

SUMMARY

[0006] The innovations described in the claims each have several 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.

[0007] One aspect of this disclosure is a multi-path filter for filtering a radio frequency signal. The multi-path filter includes a first signal path and a second signal path. The first signal path is from a node of the multi-path filter to an output port of the multi-path filter. The first signal path includes a series acoustic wave resonator. The second signal path is from the node to the output port. The second signal path includes a shunt acoustic wave resonator and a phase shifter.

[0008] The multi-path filter can have a passband formed by at least a combined impedance response of the first signal path and the second signal path. The passband can span at least 800 megahertz. The passband can have a bandwidth that is at least 20% of a center frequency of the passband. The passband can corresponds to a fifth generation New Radio operating band. Impedances of the first signal path and the second signal path can cancel each other outside of the passband to form rejections.

[0009] The multi-path filter can have a rejection of at least 50 decibels for a Wi-Fi frequency band.

[0010] Frequency responses of the first signal path and the second signal path can combine in a passband of the multi-path filter. The frequency responses of the first signal path and the second signal path can cancel for a rejection band of the multi-path filter that is outside of the passband.

[0011] The phase shifter can include a transmission line and a capacitor. The phase shifter can include a coil inductor and a capacitor.

[0012] The multi-path filter can further include a second series acoustic wave resonator coupled between an input port of the multi-path filter and the node.

[0013] The multi-path filter can further include a second series acoustic wave resonator and a second shunt acoustic wave resonator. The phase shifter can be coupled between the second shunt acoustic wave resonator and the output port. The second series acoustic wave resonator can be coupled between the shunt acoustic wave resonator and the second shunt acoustic wave resonator.

electrically connected between ground and a node between the series acoustic wave resonator and a second series acoustic wave resonator.

[0024] The extractor section can include a third acoustic wave resonator. The phase shifter can be coupled between the second shunt acoustic wave resonator and the output port.

[0025] The multi-path filter can be a receive filter.

[0026] The phase shifter can include a capacitor and a transmission line inductor. The phase shifter can include a capacitor, a coil inductor, and a transmission line inductor.

[0027] The passband can span at least 800 megahertz. The passband can have a bandwidth of at least 20% of a center frequency of the passband.

[0028] The rejection band can correspond to a Wi-Fi frequency band. The rejection band can have a rejection of at least 50 decibels.

[0029] The passband can correspond to a fifth generation New Radio operating band.

[0030] There is disclosed a multiplexer that includes a multi-path filter in accordance with any suitable principles and advantages disclosed herein and a second filter connected to the multi-path filter at a common node.

[0030A] Another aspect of this disclosure is a multiplexer for filtering radio frequency signals. The multiplexer includes a multi-path filter and a second filter. The multi-path filter includes a first signal path and a second signal path. The first signal path is from a node of the multi-path filter to an output port of the multi-path filter and includes a series acoustic wave resonator. The second signal path is from the node to the output port and includes a shunt acoustic wave resonator and a phase shifter. The second filter is coupled to the multi-path filter at a common node.

[0031] There is disclosed a radio frequency module that includes a multi-path filter in accordance with any suitable principles and advantages disclosed herein, radio frequency circuitry, and a package structure enclosing the multi-path filter and the radio frequency circuitry.

[0031A] Another aspect of this disclosure is a radio frequency module. The radio frequency module includes a multi-path filter. The multi-path filter includes a first signal path and a second signal path. The first signal path is from a node of the multi-path filter to

an output port of the multi-path filter and includes a series acoustic wave resonator. The second signal path is from the node to the output port and includes a shunt acoustic wave resonator and a phase shifter. The radio frequency module further includes a radio frequency circuitry and a package structure that encloses the multi-path filter and the radio frequency circuitry.

[0032] There is disclosed a radio frequency system that includes an antenna, a multi-path filter in accordance with any suitable principles and advantages disclosed herein, and an antenna switch configured to selectively electrically connect the antenna and a signal path that includes the multi-path filter.

[0032A] Another aspect of this disclosure is a radio frequency system that includes an antenna and a multi-path filter. The multi-path filter includes a band pass section and an extractor section, the band pass section is coupled between an input port and an output port, the band pass section includes a series acoustic wave resonator, the extractor section includes a second acoustic wave resonator and a phase shifter, the second acoustic wave resonator and the phase shifter are in a signal path between the input port and the output port, the multi-path filter has a passband formed by at least a combined impedance response of the band pass section and the extractor section, and the multi-path filter has a rejection band outside the passband that is formed by at least cancellation of impedance responses of the band pass section and the extractor section. The radio frequency system further includes an antenna switch configured to selectively electrically connect the antenna and a signal path that includes the multi-path filter.

[0033] There is disclosed a wireless communication device that includes a radio frequency front end including a multi-path filter in accordance with any suitable principles and advantages disclosed herein, an antenna coupled to the radio frequency front end, a transceiver in communication with the radio frequency front end, and a baseband processor in communication with the transceiver.

[0033A] Another aspect of this disclosure is a wireless communication device. The wireless communication device includes a radio frequency front end. The radio frequency front end includes multi-path filter that includes a band pass section and an extractor section, the band pass section is coupled between an input port and an output port, the band pass section includes a series acoustic wave resonator, the extractor section includes a second

acoustic wave resonator and a phase shifter, the second acoustic wave resonator and the phase shifter are in a signal path between the input port and the output port, the multi-path filter has a passband formed by at least a combined impedance response of the band pass section and the extractor section, and the multi-path filter has a rejection band outside the passband that is formed by at least cancellation of impedance responses of the band pass section and the extractor section. The wireless communication device further includes an antenna coupled to the radio frequency front end, a transceiver in communication with the radio frequency front end, and a baseband processor in communication with the transceiver.

[0034] There is disclosed a method of radio frequency signal processing. The method includes receiving a radio frequency signal via at least an antenna and filtering the radio frequency signal with a multi-path filter in accordance with any suitable principles and advantages disclosed herein.

[0035] 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.

BRIEF DESCRIPTION OF THE DRAWINGS

[0036] Embodiments of this disclosure will now be described, by way of non-limiting example, with reference to the accompanying drawings.

[0037] Figure 1A is a schematic diagram of a multi-path filter according to an embodiment.

[0038] Figure 1B is a graph of frequency response and phase of signal paths of the multi-path filter of Figure 1A.

[0039] Figure 2A is a schematic diagram of a multi-path filter according to an embodiment.

[0040] Figure 2B is a graph of frequency response and phase difference for the multi-path filter of Figure 2A.

[0041] Figure 3 is a schematic diagram of a multi-path filter according to an embodiment.

[0042] Figure 4A is a graph of frequency response of the multi-path filter of Figure 3.

[0043] Figure 4B is a graph of phase over frequency of the multi-path filter of Figure 3.

[0044] Figure 5A is a schematic diagram of a ladder filter.

[0045] Figure 5B is a schematic diagram of a multi-path filter according to an embodiment.