wave filters can be arranged as a duplexer. There are technical challenges associated with filtering signals with relatively close frequencies using different filters of a multiplexer. In addition, there are a variety of engineering tradeoffs associated with a filter that filters signals under different conditions.

SUMMARY

[0005] The innovations described in the claims each have several examples, 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] One aspect of this disclosure is a switchable acoustic wave filter that includes a first acoustic wave resonator, a second acoustic wave resonator, and a switch configured to electrically connect the first acoustic wave resonator to a node of the switchable acoustic wave filter in a first state of the switch and to electrically isolate the first acoustic wave resonator from the node of the switchable acoustic wave filter in a second state of the switch. The switchable acoustic wave filter is configured to receive a radio frequency signal, filter the radio frequency signal with at least the first acoustic wave resonator and the second acoustic wave resonator in the first state, and filter the radio frequency signal with at least the second acoustic wave resonator in the second state. The switchable acoustic wave filter configured to be coupled to a second filter, a band edge of the switchable acoustic wave filter and a band edge of the second filter being closer in frequency in the first state of the switch than in the second state of the switch, the first state being associated with the second filter being inactive and the second state being associated with co-existence.

[0007] The switchable acoustic wave filter can have a different bandwidth in the first state than in the second state. The switch can electrically connect an electrode of the first acoustic wave resonator to a termination impedance in the second state.

[0008] The switchable acoustic wave filter can include a third acoustic wave resonator. The switch can electrically isolate the third acoustic wave resonator from the node in the first state and electrically connect the third acoustic wave resonator to the node in the second state. The first acoustic wave resonator and the third acoustic wave resonator can have different resonant frequencies.

[0009] The first acoustic wave resonator can be a series resonator. Alternatively, the first acoustic wave resonator can be a shunt resonator. The first acoustic wave resonator can be a bulk acoustic wave resonator in certain applications.

[0010] The switchable acoustic wave filter can be a band pass filter. The switchable acoustic wave filter can be a band stop filter. The switchable acoustic wave filter

can be configured to filter a wireless local area network signal. The switchable acoustic wave filter can be configured to filter a cellular signal. The switchable acoustic wave filter can have a single switch loss.

[0011] The switchable acoustic wave filter can include a second switch and a fourth acoustic wave resonator. The second switch can electrically connect and electrically isolate the fourth acoustic wave resonator from a second node of the switchable acoustic wave filter in different states.

[0012] Another example of this disclosure is a multiplexer that includes a switchable acoustic wave filter and a second filter coupled to the switchable acoustic wave filter at a common node. The switchable acoustic wave filter includes a first acoustic wave resonator, a second acoustic wave resonator, and a switch. The switch is configured to electrically connect the first acoustic wave resonator to a node of the switchable acoustic wave filter in a first state and to electrically isolate the first acoustic wave resonator from the node of the switchable acoustic wave filter in a second state. The switchable acoustic wave filter is configured to receive a radio frequency signal, filter the radio frequency signal with at least the first acoustic wave resonator and the second acoustic wave resonator in the first state, and filter the radio frequency signal with at least the second acoustic wave resonator in the second state.

[0012a] In another aspect, the present disclosure refers to a multiplexor that comprises a switchable acoustic wave filter including a first acoustic wave resonator, a second acoustic wave resonator, and a switch configured to electrically connect the first acoustic wave resonator to a node of the switchable acoustic wave filter in a first state of the switch and to electrically isolate the first acoustic wave resonator from the node of the switchable acoustic wave filter in a second state of the switch, the switchable acoustic wave filter configured to receive a radio frequency signal, filter the radio frequency signal with at least the first acoustic wave resonator and the second acoustic wave resonator in the first state, and filter the radio frequency signal with at least the second acoustic wave resonator in the second state, and a second filter coupled to the switchable acoustic wave filter, a band edge of the switchable acoustic wave filter and a band edge of the second filter being closer in frequency in the first state of the switch than in the second state of the switch, the first state being associated with the second filter being inactive and the second state being associated with co-existence.

[0013] The second filter can be a second switchable acoustic wave filter configured to selectively electrically couple an acoustic wave resonator to a node of the second filter. The multiplexer can include a third filter coupled to the common node.

[0014] The switchable acoustic wave filter can have a single switch loss. The second state can be associated with co-existence.

[0015] Another aspect of this disclosure is a method of radio frequency filtering. The method includes filtering a radio frequency signal with at least a first acoustic wave resonator and a second acoustic wave resonator of a switchable acoustic wave filter when a switch of the switchable acoustic wave filter is in a first state, toggling a state of the witch of the switchable acoustic wave filter from the first state to a second state, and filtering a radio frequency signal with at least the second acoustic wave resonator of the switchable acoustic wave filter and not with the first acoustic wave resonator when the switch of the switchable acoustic wave filter is in the second state, a band edge of the switchable acoustic wave filter and a band edge of a second filter being closer in frequency in the first state of the switch than in the second state of the switch, the first state being associated with the second filter being inactive and the second state being associated with co-existence, and the second filter being coupled to the switchable acoustic wave filter.

[0016] The toggling can change a bandwidth of the switchable acoustic wave filter. The switchable acoustic wave filter can have a single switch loss.

[0017] Another example of this disclosure is a multiplexer with a switchable acoustic wave filter. The multiplexer includes a first filter configured to receive a radio frequency signal and a second filter connected to the first filter at a common node. The first filter includes one or more acoustic wave resonators, switchable acoustic wave resonators, and a switch configurable into at least a first state and a second state. The switch is configured to select a different subset of the switchable acoustic wave resonators to filter the radio frequency signal together with at least the one or more acoustic wave resonators in the first state than in the second state.

[0017a] In another aspect, the present disclosure refers to a multiplexer with a switchable acoustic wave filter, the multiplexer comprising, a first filter configured to receive a radio frequency signal, the first filter including one or more acoustic wave resonators, switchable acoustic wave resonators, and a switch configurable into at least a first state and a second state, the switch configured to select a different subset of the switchable acoustic wave resonators to filter the radio frequency signal together with at least the one or more acoustic wave resonators in the first state than in the second state, and a second filter connected to the first filter, a band edge of the first filter and a band edge of the second filter being closer in frequency in the first state of the switch than in the second state of the switch, the first state being associated with the second filter being inactive and the second state being associated with co-existence.

[0018] The second state can be associated with co-existence. The first filter can have lower performance associated with an operating band for the second state relative to the first state. The first filter can be a band pass filter having a pass band, where the pass band covers a smaller frequency range for the second state relative to the first state. The first filter can be a band stop filter having a stop band, where the stop band covers a smaller frequency range for the second state relative to the first state.

[0019] The switchable acoustic wave resonators can include series resonators. The switchable acoustic wave resonators can include shunt resonators.

[0020] A band edge of the first filter and a band edge of the second filter can be closer in frequency in the first state of the switch than in the second state of the switch. The first state can be associated with associated with the second filter being inactive and the second state can be associated with co-existence.

[0021] The second filter can include a second switch and second switchable acoustic wave resonators. The first filter can be configured to move a band edge of a frequency response of the first filter by toggling the switch between the first state and the second state. The second filter can be configured to move a band edge of a frequency response of the second filter with the second switch. The multiplexer can include an inductor-capacitor circuit coupled between both the first filter and the second filter and an antenna node of the multiplexer. The inductor-capacitor filter can attenuate a harmonic generated by the switch.

[0022] The first filter can be a band pass filter and the second filter can be a band stop filter. The first filter can be a band stop filter and the second filter can be a band pass filter. The first filter and the second filter can be band pass filters.

[0023] The first filter can have a single switch loss. The first filter can include a second switch and second switchable acoustic wave resonators.

[0024] The first filter and the second filter can be configured to filter radio frequency signals associated with different frequency bands. The different frequency bands can include a wireless local area network band and a cellular band.

[0025] The first filter and the second filter can have respective band edges that are within 5 megahertz of each other.

[0026] The different subsets can include a first subset and a second subset, where the first subset consists of a first switchable acoustic wave resonator and the second subset consists of a second switchable acoustic wave resonator.

[0027] Another example of this disclosure is a wireless communication that includes an antenna switch, an antenna, and an antenna-plexer. The antenna-plexer including a first filter and a second filter coupled to the first filter at a common node. The first filter is in a signal path between the antenna switch and the antenna, a first filter configured to receive a radio frequency signal, the first filter including one or more acoustic wave resonators, switchable acoustic wave resonators, and a switch configurable into at least a first state and a second state, the switch configured to select a different subset of the switchable acoustic wave resonators to filter the radio frequency signal together with at least the one or more acoustic wave resonators in the first state than in the second state.

[0027a] In another aspect, the present disclosure refers to a wireless communication device comprising, an antenna switch, an antenna, and an antenna-plexer including a first filter and a second filter coupled to the first filter, the first filter being in a signal path between the antenna switch and the antenna, the first filter configured to receive a radio frequency signal, the first filter including one or more acoustic wave resonators, switchable acoustic wave resonators, and a switch configurable into at least a first state and a second state, the switch configured to select a different subset of the switchable acoustic wave resonators to filter the radio frequency signal together with at least the one or more acoustic wave resonators in the first state than in the second state, a band edge of the first filter and a band edge of the second filter being closer in frequency in the first state of the switch than in the second state of the switch, the first state being associated with the second filter being inactive and the second state being associated with co-existence.

[0028] Another aspect of this disclosure is a switchable filter that includes one or more acoustic wave resonators, switchable acoustic wave resonators, and a switch configurable into at least a first state and a second state. The switch is configured to select a different subset of the switchable acoustic wave resonators to filter a radio frequency signal together with at least the one or more acoustic wave resonators in the first state than in the second state, the switchable filter configured to be coupled to a second filter, a band edge of the switchable acoustic wave filter and a band edge of the second filter being closer in frequency in the first state of the switch than in the second state of the switch, the first state being associated with the second filter being inactive and the second state being associated with co-existence.

[0029] For purposes of summarizing the disclosure, certain examples, 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 example. 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. A switchable acoustic wave filter comprising:

a first acoustic wave resonator;

a second acoustic wave resonator; and

a switch configured to electrically connect the first acoustic wave resonator to a node of the switchable acoustic wave filter in a first state of the switch and to electrically isolate the first acoustic wave resonator from the node of the switchable acoustic wave filter in a second state of the switch; the switchable acoustic wave filter configured to receive a radio frequency signal, filter the radio frequency signal with at least the first acoustic wave resonator and the second acoustic wave resonator in the first state, and filter the radio frequency signal with at least the second acoustic wave resonator in the second state;

the switchable acoustic wave filter configured to be coupled to a second filter, a band edge of the switchable acoustic wave filter and a band edge of the second filter being closer in frequency in the first state of the switch than in the second state of the switch, the first state being associated with the second filter being inactive and the second state being associated with co-existence.

2. The switchable acoustic wave filter of claim 1 wherein the switchable acoustic wave filter has a different bandwidth in the first state than in the second state.

3. The switchable acoustic wave filter of claim 1 further comprising a third acoustic wave resonator, the switch configured to electrically isolate the third acoustic wave resonator from the node in the first state and electrically connect the third acoustic wave resonator to the node in the second state.

4. The switchable acoustic wave filter of claim 3 wherein the first acoustic wave resonator and the third acoustic wave resonator have different resonant frequencies.

5. The switchable acoustic wave filter of claim 1 wherein the first acoustic wave resonator is a series resonator.

6. The switchable acoustic wave filter of claim 1 wherein the first acoustic wave resonator is a shunt resonator.

7. The switchable acoustic wave filter of claim 1 wherein the first acoustic wave resonator is a bulk acoustic wave resonator.

8. The switchable acoustic wave filter of claim 1 wherein the switchable acoustic wave filter is a band pass filter.

9. The switchable acoustic wave filter of claim 1 wherein the switchable acoustic wave filter is a band stop filter.

10. The switchable acoustic wave filter of claim 1 wherein the switchable acoustic wave filter has a single switch loss.

11. The switchable acoustic wave filter of claim 1 further comprising a second switch and a fourth acoustic wave resonator, the second switch configured to electrically connect and electrically isolate the fourth acoustic wave resonator from a second node of the switchable acoustic wave filter in different states.

12. The switchable acoustic wave filter of claim 1 wherein the switch is configured to electrically connect an electrode of the first acoustic wave resonator to a termination impedance in the second state.

13. The switchable acoustic wave filter of claim 1 wherein the switchable acoustic wave filter is configured to filter a wireless local area network signal.

14. The switchable acoustic wave filter of claim 1 wherein the switchable acoustic wave filter is configured to filter a cellular signal.

15. A multiplexer comprising:

a switchable acoustic wave filter including a first acoustic wave resonator, a second acoustic wave resonator, and a switch configured to electrically connect the first acoustic wave resonator to a node of the switchable acoustic wave filter in a first state of the switch and to electrically isolate the first acoustic wave resonator from the node of the switchable acoustic wave filter in a second state of the switch; the switchable acoustic wave filter configured to receive a radio frequency signal, filter the radio frequency signal with at least the first acoustic wave resonator and the second acoustic wave resonator in the first state, and filter the radio frequency signal with at least the second acoustic wave resonator in the second state; and

a second filter coupled to the switchable acoustic wave filter, a band edge of the switchable acoustic wave filter and a band edge of the second filter being closer in frequency in the first state of the switch than in the second state of the switch, the first state being associated with the second filter being inactive and the second state being associated with co-existence.

16. The multiplexer of claim 15 wherein the second filter is a second switchable acoustic wave filter configured to selectively electrically couple an acoustic wave resonator to a node of the second filter.

17. The multiplexer of claim 15 wherein the switchable acoustic wave filter has a single switch loss.

18. The multiplexer of claim 15 wherein the second state is associated with co-existence.

19. A method of radio frequency filtering, the method comprising:

filtering a radio frequency signal with at least a first acoustic wave resonator and a second acoustic wave resonator of a switchable acoustic wave filter when a switch of the switchable acoustic wave filter is in a first state;

toggling a state of the switch of the switchable acoustic wave filter from the first state to a second state; and

filtering a radio frequency signal with at least the second acoustic wave resonator of the switchable acoustic wave filter and not with the first acoustic wave resonator when the switch of the switchable acoustic wave filter is in the second state, a band edge of the switchable acoustic wave filter and a band edge of a second filter being closer in frequency in the first state of the switch than in the second state of the switch, the first state being associated with the second filter being inactive and the second state being associated with co-existence, and the second filter being coupled to the switchable acoustic wave filter.

20. The method of claim 19 wherein the toggling changes a bandwidth of the switchable acoustic wave filter, and the switchable acoustic wave filter has a single switch loss.

21. A multiplexer with a switchable acoustic wave filter, the multiplexer comprising:

a first filter configured to receive a radio frequency signal, the first filter including one or more acoustic wave resonators, switchable acoustic wave resonators, and a switch configurable into at least a first state and a second state, the switch configured to select a different subset of the switchable acoustic wave resonators to filter the radio frequency signal together with at least the one or more acoustic wave resonators in the first state than in the second state; and

a second filter connected to the first filter, a band edge of the first filter and a band edge of the second filter being closer in frequency in the first state of the switch than in the second state of the switch, the first state being associated with the second filter being inactive and the second state being associated with co-existence.

22. The multiplexer of claim 21 wherein the second state is associated with co-existence, and the first filter has lower performance associated with an operating band for the second state relative to the first state.

23. The multiplexer of claim 22 wherein the first filter is a band pass filter having a pass band, and the pass band covers a smaller frequency range for the second state relative to the first state.

24. The multiplexer of claim 22 wherein the first filter is a band stop filter having a stop band, and the stop band covers a smaller frequency range for the second state relative to the first state.

25. The multiplexer of claim 21 wherein the switchable acoustic wave resonators include series resonators.

26. The multiplexer of claim 21 wherein the switchable acoustic wave resonators include shunt resonators.

27. The multiplexer of claim 21 wherein the second filter includes a second switch and second switchable acoustic wave resonators.

28. The multiplexer of claim 27 wherein the first filter is configured to move a band edge of a frequency response of the first filter by toggling the switch between the first state and the second state, and the second filter is configured to move a band edge of a frequency response of the second filter with the second switch.

29. The multiplexer of claim 27 further comprising an inductor-capacitor circuit coupled between both the first filter and the second filter and an antenna node of the multiplexer, the inductor-capacitor circuit configured to attenuate a harmonic generated by the switch.

30. The multiplexer of claim 21 wherein the first filter is a band pass filter and the second filter is a band stop filter.

31. The multiplexer of claim 21 wherein the first filter is a band stop filter and the second filter is a band pass filter.

32. The multiplexer of claim 21 wherein the first filter and the second filter are band pass filters.

33. The multiplexer of claim 21 wherein the first filter includes a second switch and second switchable acoustic wave resonators.

34. The multiplexer of claim 21 wherein the first filter and the second filter are configured to filter radio frequency signals associated with different frequency bands, and the different frequency bands include a wireless local area network band and a cellular band.

35. The multiplexer of claim 21 wherein the first filter and the second filter have respective band edges that are within 5 megahertz of each other.

36. The multiplexer of claim 21 wherein the different subsets include a first subset and a second subset, the first subset consisting of a first switchable acoustic wave resonator, and the second subset consisting of a second switchable acoustic wave resonator.

37. The multiplexer of claim 21 wherein the first filter has a single switch loss.

38. A wireless communication device comprising:

an antenna switch;

an antenna; and

an antenna-plexer including a first filter and a second filter coupled to the first filter, the first filter being in a signal path between the antenna switch and the antenna, the first filter configured to receive a radio frequency signal, the first filter including one or more acoustic wave resonators, switchable acoustic wave resonators, and a switch configurable into at least a first state and a second state, the switch configured to select a different subset of the switchable acoustic wave resonators to filter the radio frequency signal together with at least the one or more acoustic wave resonators in the first state than in the second state, a band edge of the first filter and a band edge of the second filter being closer in frequency in the first state of the switch than in the second

state of the switch, the first state being associated with the second filter being inactive and the second state being associated with co-existence.

39. A switchable filter comprising:

one or more acoustic wave resonators;

switchable acoustic wave resonators; and

a switch configurable into at least a first state and a second state, the switch configured to select a different subset of the switchable acoustic wave resonators to filter a radio frequency signal together with at least the one or more acoustic wave resonators in the first state than in the second state,

the switchable filter configured to be coupled to a second filter, a band edge of the switchable acoustic wave filter and a band edge of the second filter being closer in frequency in the first state of the switch than in the second state of the switch, the first state being associated with the second filter being inactive and the second state being associated with co-existence.