[0020] Figure 11A is a block diagram that illustrates different die that include acoustic wave resonators of filters according to embodiments discussed herein.

[0021] Figure 11B is a block diagram that illustrates different die that include acoustic wave resonators of filters according to embodiments discussed herein.

[0022] Figure 11C is a block diagram that illustrates different die that include acoustic wave resonators of filters according to embodiments discussed herein.

[0023] Figure 12 is a schematic block diagram of a module that includes a power amplifier, a switch, and filters in accordance with one or more embodiments.

[0024] Figure 13 is a schematic block diagram of a module that includes power amplifiers, switches, and filters in accordance with one or more embodiments.

[0025] Figure 14 is a schematic block diagram of a module that includes power amplifiers, switches, filters in accordance with one or more embodiments, and an antenna switch.

[0026] Figure 15 is a schematic block diagram of a wireless communication device that includes filters in accordance with one or more embodiments.

[0027] The disclosure described in the claims each have several embodiments, no single one of which is solely responsible for its desirable attributes. Without limiting the scope of the embodiments, some prominent features of this disclosure will now be briefly described.

[0027a] In on aspect, there is provided a multiplexer comprising four acoustic wave filters coupled to a common node, the four acoustic wave filters including a first acoustic wave filter that includes surface acoustic wave resonators and a series bulk acoustic wave resonator coupled between the surface acoustic wave resonators and the common node, and the four acoustic wave filters including a second acoustic wave filter that includes second surface acoustic wave resonators and a second series bulk acoustic wave resonator coupled between the second surface acoustic wave resonators and the common node.

[0027b] In one aspect, there is provided a wireless communication device comprising:

an antenna configured to receive a radio frequency signal;

a multiplexer in communication with the antenna, the multiplexer including four acoustic wave filters coupled to a common node, the four acoustic wave filters including a first acoustic wave filter that includes surface acoustic wave resonators and a series bulk

acoustic wave resonator coupled between the surface acoustic wave resonators and the common node; and

a frequency multiplexing circuit coupled between the common node and the antenna.

[0027c] In one aspect, there is provided a filter assembly comprising:

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

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

[0028] One embodiment of this disclosure is a filter assembly that includes a first acoustic wave filter coupled to a common node and a second acoustic wave filter coupled to the common node. The first acoustic wave filter includes surface acoustic wave resonators and a series bulk acoustic wave resonator coupled between the surface acoustic wave resonators and the common node.

[0029] The surface acoustic wave resonators can include a series surface acoustic wave resonator in series with the series bulk acoustic wave resonator. The series surface acoustic wave resonator can be a one-port resonator. The series surface acoustic wave resonator can be a double mode surface acoustic wave resonator.

[0030] The first acoustic wave filter can include more than twice as many surface acoustic wave resonators as bulk acoustic wave resonators. The surface acoustic wave resonators can implement at least 70% of resonators of the first acoustic wave filter. The surface acoustic wave resonators can implement at least 80% of resonators of the first acoustic wave filter.

[0031] The series bulk acoustic wave resonator can be coupled between all surface acoustic wave resonators of the first acoustic wave filter and the common node. The surface acoustic wave resonators can include at least five resonators.

[0032] The first acoustic wave filter can further include a shunt bulk acoustic wave resonator coupled to the common node. The shunt bulk acoustic wave resonator can be coupled to the surface acoustic wave resonators by way of the series bulk acoustic wave resonator.

[0033] The second acoustic wave filter can include second surface acoustic wave resonators and a second series bulk acoustic wave resonator coupled between the second surface acoustic wave resonators and the common node. The second acoustic wave filter can include one or more suitable features of the first acoustic wave filter.

[0034] The filter assembly can further include at least two additional acoustic wave filters coupled to the common node. The filter assembly can further include at least four additional acoustic wave filters coupled to the common node. The filter assembly can further include at least six additional acoustic wave filters coupled to the common node.

[0035] The filter assembly can be arranged as a triplexer. The filter assembly can be arranged a quadplexer. The filter assembly can be arranged a pentaplexer. The filter assembly can be arranged a hexaplexer. The filter assembly can be arranged a heptaplexer. The filter assembly can be arranged an octoplexer.

[0036] The common node can be an antenna node.

[0037] Another embodiment of this disclosure is a multiplexer that includes four acoustic wave filters coupled to a common node. The four acoustic wave filters include a first acoustic wave filter that includes surface acoustic wave resonators and a series bulk acoustic wave resonator coupled between the surface acoustic wave resonators and the common node.

node. The fourth acoustic wave filter can include one or more suitable features of the first acoustic wave filter.

[0044] Another embodiment of this disclosure is a packaged module that includes one or more first die and a second die. The one or more first die includes a first group of surface acoustic wave resonators and a second group of surface acoustic wave resonators. The first group of surface acoustic wave resonators is included in a first acoustic wave filter coupled to a common node. The second die includes a series bulk acoustic wave resonator. The second group of surface acoustic wave resonators and the series bulk acoustic wave resonator are included in a second acoustic wave filter coupled to the common node. The series bulk acoustic wave resonator is coupled between the second group of surface acoustic wave resonators and the common node.

[0045] The packaged module can further include a multi-throw switch coupled to the first filter and the second filter. The multi-throw switch can have a single throw coupled to the common mode. Alternatively, the multi-throw switch can have a first throw coupled to the first acoustic wave filter and a second throw coupled to the second acoustic wave filter. In some instances, the packaged module can further include a power amplifier configured to provide a radio frequency signal to at least one of the first acoustic wave filter or the second acoustic wave filter by way of the multi-throw switch.

[0046] The packaged module can further include a power amplifier.

[0047] The packaged module can include one or more suitable features of an acoustic wave filter and/or a multiplexer discussed herein.

[0048] Another embodiment of this disclosure is a wireless communication device that includes an antenna configured to receive a radio frequency signal and a multiplexer in communication with the antenna. The multiplexer includes four acoustic wave filters coupled to a common node. The four acoustic wave filters include a first acoustic wave filter that includes surface acoustic wave resonators and a series bulk acoustic wave resonator coupled between the surface acoustic wave resonators and the common node.

[0049] The wireless communication device can be configured as a mobile phone.

[0050] The wireless communication device can further include a frequency multiplexing circuit coupled between the common node and the antenna. The frequency multiplexing circuit can be a diplexer or a triplexer.

[0051] The wireless communication device can further include an antenna switch coupled between the common node and the antenna.

[0052] The radio frequency signal can be a carrier aggregation signal.

[0053] The antenna can be a primary antenna. The antenna can be diversity antenna. Each of the four acoustic wave filters can be configured as a receive filter in communication with the diversity antenna.

[0054] The wireless communication device can include one or more suitable features of any of the acoustic wave filters discussed herein, any of the multiplexers discussed herein, any of the packaged modules discussed herein, or any combination thereof.

[0055] Another embodiment of this disclosure is a filter assembly that includes a first acoustic wave filter having a passband and being coupled to a common node. The filter assembly also includes a second acoustic wave filter coupled to the common node. The second acoustic wave filter includes 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 has a higher quality factor in the passband of the first acoustic wave filter than the acoustic wave resonators of the first type.

[0056] The acoustic resonators of the first type can be surface acoustic wave resonators and the series acoustic wave resonator of the second type can be a bulk acoustic wave resonator. The acoustic resonators of the first type can be non-temperature compensated surface acoustic wave resonators and the series acoustic wave resonator of the second type can be a temperature compensated surface acoustic wave resonator.

[0057] The acoustic wave resonators of the first type of the second acoustic wave filter can be at least 70% of resonators of the second acoustic wave filter. The filter assembly can include 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. At least two of the

acoustic resonators of the first type can be in series with the series acoustic wave resonator of the second type.

[0058] The filter assembly can further include a third acoustic wave filter coupled to the common node and a fourth acoustic wave filter coupled to the common node. The series acoustic wave resonator of the second type can have a higher quality factor in a passband of the third acoustic wave filter than the acoustic wave resonators of the first type. The series acoustic wave resonator of the second type can have a higher quality factor in a passband of the fourth acoustic wave filter than the acoustic wave resonators of the first type.

[0059] Another aspect of this disclosure is a multiplexer with acoustic wave filters. The multiplexer includes a first acoustic wave filter coupled to a common node and three other acoustic wave filters coupled to the common node. The first acoustic wave filter includes 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. Each of the three other acoustic wave filters has a respective pass band. The series acoustic wave resonator of the second type has a higher quality factor in each of the respective passbands of the three other acoustic wave filters than the acoustic wave resonators of the first type.

[0060] The acoustic resonators of the first type can be surface acoustic wave resonators and the series acoustic wave resonator of the second type can be a bulk acoustic wave resonator. The acoustic resonators of the first type can be non-temperature compensated surface acoustic wave resonators and the series acoustic wave resonator of the second type can be a temperature compensated surface acoustic wave resonator.

[0061] At least one of the three other acoustic wave filters can include second acoustic wave resonators of the first type and a second series acoustic wave resonator of the second type coupled between the second acoustic wave resonators of the first type and the common node.

[0062] The multiplexer can be a quadplexer. The multiplexer can further include two additional acoustic wave filters coupled to the common node.

[0063] Another embodiment of this disclosure is a method of processing a carrier aggregation signal. The method includes filtering the carrier aggregation signal with a first

WHAT IS CLAIMED IS:

1. A multiplexer comprising four acoustic wave filters coupled to a common node, the four acoustic wave filters including a first acoustic wave filter that includes surface acoustic wave resonators and a series bulk acoustic wave resonator coupled between the surface acoustic wave resonators and the common node, and the four acoustic wave filters including a second acoustic wave filter that includes second surface acoustic wave resonators and a second series bulk acoustic wave resonator coupled between the second surface acoustic wave resonators and the common node.

2. The multiplexer of claim 1 wherein the surface acoustic wave resonators include a series surface acoustic wave resonator in series with the series bulk acoustic wave resonator.

3. The multiplexer of claim 1 wherein the surface acoustic wave resonators of the first acoustic wave filter are at least 70% of resonators of the first acoustic wave filter.

4. The multiplexer of claim 1 wherein at least 70% of resonators of multiplexer are surface acoustic wave resonators.

5. The multiplexer of claim 1 wherein the series bulk acoustic wave resonator is coupled between all surface acoustic wave resonators of the first acoustic wave filter and the common node.

6. The multiplexer of claim 1 wherein the first acoustic wave filter further includes a shunt bulk acoustic wave resonator coupled to the surface acoustic wave resonators by way of the series bulk acoustic wave resonator.

7. The multiplexer of claim 1 further comprising two additional acoustic wave filters coupled to the common node.

8. The multiplexer of claim 1 wherein the first acoustic wave filter includes a shunt bulk acoustic wave resonator, the series bulk acoustic wave resonator coupled between the shunt bulk acoustic wave resonator and the surface acoustic wave resonators.

9. A wireless communication device comprising:

an antenna configured to receive a radio frequency signal;

a multiplexer in communication with the antenna, the multiplexer including four acoustic wave filters coupled to a common node, the four acoustic wave filters including a first acoustic wave filter that includes surface acoustic wave resonators and a series bulk acoustic wave resonator coupled between the surface acoustic wave resonators and the common node; and

a frequency multiplexing circuit coupled between the common node and the antenna.

10. The wireless communication device of claim 9 further comprising an antenna switch coupled between the common node and the antenna.

11. The wireless communication device of claim 9 wherein the radio frequency signal is a carrier aggregation signal.

12. A filter assembly comprising:

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

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

13. The filter assembly of claim 12 further comprising at least two additional acoustic wave filters coupled to the common node.

14. The filter assembly of claim 12 further comprising at least four additional acoustic wave filters coupled to the common node.

15. The filter assembly of claim 12 wherein the surface acoustic wave resonators include a series surface acoustic wave resonator in series with the series bulk acoustic wave resonator.

16. The filter assembly of claim 12 wherein the surface acoustic wave resonators implement at least 70% of resonators of the first acoustic wave filter.

17. The filter assembly of claim 12 wherein the series bulk acoustic wave resonator is coupled between all surface acoustic wave resonators of the first acoustic wave filter and the common node.

18. The filter assembly of claim 12 wherein the surface acoustic wave resonators include at least five resonators.

19. The filter assembly of claim 12 wherein the surface acoustic wave resonators are implemented on a different die than the series bulk acoustic wave resonator.

20. The filter assembly of claim 12 further comprising a third acoustic wave filter coupled to the common node, the third acoustic wave filter including third surface

acoustic wave resonators and a third series bulk acoustic wave resonator coupled between the third surface acoustic wave resonators and the common node.