transmit filter and at least a second transmit radio frequency signal with a second transmit filter, the first and second transmit filters each including a first stage in communication with an input of a final stage, the first stage including bulk acoustic wave resonators and but not surface acoustic wave resonators, the final stage having at least a series surface acoustic wave resonator but not bulk acoustic wave resonators, an output of the final stage coupled to a common node; filtering first and second receive radio frequency signals with first and second receive filters, the inputs of the first and second receive filters coupled to the common node, the first receive filter including a first plurality of surface acoustic wave resonators, the second receive filter including a second plurality of surface acoustic wave resonators; and suppressing a first target signal by applying to the input of first transmit filter a first anti-phase signal to a first target signal at a first particular frequency with a first loop circuit including a third plurality of surface acoustic wave resonators coupled to the common node and the input of the first transmit filter; and suppressing the target signal by separately applying to the input of the transmit filter a second anti-phase signal with a second loop circuit including a fourth plurality of surface acoustic wave resonators coupled to an output of the first receive filter and the input of the transmit filter. In one embodiment ~~aspect~~, an acoustic wave device is disclosed. The acoustic wave device can include a transmit filter that includes bulk acoustic wave resonators and a series surface acoustic wave resonator that is coupled between the bulk acoustic wave resonators and a transmit output node. The transmit filter can be configured to filter a radio frequency signal. The acoustic wave device also includes a loop circuit that is coupled to the transmit

filter. The loop circuit can be configured to generate an anti-phase signal to a target signal at a particular frequency.

[0007] In some embodiments, the acoustic wave device further includes a receive filter that includes surface acoustic wave resonators. In some embodiments, the transmit filter and the receive filter are included in a duplexer. In some embodiments, the acoustic wave device further includes a second loop circuit that is coupled to the receive filter. In some embodiments, the series surface acoustic wave resonator and at least one of the surface acoustic wave resonators are implemented on a common die. In some embodiments, the loop circuit includes another surface acoustic wave element implemented on the common die.

[0008] In some embodiments, the acoustic wave device further includes a receive filter that is configured to output a single-ended radio frequency signal, the receive filter being coupled to the loop circuit.

[0009] In one embodiment ~~aspect~~, a filter assembly is disclosed. The filter assembly can include a first filter coupled to a common node, and a second filter coupled to the common node. The second filter can be configured to filter a radio frequency signal. The second filter can include acoustic wave resonators of a first type and a series acoustic wave resonator of a second type that is coupled between the acoustic wave resonators of the first type and the common node. The series acoustic wave resonator of the second type can have a higher suppression of a second harmonic of a radio frequency signal than the acoustic wave resonators of the first type. The filter assembly can also include a loop circuit that is coupled to the second filter. The loop circuit can be configured to generate an anti-phase signal to a target signal at a particular frequency.

[0010] In some embodiments, the acoustic wave resonators of the first type are bulk acoustic wave resonators and the series acoustic wave resonator of the second type is a surface acoustic wave resonator. In some embodiments, the loop circuit includes surface acoustic wave elements. In some embodiments, at least one of the surface acoustic wave elements and the series acoustic wave resonator of the second type are included on a common die.

[0011] In some embodiments, the filter assembly includes a first die that includes the acoustic wave resonators of the first type and a second die that includes the series acoustic wave resonator of the second type.

[0012] In some embodiments, the first filter includes acoustic wave resonators.

[0013] In some embodiments, the filter assembly further includes a second loop circuit that is coupled to the first filter.

[0014] In one embodiment ~~aspect~~, a method of processing a radio frequency signal is disclosed. The method can include filtering a radio frequency signal with a transmit filter. The transmit filter can include bulk acoustic wave resonators and a series surface acoustic wave resonator that is coupled between the bulk acoustic wave resonators and a transmit output node of the transmit filter. The method can also include suppressing a target signal by applying, to the transmit filter, an anti-phase signal to the target signal at a particular frequency.

[0015] In some embodiments, the method further includes filtering a second radio frequency signal with a receive filter that includes surface acoustic wave resonators. In some embodiments, the transmit filter and the receive filter are included in a duplexer. In some embodiments, the series surface acoustic wave resonator and at least one of the surface acoustic wave resonators are implemented on a common die. In some embodiments, the receive filter is configured to output a single-ended radio frequency signal.

[0016] In some embodiments, the method further includes generating the anti-phase signal by a loop circuit that is coupled to the transmit filter. The loop circuit can include a surface acoustic wave element implemented on the same die as the series surface acoustic wave resonator.

[0017] In one embodiment~~aspect~~, a multiplexer is disclosed. The multiplexer can include a transmit filter that is coupled to a common node. The transmit filter can include bulk acoustic wave resonators and a series surface acoustic wave resonator that is coupled between the bulk acoustic wave resonators and the common node. The transmit filter can be configured to filter a transmit radio frequency signal. The multiplexer can also include a receive filter that is coupled to the common node. The receive filter can be configured to provide a single-ended radio frequency receive signal.

[0018] In some embodiments, the multiplexer further includes a loop circuit that is coupled to the transmit filter. The loop circuit can be configured to generate an anti-phase signal to a target signal at a particular frequency. The loop circuit can include surface

acoustic wave elements. In some embodiments, the surface acoustic wave elements and the series surface acoustic wave resonator are included on a common die.

[0019] In some embodiments, the transmit filter and the receiver filter are arranged as a duplexer.

[0020] In some embodiments, the transmit filter includes a shunt surface acoustic wave resonator that is coupled to a node between the bulk acoustic wave resonators and the common node.

[0021] In some embodiments, the bulk acoustic wave resonators of the transmit filter are at least 80% of resonators of the transmit filter.

[0022] In some embodiments, the receive filter includes surface acoustic wave resonators.

[0023] In some embodiments, the series surface acoustic wave resonator is coupled between all bulk acoustic wave resonators of the transmit wave filter and the common node.

[0024] In some embodiments, the multiplexer further includes two filters coupled to the common node. The multiplexer can be configured as a quadplexer.

[0025] In one embodiment~~aspect~~, a filter assembly is disclosed. The filter assembly can include a first filter that is coupled to a common node. The first filter can be configured to provide a single-ended radio frequency output signal. The filter assembly can also include a second filter that is coupled to the common node and configured to filter a radio frequency signal. The second filter can include acoustic wave resonators of a first type and a series acoustic wave resonator of a second type that is coupled between the acoustic wave resonators of the first type and the common node. The series acoustic wave resonator of the second type can have a higher suppression of a second harmonic of a radio frequency signal than the acoustic wave resonators of the first type.

[0026] In some embodiments, the acoustic wave resonators of the first type are bulk acoustic wave resonators and the series acoustic wave resonator of the second type is a surface acoustic wave resonator. In some embodiments, the bulk acoustic wave resonators and the series acoustic wave resonator are implemented on a common filter die and enclosed within a common cap.

[0027] In some embodiments, the filter assembly includes a first die that includes the acoustic wave resonators of the first type and a second die that includes the series acoustic wave resonator of the second type.

[0028] In some embodiments, the first filter includes acoustic wave resonators of the first type.

[0029] In some embodiments, the filter assembly further includes a loop circuit that is coupled to the second filter. The loop circuit can be configured to generate an anti-phase signal to a target signal at a particular frequency. In some embodiments, the loop circuit includes acoustic wave elements on the same die as the acoustic wave resonators of the second type. In some embodiments, the first filter is a receive filter, the second filter is a transmit filter, and the first filter and the second filter are included in a duplexer.

[0030] In one embodiment~~aspect~~ a wireless communication device is disclosed. The wireless communication device can include an antenna and a multiplexer that is coupled to the antenna. The multiplexer can include a receive filter that is configured to provide a single-ended radio frequency receive signal. The multiplexer can also include a transmit filter that includes bulk acoustic wave resonators and a series surface acoustic wave resonator that is coupled between the bulk acoustic wave resonators and the antenna. The transmit filter can be configured to filter a transmit radio frequency signal.

[0031] In some embodiments, the wireless communication device further includes a loop circuit that is coupled to the transmit filter. The loop circuit can be configured to generate an anti-phase signal to a target signal at a particular frequency.

[0032] In some embodiments, the transmit filter and the receiver filter are arranged as a duplexer, and the receive filter includes surface acoustic wave resonators.

[0033] In one embodiment~~aspect~~, an acoustic wave device is disclosed. The acoustic wave device can include a transmit filter that includes bulk acoustic wave resonators and a series surface acoustic wave resonator that is coupled between the bulk acoustic wave resonators and a transmit output node. The acoustic wave device can also include a receive filter that includes surface acoustic wave resonators. The receive filter can be coupled to the transmit filter at a common node. The transmit filter and the receive filter can be included in a multiplexer. The acoustic wave device can also include a loop circuit that is coupled to the

receive filter. The loop circuit can be configured to generate an anti-phase signal to a target signal at a particular frequency.

[0034] In some embodiments, the multiplexer is a duplexer.

[0035] In some embodiments, the acoustic wave device further includes a second loop circuit coupled to the transmit filter.

[0036] In some embodiments, the series surface acoustic wave resonator and at least one of the surface acoustic wave resonators are implemented on a common die. In some embodiments, the loop circuit includes a surface acoustic wave element implemented on the common die.

[0037] In some embodiments, the receive filter is configured to output a single-ended radio frequency signal.

[0038] In one embodiment~~aspect~~, a filter assembly is disclosed. The filter assembly can include a first filter that is coupled to a common node and a second filter that is coupled to the common node. The second filter can be configured to filter a radio frequency signal. The second filter can include acoustic wave resonators of a first type and a series acoustic wave resonator of a second type that is coupled between the acoustic wave resonators of the first type and the common node. The series acoustic wave resonator of the second type can have a higher suppression of a second harmonic of a radio frequency signal than the acoustic wave resonators of the first type. The filter assembly can also include a loop circuit that is coupled to the first filter. The loop circuit can be configured to generate an anti-phase signal to a target signal at a particular frequency.

[0039] In some embodiments, the acoustic wave resonators of the first type are bulk acoustic wave resonators and the series acoustic wave resonator of the second type is a surface acoustic wave resonator.

[0040] In some embodiments, the filter assembly includes a first die that includes the acoustic wave resonators of the first type and a second die that includes the series acoustic wave resonator of the second type.

[0041] In some embodiments, the first filter includes acoustic wave resonators.

[0042] In some embodiments, the filter assembly further includes a second loop circuit coupled to the second filter. In some embodiments, the loop circuit includes acoustic wave resonators of the second type. In some embodiments, the acoustic wave resonators of

the second type and the series acoustic wave resonator of the second type are included on a common die.

[0043] In some embodiments, the first filter is configured to output a single-ended radio frequency signal

[0044] In one embodiment~~aspect~~, a method of processing a radio frequency signal is disclosed. The method can include filtering a transmit radio frequency signal with a transmit filter. The transmit filter can include bulk acoustic wave resonators and a series surface acoustic wave resonator that is coupled between the bulk acoustic wave resonators and a transmit output node. The method can also include filtering a receive radio frequency signal with a receive filter. The receive filter can include acoustic wave resonators. The method can further include suppressing a target signal by applying, to the receive filter, an anti-phase signal to the target signal at a particular frequency.

[0045] In some embodiments, the acoustic wave resonators of the receive filter include surface acoustic wave resonators. In some embodiments, the series surface acoustic wave resonator and at least one of the surface acoustic wave resonators are implemented on a common die.

[0046] In some embodiments, the transmit filter and the receive filter are included in a duplexer.

[0047] In some embodiments, the receive filter is configured to output a single-ended receive radio frequency signal.

[0048] In some embodiments, the suppressing includes generating the anti-phase signal by a loop circuit coupled to the transmit filter.

[0049] For purposes of summarizing the disclosure, certain aspects, advantages and novel features of the innovations have been described herein. It is to be understood that not necessarily all such advantages may be achieved in accordance with any particular embodiment. Thus, the innovations may be embodied or carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other advantages as may be taught or suggested herein.

WHAT IS CLAIMED IS:

1. An acoustic wave device comprising:

a transmit filter including bulk acoustic wave resonators and a series surface acoustic wave resonator coupled between the bulk acoustic wave resonators and a transmit output node, the transmit filter configured to filter a radio frequency signal; and

a loop circuit coupled to the transmit filter, the loop circuit configured to generate an anti-phase signal to a target signal at a particular frequency.

2. The acoustic wave device of claim 1 further comprising a receive filter that includes surface acoustic wave resonators.

3. The acoustic wave device of claim 2 wherein the transmit filter and the receive filter are included in a duplexer.

4. The acoustic wave device of claim 2 further comprising a second loop circuit coupled to the receive filter.

5. The acoustic wave device of claim 2 wherein the series surface acoustic wave resonator and at least one of the surface acoustic wave resonators are implemented on a common die.

6. The acoustic wave device of claim 5 wherein the loop circuit includes another surface acoustic wave element implemented on the common die.

7. The acoustic wave device of claim 1 further comprising a receive filter configured to output a single-ended radio frequency signal, the receive filter being coupled to the loop circuit.

~~8. A filter assembly comprising:~~

~~a first filter coupled to a common node;~~

~~a second filter coupled to the common node and configured to filter a radio frequency signal, the second filter including acoustic wave resonators of a first type and a series acoustic wave resonator of a second type coupled between the acoustic wave resonators of the first type and the common node, the series acoustic wave resonator of the second type having a higher suppression of a second harmonic of a radio frequency signal than the acoustic wave resonators of the first type; and~~

~~a loop circuit coupled to the second filter, the loop circuit configured to generate an anti-phase signal to a target signal at a particular frequency.~~

~~9. The filter assembly of claim 8 wherein the acoustic wave resonators of the first type are bulk acoustic wave resonators and the series acoustic wave resonator of the second type is a surface acoustic wave resonator.~~

~~10. The filter assembly of claim 9 wherein the loop circuit includes surface acoustic wave elements.~~

~~11. The filter assembly of claim 10 wherein at least one of the surface acoustic wave elements and the series acoustic wave resonator of the second type are included on a common die.~~

~~12. The filter assembly of claim 8 wherein the filter assembly includes a first die that includes the acoustic wave resonators of the first type and a second die that includes the series acoustic wave resonator of the second type.~~

1. ~~The filter assembly of claim 8 wherein the first filter includes acoustic wave resonators.~~

2. The filter assembly of claim 8 further comprising a second loop circuit coupled to the first filter.

3. A method of processing a radio frequency signal, the method comprising:

filtering a radio frequency signal with a transmit filter, the transmit filter including bulk acoustic wave resonators and a series surface acoustic wave resonator coupled between the bulk acoustic wave resonators and a transmit output node of the transmit filter; and

suppressing a target signal by applying, to the transmit filter, an anti-phase signal to the target signal at a particular frequency.

4. The method of claim 15 further comprising filtering a second radio frequency signal with a receive filter that includes surface acoustic wave resonators.

5. The method of claim 16 wherein the transmit filter and the receive filter are included in a duplexer.

6. The method of claim 17 wherein the series surface acoustic wave resonator and at least one of the surface acoustic wave resonators are implemented on a common die.

7. The method of claim 17 wherein the receive filter is configured to output a single-ended radio frequency signal.

8. The method of claim 15 further comprising generating the anti-phase signal by a loop circuit coupled to the transmit filter, the loop circuit including a surface acoustic wave element implemented on the same die as the series surface acoustic wave resonator.

9. A multiplexer comprising:

a transmit filter coupled to a common node, the transmit filter including bulk acoustic wave resonators and a series surface acoustic wave resonator coupled

between the bulk acoustic wave resonators and the common node, and the transmit filter configured to filter a transmit radio frequency signal; and

a receive filter coupled to the common node, the receive filter configured to provide a single-ended radio frequency receive signal.

10. The multiplexer of claim 21 further comprising a loop circuit coupled to the transmit filter, the loop circuit configured to generate an anti-phase signal to a target signal at a particular frequency, the loop circuit including surface acoustic wave elements.

11. The multiplexer of claim 22 wherein the surface acoustic wave elements and the series surface acoustic wave resonator are included on a common die.

12. The multiplexer of claim 21 wherein the transmit filter and the receiver filter are arranged as a duplexer.

13. The multiplexer of claim 21 wherein the transmit filter includes a shunt surface acoustic wave resonator coupled to a node between the bulk acoustic wave resonators and the common node.

14. The multiplexer of claim 21 wherein the bulk acoustic wave resonators of the transmit filter are at least 80% of resonators of the transmit filter.

15. The multiplexer of claim 21 wherein the receive filter includes surface acoustic wave resonators.

16.2. The multiplexer of claim 21 wherein the series surface acoustic wave resonator is coupled between all bulk acoustic wave resonators of the transmit wave filter and the common node.

~~17. The multiplexer of claim 21 further comprising two filters coupled to the common node, the multiplexer configured as a quadplexer.~~

~~18. A filter assembly comprising:~~

~~a first filter coupled to a common node, the first filter configured to provide a single-ended radio frequency output signal; and~~

~~a second filter coupled to the common node and configured to filter a radio frequency signal, the second filter including acoustic wave resonators of a first type and a series acoustic wave resonator of a second type coupled between the acoustic wave resonators of the first type and the common node, the series acoustic wave resonator of the second type having a higher suppression of a second harmonic of a radio frequency signal than the acoustic wave resonators of the first type.~~

~~19. The filter assembly of claim 30 wherein the acoustic wave resonators of the first type are bulk acoustic wave resonators and the series acoustic wave resonator of the second type is a surface acoustic wave resonator.~~

~~20. The filter assembly of claim 31 wherein the bulk acoustic wave resonators and the series acoustic wave resonator are implemented on a common filter die and enclosed within a common cap.~~

~~21. The filter assembly of claim 30 wherein the filter assembly includes a first die that includes the acoustic wave resonators of the first type and a second die that includes the series acoustic wave resonator of the second type.~~

~~22.~~3. ~~The filter assembly of claim 30 wherein the first filter includes acoustic wave resonators of the first type.~~

~~23. The filter assembly of claim 30 further comprising a loop circuit coupled to the second filter, the loop circuit configured to generate an anti-phase signal to a target signal at a particular frequency.~~

~~24. The filter assembly of claim 35 wherein the loop circuit includes acoustic wave elements on the same die as the acoustic wave resonators of the second type.~~

~~25. The filter assembly of claim 35 wherein the first filter is a receive filter, the second filter is a transmit filter, and the first filter and the second filter are included in a duplexer.~~

~~26. A wireless communication device comprising:~~

~~an antenna; and~~

~~a multiplexer coupled to the antenna, the multiplexer including a receive filter configured to provide a single-ended radio frequency receive signal, and a transmit filter including bulk acoustic wave resonators and a series surface acoustic wave resonator coupled between the bulk acoustic wave resonators and the antenna, the transmit filter configured to filter a transmit radio frequency signal.~~

~~27. The wireless communication device of claim 38 further comprising a loop circuit coupled to the transmit filter, the loop circuit configured to generate an anti-phase signal to a target signal at a particular frequency.~~

~~28. The wireless communication device of claim 38 wherein the transmit filter and the receiver filter are arranged as a duplexer, and the receive filter includes surface acoustic wave resonators.~~

29. An acoustic wave device comprising:

a transmit filter including bulk acoustic wave resonators and a series surface acoustic wave resonator coupled between the bulk acoustic wave resonators and a transmit output node;

a receive filter including surface acoustic wave resonators, the receive filter coupled to the transmit filter at a common node, and the transmit filter and the receive filter included in a multiplexer; and

a loop circuit coupled to the receive filter, the loop circuit configured to generate an anti-phase signal to a target signal at a particular frequency.

30. The acoustic wave device of claim 41 wherein the multiplexer is a duplexer.

31. The acoustic wave device of claim 41 further comprising a second loop circuit coupled to the transmit filter.

32. The acoustic wave device of claim 41 wherein the series surface acoustic wave resonator and at least one of the surface acoustic wave resonators are implemented on a common die.

33. The acoustic wave device of claim 44 wherein the loop circuit includes a surface acoustic wave element implemented on the common die.

34. The acoustic wave device of claim 41 wherein the receive filter is configured to output a single-ended radio frequency signal.

35. A filter assembly comprising:

a first filter coupled to a common node;

a second filter coupled to the common node and configured to filter a radio frequency signal, the second filter including acoustic wave resonators of a first type and a series acoustic wave resonator of a second type coupled between the acoustic wave resonators of the first type and the common node, the series acoustic wave

~~resonator of the second type having a higher suppression of a second harmonic of a radio frequency signal than the acoustic wave resonators of the first type; and~~

~~a loop circuit coupled to the first filter, the loop circuit configured to generate an anti-phase signal to a target signal at a particular frequency.~~

~~36. The filter assembly of claim 47 wherein the acoustic wave resonators of the first type are bulk acoustic wave resonators and the series acoustic wave resonator of the second type is a surface acoustic wave resonator.~~

~~37. The filter assembly of claim 47 wherein the filter assembly includes a first die that includes the acoustic wave resonators of the first type and a second die that includes the series acoustic wave resonator of the second type.~~

~~38. The filter assembly of claim 47 wherein the first filter includes acoustic wave resonators.~~

~~39. The filter assembly of claim 47 further comprising a second loop circuit coupled to the second filter.~~

~~40. The filter assembly of claim 51 wherein the loop circuit includes acoustic wave resonators of the second type.~~

~~41. The filter assembly of claim 52 wherein the acoustic wave resonators of the second type and the series acoustic wave resonator of the second type are included on a common die.~~

~~42. The acoustic wave device of claim 47 wherein the first filter is configured to output a single-ended radio frequency signal~~

~~43. A method of processing a radio frequency signal, the method comprising:~~

~~filtering a transmit radio frequency signal with a transmit filter, the transmit filter including bulk acoustic wave resonators and a series surface acoustic wave resonator coupled between the bulk acoustic wave resonators and a transmit output node;~~

~~filtering a receive radio frequency signal with a receive filter, the receive filter including acoustic wave resonators; and~~

~~suppressing a target signal by applying, to the receive filter, an anti-phase signal to the target signal at a particular frequency.~~

~~44. The method of claim 55 wherein the acoustic wave resonators of the receive filter include surface acoustic wave resonators.~~

~~45. The method of claim 56 wherein the series surface acoustic wave resonator and at least one of the surface acoustic wave resonators are implemented on a common die.~~

~~46. The method of claim 55 wherein the transmit filter and the receive filter are included in a duplexer.~~

~~47. The method of claim 55 wherein the receive filter is configured to output a single-ended receive radio frequency signal.~~

~~48. The method of claim 55 wherein the suppressing includes generating the anti-phase signal by a loop circuit coupled to the transmit filter.~~

What is claimed is:

1. An acoustic wave device comprising:

at least first and second transmit filters each including a first stage in communication with an input of a final stage, the first stage including bulk acoustic wave resonators but not surface wave acoustic resonators, the final stage having at least a series surface acoustic wave resonator but not bulk acoustic wave resonators, an output of the final stage coupled to a common node;

first and second receive filters, the first receive filter including a first plurality of surface acoustic wave resonators, the second receive filter including a second plurality of surface acoustic wave resonators, inputs of the first and second receive filters coupled to outputs of the first and second transmit filters at the common node, the first and second transmit filters and the first and second receive filters included in a multiplexer; and

a first loop circuit including a third plurality of surface acoustic wave resonators coupled to an output of the first receive filter and an input of the first transmit filter, the first loop circuit configured to generate and apply a first anti-phase signal at the input of the transmit filter to a target signal at a first particular frequency; and

a second loop circuit including a fourth plurality of surface acoustic wave resonators coupled to the common node and the input of the first transmit filter, the second loop circuit configured to generate and separately apply a second anti-phase signal at the input of the transmit filter to the target signal at a second particular frequency.

2. The acoustic wave device of claim 1 wherein the multiplexer is a duplexer.

3. The acoustic wave device of claim 1 wherein the second loop circuit improves carrier aggregation band attenuation.

4. The acoustic wave device of claim 1 wherein the series surface acoustic wave resonator and at least one of the first plurality of surface acoustic wave resonators are implemented on a common die.

5. The acoustic wave device of claim 4 wherein the first loop circuit includes a surface acoustic wave element implemented on the common die.

6. The acoustic wave device of claim 1 wherein the receive filter is configured to output a single-ended radio frequency signal.

7. The acoustic wave device of claim 1 wherein the final stage further includes at least one shunt surface acoustic wave resonator.

8. The acoustic wave device of claim 7 wherein the series surface acoustic wave resonator and the shunt surface acoustic wave resonator in the final stage each include their own interdigital transducer electrode and do not share a bus bar.

9. The acoustic wave device of claim 1 wherein the series surface acoustic wave resonator in the final stage improves antenna matching relative to the first stage.

10. A method of processing a radio frequency signal, the method comprising: filtering at least a first transmit radio frequency signal with a first transmit filter and at least a second transmit radio frequency signal with a second transmit filter, the first and second transmit filters each including a first stage in communication with an input of a final stage, the first stage including bulk acoustic wave resonators and but not surface acoustic wave resonators, the final stage having at least a series surface acoustic wave resonator but not bulk acoustic wave resonators, an output of the final stage coupled to a common node; filtering first and second receive radio frequency signals with first and second receive filters, the inputs of the first and second receive filters coupled to the common node, the first receive filter including a first plurality of surface acoustic wave resonators, the second receive filter including a second plurality of surface acoustic wave resonators; and

suppressing a first target signal by applying to the input of first transmit filter a first anti-phase signal to a first target signal at a first particular frequency with a first loop circuit including a third plurality of surface acoustic wave resonators coupled to the common node and the input of the first transmit filter; and suppressing the target signal by separately applying to the input of the transmit filter a second anti-phase signal with a second loop circuit including a fourth plurality of surface acoustic wave resonators coupled to an output of the first receive filter and the input of the transmit filter.

11. The method of claim 10 wherein the first plurality of surface acoustic wave resonators of the first receive filter are on a common die.

12. The method of claim 11 wherein the series surface acoustic wave resonator of the first transmit filter and at least one of the first plurality of surface acoustic wave resonators of the receive filter are implemented on the common die.

13. The method of claim 10 wherein the first and second transmit filters and the first and second receive filters are included in a multiplexer.

14. The method of claim 10 wherein the first receive filter is configured to output a single-ended receive radio frequency signal.

15. The method of claim 10 wherein the suppressing includes generating the anti-phase signal by the first loop circuit that improves carrier aggregation band attenuation.

16. The method of claim 10 wherein the final stage further includes at least one shunt surface acoustic wave resonator.

17. The method of claim 16 wherein the series surface acoustic wave resonator and the shunt surface acoustic wave resonator in the final stage each include their own interdigital transducer electrode and do not share a bus bar.

18. The method of claim 10 wherein the final stage includes a plurality of shunt surface acoustic wave resonators.

19. The method of claim 10 wherein the series surface acoustic wave resonator in the final stage improves antenna matching relative to the first stage