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(54) **ALL-ACOUSTIC DUPLEXERS USING DIRECTIONAL COUPLERS**

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H03H 9/72	(2006.01)
H01P 5/18	(2006.01)
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H03H 9/02	(2006.01)

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CPC *H03H 9/725* (2013.01); *H01P 5/18* (2013.01); *H03H 9/706* (2013.01); *H03H 2009/02165* (2013.01)

(58) **Field of Classification Search**
CPC H03H 9/6443; H03H 9/6466; H03H 9/725
USPC 333/133, 195, 117
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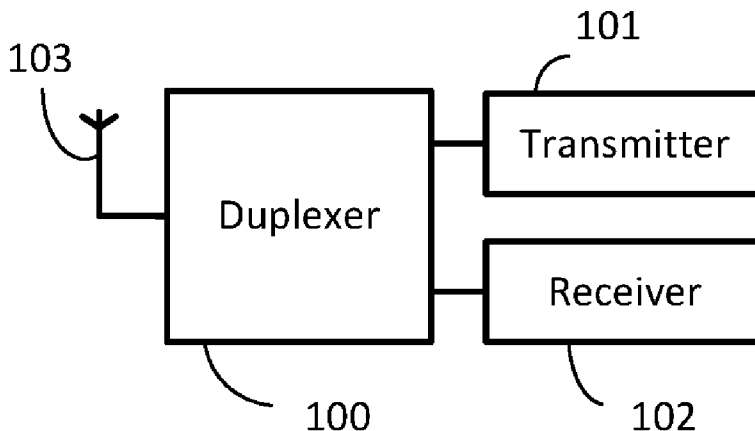
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(57)   **ABSTRACT**

An all-acoustic filter includes acoustic directional couplers and acoustic filters. In one embodiment, the all-acoustic filter includes two acoustic directional couplers, pair of matched acoustic filters corresponding to either transmit or receive frequency bands, and another acoustic filter corresponding to the other of transmit or receive frequency bands. An all-acoustic duplexer may be realized monolithically in a small form factor, may be tunable, may support multiple transmit or receive frequency bands, or may include schemes for antenna mismatch correction.

20 Claims, 17 Drawing Sheets

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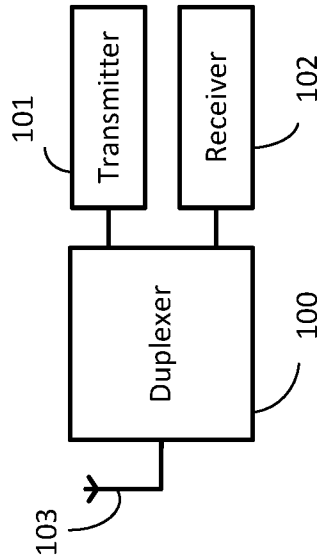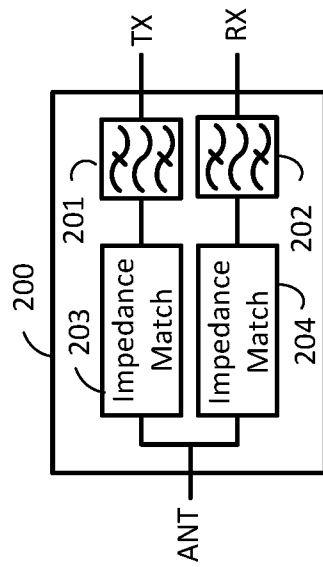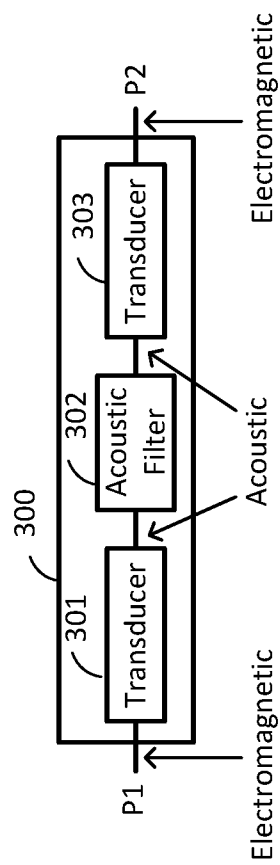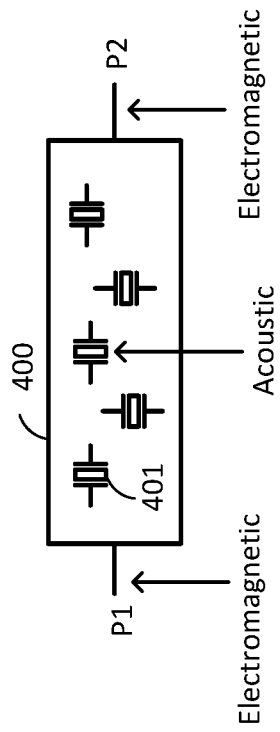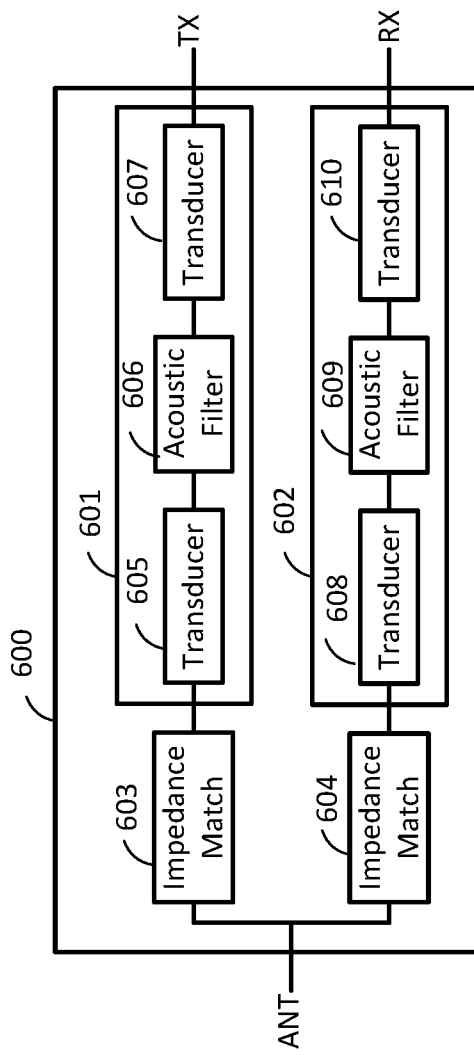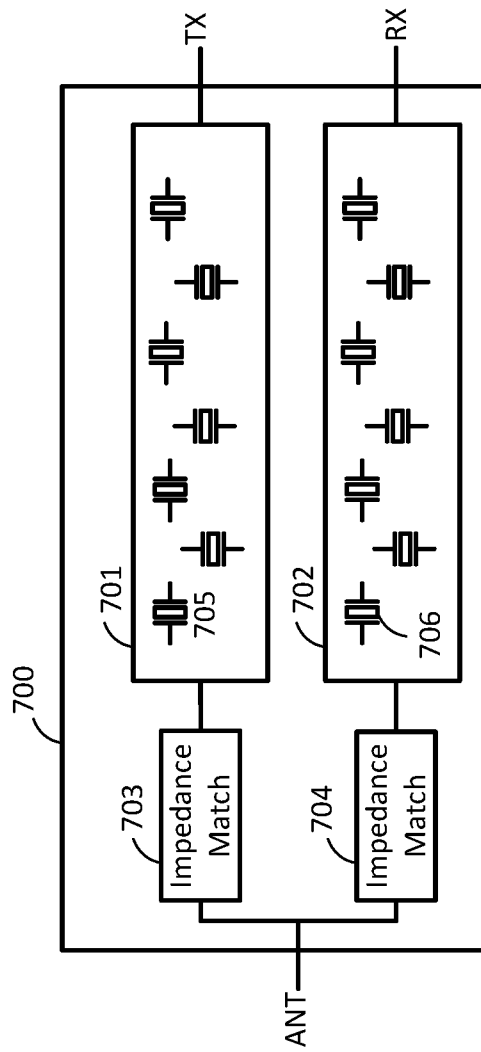
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FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG. 5

FIG. 6

FIG. 7
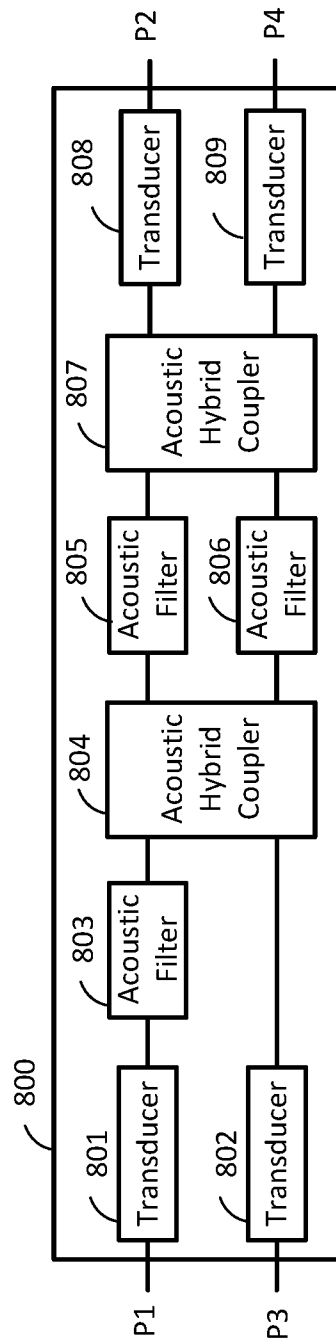
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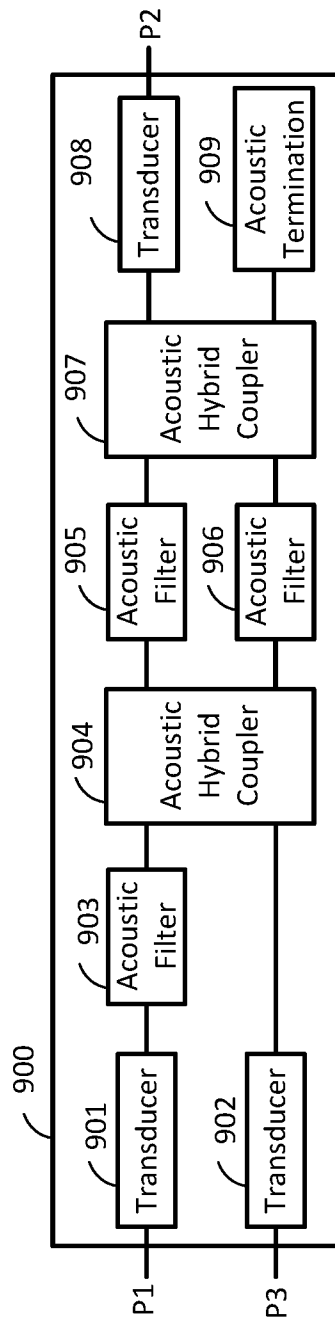
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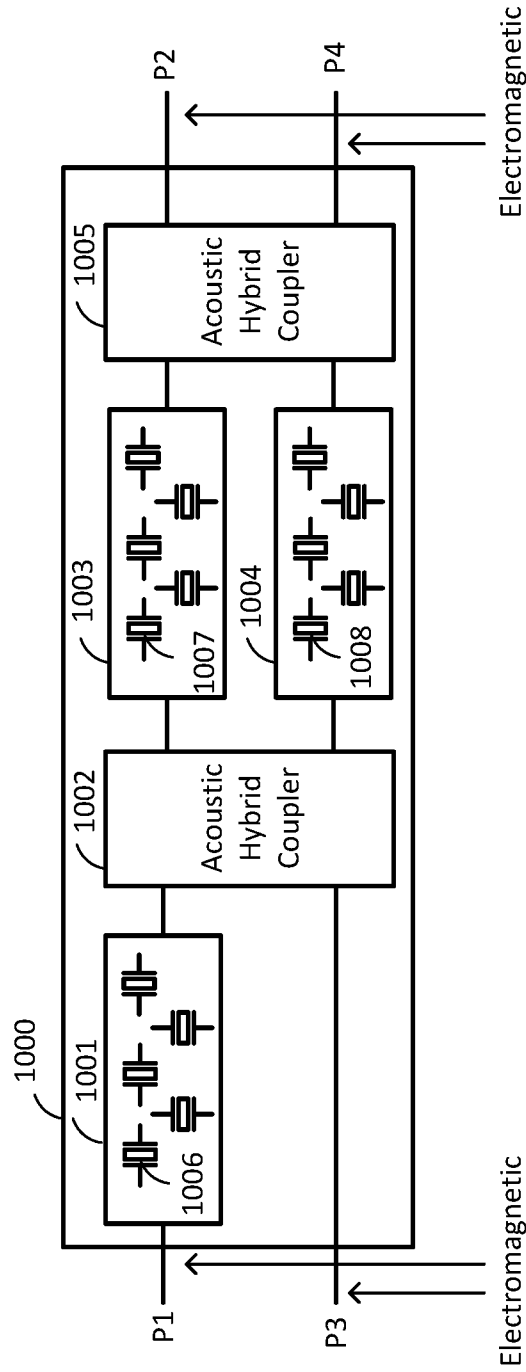
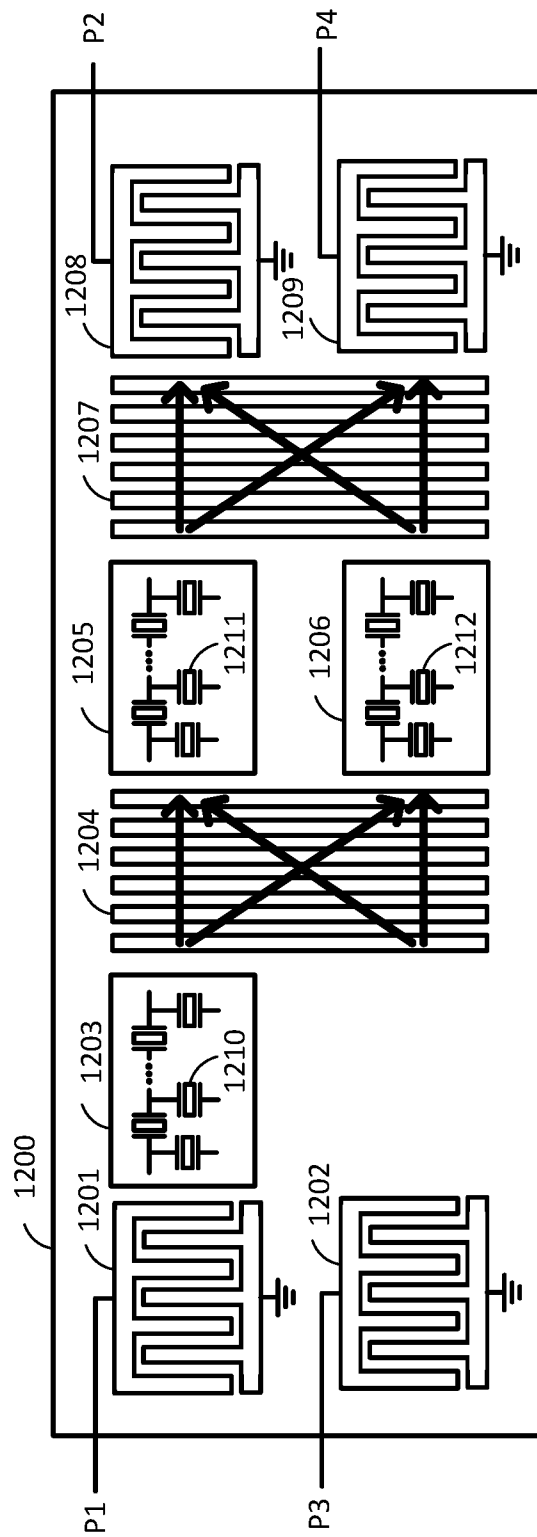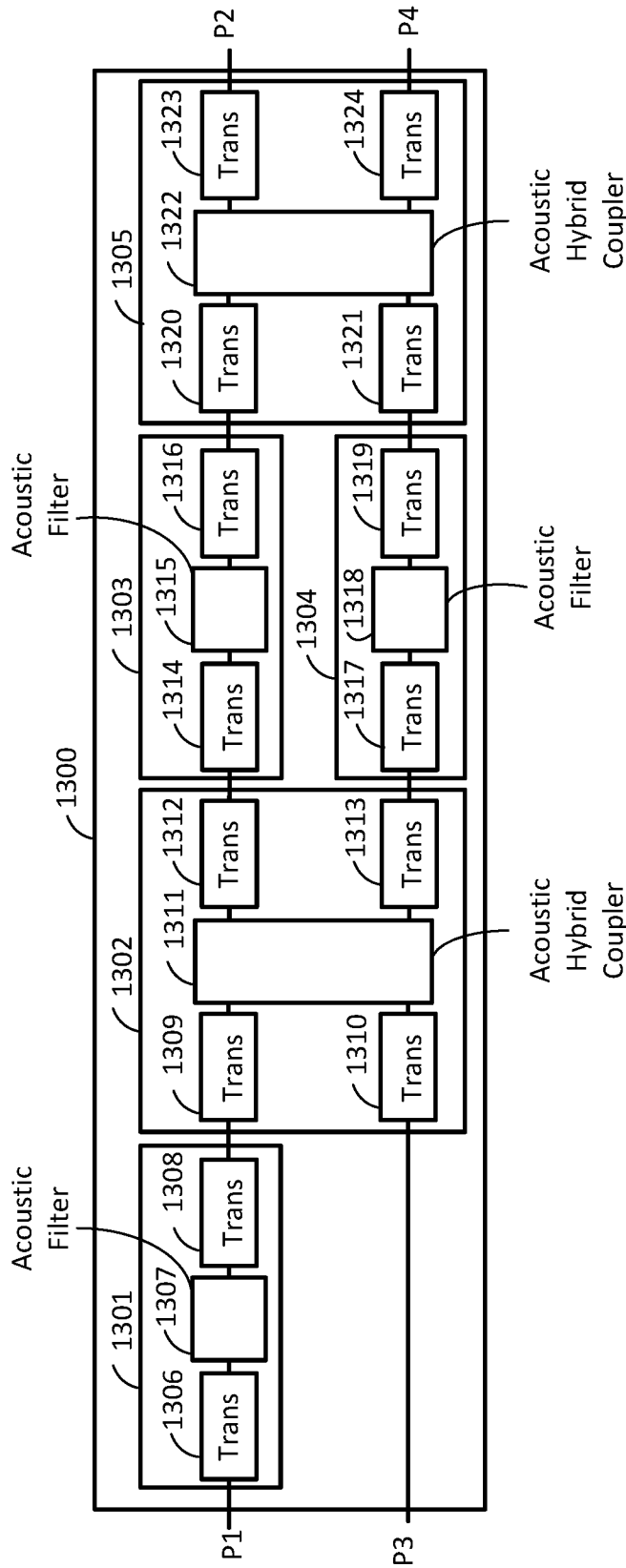FIG. 10
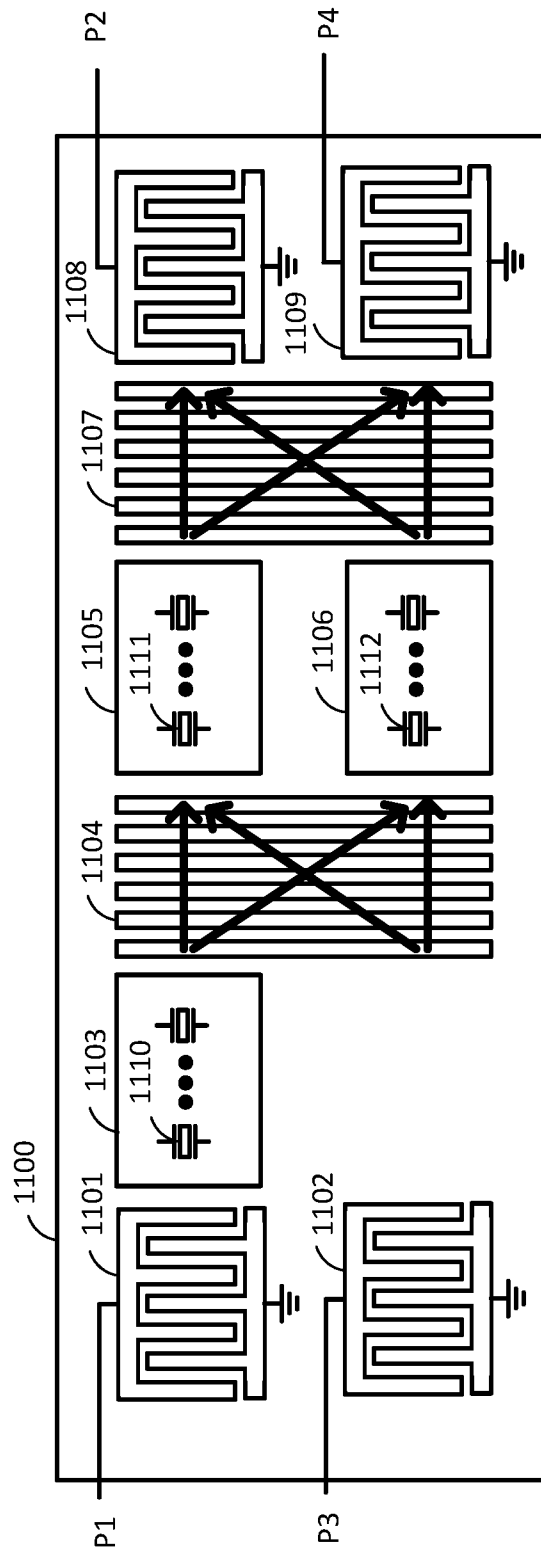
FIG. 11

FIG. 12

FIG. 13

FIG. 14

FIG. 15

FIG. 16

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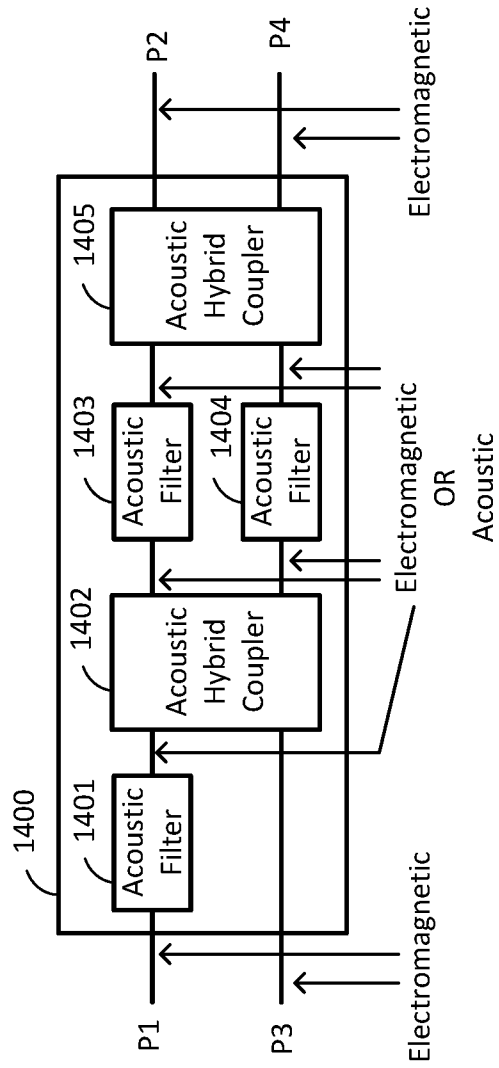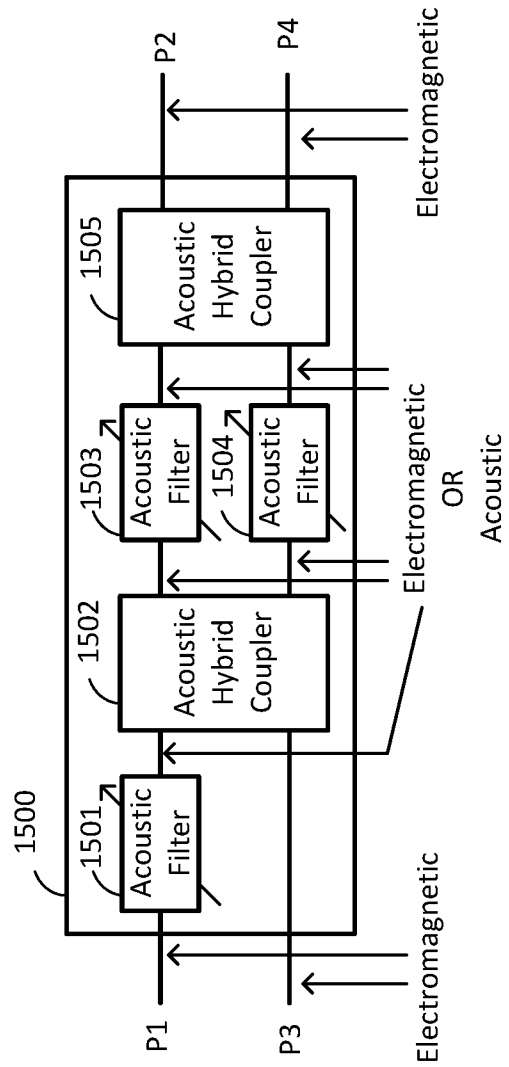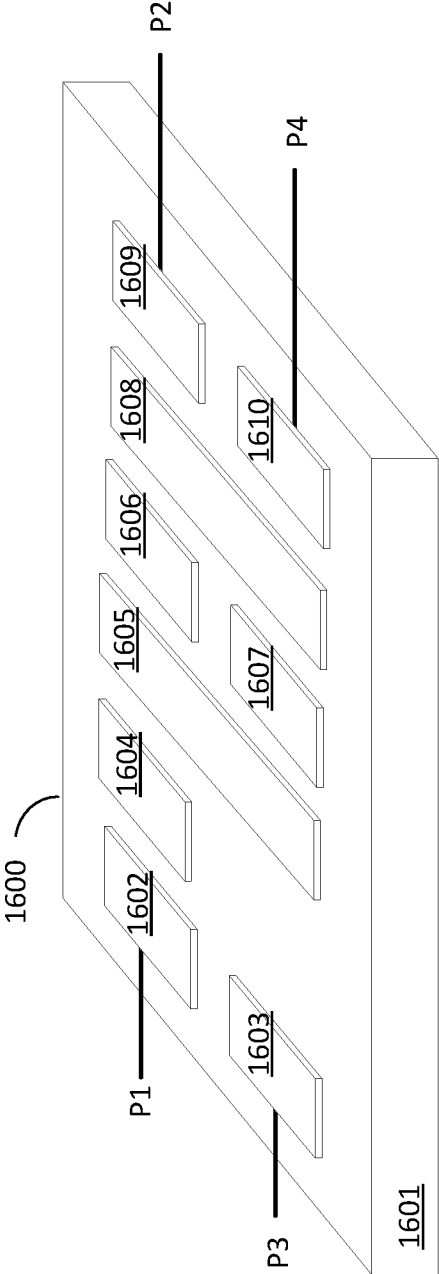
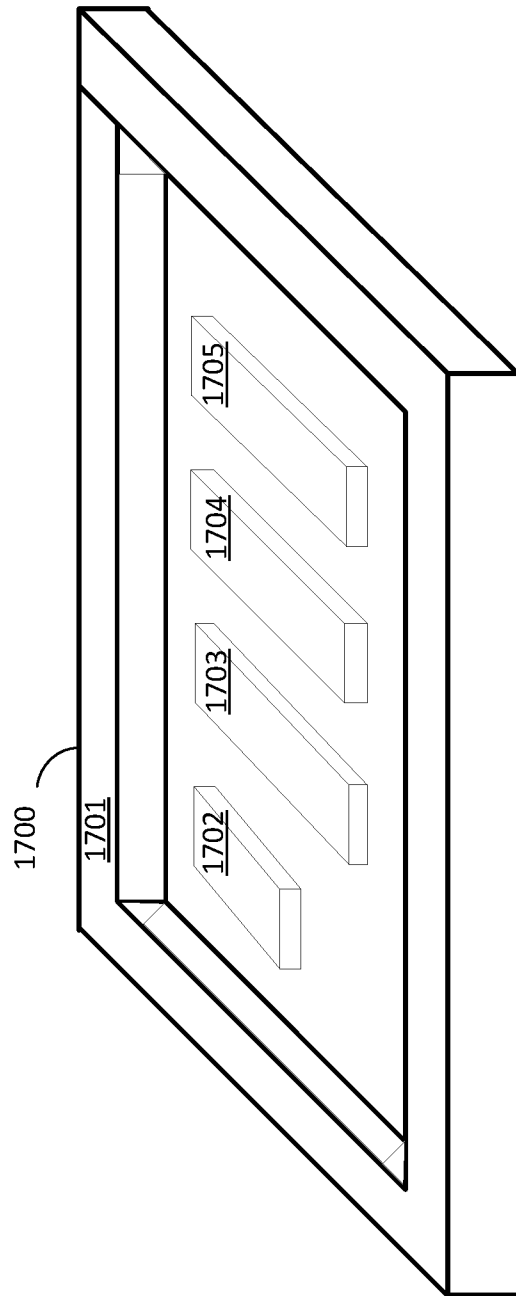FIG. 17

ALL-ACOUSTIC DUPLEXERS USING DIRECTIONAL COUPLERS

CROSS-REFERENCE TO RELATED APPLICATIONS/INCORPORATION BY REFERENCE

This patent application makes reference to, claims priority to, and claims benefit from U.S. Provisional Application No. 62/215,444, filed on Sep. 8, 2015.

The above-referenced application is hereby incorporated herein by reference in its entirety.

FIELD OF THE DISCLOSURE

Certain embodiments of the disclosure relate to radio frequency (RF) filters and duplexers. More specifically, certain embodiments of the disclosure relate to a method and system for all-acoustic duplexers that use acoustic directional couplers and acoustic filters for various communication systems including frequency division duplex, multi-standard, multi-antenna, or multi-band communication standards, for example.

BACKGROUND OF THE DISCLOSURE

RF filters and duplexers have been essential components of communication systems. High selectivity, low insertion loss, compact size, ability to handle large signals (power handling), high linearity, manufacturability, and low cost may be some of the important desired features for RF filters and duplexers.

The requirements for RF filters and duplexers have become more stringent in light of new communication standards where information channels and frequency bands are closer to each other, new communication devices such as smartphones where the footprint and cost of all components must be very small as more components are needed in support of multiple standards and applications, and co-existent communication systems where multiple communication transmitters and receivers work simultaneously.

Linearity, noise, and power handling requirements typically lead to utilization of passive RF filters and duplexers in many applications. The performance of passive RF filters and duplexers may be limited by the quality factor (Q) of the components that are used in their realization. The filter selectivity as well as passband requirement may lead to a filter topology and filter order. For a given RF filter or duplexer topology and order, insertion loss may reduce with the increase of component Q.

Various technologies can be used to realize passive RF filters and duplexers. For instance, capacitors, inductors, or transmission lines can be used to realize passive RF filters and duplexers. Electromagnetic resonators, including transmission line and dielectric waveguide resonators, can also be used to realize passive filters and duplexers. The quality factor of such components is typically proportional to their overall physical size. As such, it has been difficult to realize compact low-loss selective passive RF filters and duplexers using electromagnetic components and resonators.

Piezoelectric material can be used to realize compact high-Q resonators. Crystal resonators have been widely used to generate spectrally-pure oscillators. Surface acoustic wave (SAW) resonators have been widely used to realize compact low-loss selective RF filters and duplexers as well as oscillators. More recently, bulk acoustic wave (BAW) resonators have been used to construct high-performance RF filters and duplexers as well as oscillators.

Ceramic resonators and micro electro mechanical system (MEMS) resonators with high quality factor have also been used in frequency generation as well as filtering applications.

RF SAW filters and duplexers have been used widely in wireless communications such as cellular phones, wireless local area network (WLAN) transceivers, global positioning system (GPS) receivers, cordless phones, and so forth. RF SAW filters have been used as band-select filters, image-reject filters, intermediate frequency (IF) filters, transmitter noise or spur reduction filters, and so forth. A typical smartphone may have several SAW resonators, SAW filters, and SAW duplexers to support various communication systems and standards.

Over the past decade, significant research and development on BAW technology has resulted in BAW resonators that have lower loss (or higher Q) or are more compact, especially at higher frequencies, compared with SAW resonators. Therefore, RF filters and duplexers that use BAW resonators may have lower insertion loss, or higher selectivity, or smaller form factor compared with those that utilize SAW resonators especially at higher frequencies. Thin film bulk acoustic resonators (FBAR) and solidly mounted resonators (SMR) are a common example of BAW resonators.

Modern wireless communication standards designate many different operational frequency bands to support the increase in the overall wireless capacity and reach. For instance, cellular phone standards may include RF frequency bands that span around 700 MHz to around 4000 MHz. Furthermore, in order to increase the overall wireless capacity, the frequency spacing between adjacent frequency bands or channels within the same application or different applications may be reduced. This may be done, for instance, by reducing the typical guard bands in wireless standard or by placing the transmit and receive frequency bands in a frequency division duplex (FDD) scheme closer to each other. As a result, RF filters and duplexers with higher selectivity may be required. More selective RF filters and duplexers that utilize a given component or technology (SAW, BAW, etc.) may incur more in-band insertion loss. The higher RF filter or duplexer insertion loss may reduce the wireless receiver noise figure and sensitivity, increase the wireless transmitter power consumption or reduce the transmitted power, and/or deteriorate the overall performance of a communication system.

In commercial systems, the choice of technology may depend on the technical performance, such as power consumption as well as economic and business considerations such as cost, size, and time to market. For instance, while one technology may offer a better performance compared with another technology, it may not be adopted for a commercial system that is cost sensitive. In the case of RF filters and duplexers, it may be desirable to use a technology that leads to the lowest-cost and/or most-compact solution, as long as a predetermined performance criterion is met. In other words, a more expensive or larger solution may not be adopted, even if it offers a better performance as compared with an alternative solution that meets an acceptable performance level at a lower cost and/or size. For instance, while RF filters and duplexers that use BAW resonators may offer lower loss compared with RF filters and duplexers that use SAW resonators for a given set of specifications, the higher relative cost of BAW technology, as well as its relatively smaller number of suppliers, may disfavor their usage in certain applications and standards. Other consid-

erations may be the ease of integration with the rest of the components in a communication system. For instance, there may be performance, business, or economic advantages to integrate RF filters and duplexers with low noise amplifiers (LNA), power amplifiers (PA), transmit/receive (T/R) or band-select switches, impedance matching networks, etc. in a compact RF module. A typical modern wireless communication device, such as a smartphone, may have a number of SAW filters and duplexers as well as a number of BAW filter and duplexers. Each SAW or BAW filter or duplexer may be used for a specific communication application, standard, or frequency band.

Architectural solutions that enable realization of highly-selective low-loss duplexers with high-isolation between transmit and receive bands are highly desirable. Specifically, it is highly desirable to use a lower cost or more compact technology within an innovative architecture that satisfies a comparable or better specification compared to what can be achieved using a more expensive or less compact technology. Examples might include replacing BAW duplexers with SAW duplexers using an innovative architecture, or replacing ceramic or cavity duplexers with BAW duplexers using an innovative architecture.

A conventional method to design acoustic resonator based filters and duplexer is to decide upon the number of resonators to be used depending on the required stopband rejection in the case of filters or the required isolation in the case of duplexers. The larger the number of resonators used in filter design, the larger may be the order of the filter and the higher may be the rejection of out-of-passband frequencies (or higher stopband rejection). Similarly, the number of resonators used in the TX and RX filters of the duplexer may determine the total isolation from TX to RX. The larger the order of the TX and RX filters (i.e., the larger the number of resonators used in them), the larger may be the amount of isolation between TX and RX. Due to the limited quality factor of the acoustic resonators, the insertion loss in the filter and duplexer may be directly proportional to the number of the resonators used. In other words, the larger the order of the filter and the TX and RX filter, the larger may be the loss of the filter and duplexer, respectively. It may be possible to break this insertion loss and isolation or stopband rejection tradeoff by incorporating hybrid couplers in the design of filters and duplexers.

Further limitations and disadvantages of conventional and traditional approaches will become apparent to one of skill in the art, through comparison of such systems with the present disclosure as set forth in the remainder of the present application with reference to the drawings.

BRIEF SUMMARY OF THE DISCLOSURE

A system and/or method for all-acoustic duplexers using directional couplers, substantially as shown in and/or described in connection with at least one of the figures, as set forth more completely in the claims.

An objective of this disclosure is to enable realization of compact, low loss, and low cost radio frequency duplexers. For instance, the disclosure enables realization of high-performance duplexers without utilizing costly process technologies. As a specific example, the disclosure enables realization of acoustic duplexers with a similar or better performance that is currently achievable only using dielectric or air cavity technologies. As another specific example, the disclosure enables realization of acoustic duplexers using low-cost surface acoustic wave processing technology with a similar or better performance that is currently achiev-

able, with a similar compact form factor, only using costly bulk acoustic wave technology.

The disclosure has application in wireless communication systems. For instance, it can be applied to handheld devices such as smartphones, tablets, cell phones, laptops, etc. that support wireless communications. The disclosure can also be applied to wireless communication base stations, including micro-, pico-, and femto-base stations, repeaters, and signal boosters. The disclosure can be used in multi-band, multi-standard, or multi-function wireless platforms.

Various advantages, aspects and novel features of the present disclosure, as well as details of an illustrated embodiment thereof, will be more fully understood from the following description and drawings.

BRIEF DESCRIPTION OF SEVERAL VIEWS OF THE DRAWINGS

The drawings are of illustrative embodiments. They do not illustrate all embodiments. Other embodiments may be used in addition or instead. Details that may be apparent or unnecessary may be omitted to save space or for more effective illustration. Some embodiments may be practiced with additional components or steps and/or without all of the components or steps that are illustrated. When the same numeral appears in different drawings, it refers to the same or like components or steps.

Represented simulation results of various embodiments are only for illustrative reasons, and are not meant to cover all possible responses that various embodiments enable. For instance, the presented simulation results cover filters with a single passband and at least one stopband (or notch) in their transfer functions. Filters with multiple passbands or stopbands may also be realized using the embodiments or other teachings of this disclosure. Filters whose transfer functions fundamentally change as a function of at least one stimulus may also be realized using the embodiments or other teachings of this disclosure.

FIG. 1 illustrates a simplified schematic of a frequency division duplex communication transceiver including an antenna, a duplexer, a transmitter, and a receiver.

FIG. 2 illustrates a realization of a duplexer including a band-pass filter tuned to the transmit frequency band, a second band-pass filter tuned to the receive frequency band, and appropriate impedance matching networks.

FIG. 3 illustrates a realization of an acoustic RF filter including a pair of transducers and an acoustic filter.

FIG. 4 illustrates a realization of an acoustic RF filter including acoustic resonators.

FIG. 5 illustrates a realization of an acoustic resonator.

FIG. 6 illustrates a realization of a duplexer including an acoustic RF band-pass filter tuned to the transmit frequency band, a second acoustic RF band-pass filter tuned to the receive frequency band, and appropriate impedance matching networks.

FIG. 7 illustrates a realization of a duplexer including an acoustic resonator-based RF band-pass filter tuned to the transmit frequency band, a second acoustic resonator-based RF band-pass filter tuned to the receive frequency band, and appropriate impedance matching networks.

FIG. 8 shows an embodiment of an acoustic duplexer based on this disclosure.

FIG. 9 shows another embodiment of an acoustic duplexer based on this disclosure.

FIG. 10 shows another embodiment of an acoustic duplexer based on this disclosure.

FIG. **11** shows another embodiment of an acoustic duplexer based on this disclosure.

FIG. **12** shows another embodiment of an acoustic duplexer based on this disclosure.

FIG. **13** shows another embodiment of an acoustic duplexer based on this disclosure.

FIG. **14** shows another embodiment of an acoustic duplexer based on this disclosure.

FIG. **15** shows another embodiment of an acoustic duplexer based on this disclosure wherein at least one of the acoustic components can be tuned in response to an electrical stimulus.

FIG. **16** shows an embodiment of an acoustic duplexer based on this disclosure wherein the duplexer is realized monolithically on a piezoelectric substrate.

FIG. **17** shows an embodiment of an acoustic duplexer based on this disclosure wherein all the individual acoustic components are integrated in a single package.

DETAILED DESCRIPTION OF THE DISCLOSURE

As utilized herein the terms "circuit" and "circuitry" refer to physical electronic components (i.e. hardware) and any software and/or firmware ("code") which may configure the hardware, be executed by the hardware, and/or otherwise be associated with the hardware. As utilized herein, "and/or" means any one or more of the items in the list joined by "and/or". As an example, "x and/or y" means any element of the three-element set $\{(x), (y), (x, y)\}$. As another example, "x, y, and/or z" means any element of the seven-element set $\{(x), (y), (z), (x, y), (x, z), (y, z), (x, y, z)\}$. As utilized herein, the term "exemplary" means serving as a non-limiting example, instance, or illustration. As utilized herein, the terms "e.g.," and "for example" set off lists of one or more non-limiting examples, instances, or illustrations.

Illustrative embodiments are now described. Other embodiments may be used in addition or instead. Details that may be apparent to a person of ordinary skill in the art may have been omitted. Some embodiments may be practiced with additional components or steps and/or without all of the components or steps that are described.

The components, steps, features, objects, benefits and advantages which have been discussed are merely illustrative. None of them, nor the discussions relating to them, are intended to limit the scope of protection in any way. Numerous other embodiments are also contemplated. These include embodiments which have fewer, additional, and/or different components, steps, features, objects, benefits and advantages. These also include embodiments in which the components and/or steps are arranged and/or ordered differently.

Unless otherwise stated, all measurements, values, ratings, positions, magnitudes, sizes, and other specifications that are set forth in this specification, including in the claims that follow, are approximate, not exact. They are intended to have a reasonable range that is consistent with the functions to which they relate and with what is customary in the art to which they pertain.

All articles, patents, patent applications, and other publications that have been cited in this disclosure are incorporated herein by reference in their entirety.

The phrase "means for" when used in a claim is intended to and should be interpreted to embrace the corresponding structures and materials that have been described and their equivalents. Similarly, the phrase "step for" when used in a claim is intended to and should be interpreted to embrace the corresponding acts that have been described and their equivalents. The absence of these phrases from a claim means that the claim is not intended to and should not be interpreted to be limited to these corresponding structures, materials, or acts, or to their equivalents.

The scope of protection is limited solely by the claims that now follow. That scope is intended and should be interpreted to be as broad as is consistent with the ordinary meaning of the language that is used in the claims when interpreted in light of this specification and the prosecution history that follows, except where specific meanings have been set forth, and to encompass all structural and functional equivalents.

Relational terms such as "first" and "second" and the like may be used solely to distinguish one entity or action from another, without necessarily requiring or implying any actual relationship or order between them. The terms "comprises," "comprising," and any other variation thereof when used in connection with a list of elements in the specification or claims are intended to indicate that the list is not exclusive and that other elements may be included. Similarly, an element preceded by an "a" or an "an" does not, without further constraints, preclude the existence of additional elements of the identical type.

FIG. **1** shows a simplified block diagram schematic of a frequency division duplex (FDD) communication system that includes an antenna **103**, a frequency duplexer **100**, a transmitter **101**, and a receiver **102**. The duplexer **100** enables utilizing the same antenna for the receiver **102** and the transmitter **101** that operate at different frequency bands.

FIG. **2** shows a simplified block diagram schematic of a frequency duplexer **200** that includes a band-pass filter **201** covering the transmit frequency band, a band-pass filter **202** covering the receive frequency band, and impedance matching networks **203** and **204** that enable connection of the filters **201** and **202** to a common antenna port (ANT) while ensuring proper driving point impedances at the transmit and receive frequency bands. In some realizations of frequency duplexers, a three-port passive impedance matching network is used instead of separate **201** and **202** networks. In order to satisfy the isolation requirement between TX and RX ports, the filters **201** and **202** are often designed as high-order filters. In order to have a low insertion loss between the TX and ANT ports and between RX and ANT ports, the high-order filters utilize passive components with high quality factors. Technologies that offer high quality factor passives and resonators are often costly or consume large footprints.

The technology used to create filters **201** and **202** depends on multiple factors including, for example, performance (e.g., in-band insertion loss, out-of-band rejection, TX-RX isolation, power handling, etc.), frequency bands of interest, cost, and form-factor. For instance, in some commercial cellular applications operating at the so-called "Low Band," which is primarily around and below 1 GHz, SAW technology is often used, while in some commercial cellular applications operating at the so-called "High Band," which is primarily around 2 GHz, BAW technology is often used. Typically, BAW duplexers are more expensive compared with SAW duplexers. It is one intention of the proposed disclosure to enable realization of frequency duplexers without requiring expensive acoustic technologies. On the other hand, in some applications, the extremely high performance requirement might necessitate using dielectric filters such as ceramic filters. These filters are typically large. It is another intention of the proposed disclosure to enable realization of high-performance frequency duplexers without requiring bulky dielectric filter technologies.

FIG. **3** shows a simplified block diagram of a two-port acoustic filter **300** that includes transducers **301** and **303** that convert the electromagnetic signals to acoustic signals and vice versa, and an acoustic filter part **302**. The acoustic filter **300** operates on electromagnetic signals—that is, both ports of the two-port acoustic filter **300** (P1 and P2) interface with electromagnetic signals. In some realizations of acoustic filters, at least some amount of acoustic filtering function is embedded within the transduction function. In order to satisfy the isolation requirement between TX and RX ports of a frequency duplexer, the acoustic filter **302** is often designed as a high-order filter. Acoustic filters are often smaller compared with their electromagnetic counterparts. Acoustic technologies that offer high quality factor components and resonators are needed to keep the pass-band insertion loss of acoustic filters at sufficiently low levels. For instance, bulk acoustic wave technologies may be used to realize extremely selective filters that are needed in frequency duplexers that support FDD schemes with close TX and RX frequency bands. Bulk acoustic wave duplexers are often more expensive when compared with surface acoustic wave duplexers. It is one intention of the proposed disclosure to enable realization of frequency duplexers without requiring expensive acoustic technologies.

FIG. **4** shows a conceptual block diagram of an acoustic filter **400** that utilizes acoustic resonators **401** in its realization. Some of the acoustic resonators may be coupled to each other (mechanically, acoustically, or electrically). The filter may be based on surface or bulk acoustic wave technologies. Bulk acoustic wave approach often leads to lower passband insertion loss, but it is often costlier when compared with the surface acoustic wave approach. The filter may include other passive components such as inductors and capacitors too.

FIG. **5** shows a simplified schematic of an acoustic resonator **501**, whose symbol is referenced as **500**, that includes interdigital transducer (IDT) **502** and acoustic reflectors **503** and **504**. The resonant frequency or frequencies are determined by the geometries of the IDT **502** and reflectors **503**, **504**, and spacing between IDT **502** and reflectors **503**, **504**. This embodiment corresponds to a surface acoustic wave (SAW) resonator. There are several other possible realizations of surface acoustic wave resonators as well as bulk acoustic wave (BAW) resonators.

FIG. **6** shows a simplified schematic of a frequency duplexer **600** that includes acoustic filters **601** and **602** covering transmit and receive frequency bands, respectively, and impedance matching networks **603** and **604**. In some realizations of frequency duplexers, a three-port passive impedance matching network is used instead of separate **603** and **604** networks. Each of the acoustic filters **601**, **602** includes a pair of transducers **605**, **607** or **608**, **610** and an acoustic filter part **606** or **609**. In some realizations of acoustic filters, at least some amount of acoustic filtering function is embedded within the transduction function. The filters may be based on surface or bulk acoustic wave technologies. Bulk acoustic wave approach often leads to lower passband insertion loss, but it is often costlier when compared with the surface acoustic wave approach. Conventional frequency duplexers based on either surface or bulk acoustic wave technologies are available for commercial applications. Acoustic filters **606** and **609** may include other passive components such as inductors and capacitors in their realizations.

FIG. **7** shows a simplified schematic of a frequency duplexer **700** that includes resonator-based acoustic filters **701** and **702** covering transmit and receive frequency bands, respectively, and impedance matching networks **703** and

704. Some of the acoustic resonators may be coupled to each other (mechanically, acoustically, or electrically). In some realizations of frequency duplexers, a three-port passive impedance matching network is used instead of separate **703** and **704** networks. Each of the acoustic filters **701**, **702** includes acoustic resonators **705**, **706**. In some realizations of acoustic filters, at least some amount of acoustic filtering function is embedded within the transduction function. The filters may be based on surface or bulk acoustic wave technologies. Bulk acoustic wave approach often leads to lower passband insertion loss, but it is often costlier when compared with the surface acoustic wave approach. Conventional frequency duplexers based on either surface or bulk acoustic wave technologies are available for commercial applications. Acoustic filters **701** and **702** may include other passive components such as inductors and capacitors in their realizations.

FIG. **8** shows an embodiment of the present disclosure. The 4-port acoustic network **800** operates on electromagnetic signals applied at ports P1, P2, P3, and P4. Electromagnetic signals applied to the 4 ports are converted to acoustic signals through transducers **801**, **802**, **808**, **809**. The main operations of the 4-port acoustic network **800** occur in acoustic domain using acoustic filters **803**, **805**, **806** and acoustic hybrid couplers **804**, **807**. Acoustic filters **805** and **806** can have the same frequency response and may be constructed to be identical. Acoustic filter **803** has a different frequency response when compared with acoustic filters **805** and **806**. Acoustic hybrid couplers **804**, **807** split the signal applied to any of their inputs on either side into two signals with nominally equal amplitude and 90° phase difference on the other side. The two ports on the same side of acoustic hybrid couplers are nominally isolated. It is possible that the electromagnetic-acoustic transduction at the ports is embedded within the acoustic filters and acoustic hybrid couplers. Acoustic filter **803** may be omitted in some implementations. Ports P1 and P2 of the 4-port acoustic network are nominally isolated irrespective of the transfer functions of the acoustic filters. Ports P3 and P4 of the 4-port acoustic network are nominally isolated irrespective of the transfer functions of the acoustic filters. The transfer function between ports P2 and P3 depends on the transfer function of the filters **805** and **806**. The transfer function between ports P1 and P3 depends on the transfer function of the filter **803** (if present) and the driving point reflection coefficient of the filters **805** and **806**. The transfer function between ports P1 and P4 depends on the transfer functions of filters **803** (if present), **805**, and **806**. The transfer function between ports P2 and P4 depends on the driving port reflection coefficient of filters **805** and **806**. Surface acoustic wave technology or bulk acoustic wave technology may be used for any of the acoustic components **803**, **804**, **805**, **806**, or **807**. Any of these acoustic components may include other passive components such as inductors and capacitors in their realizations. Additional components may be included in the design for various reasons, for instance, to improve the isolation between the adjacent ports.

In one embodiment, the 4-port acoustic network **800** may be used in an FDD communication system. In one such embodiment, port P3, P1, and P2 may be designated as antenna port, transmit port, and receive port, respectively. In this embodiment, the pass-bands of acoustic filters **805** and **806** cover the receive frequency bands while the pass-bands of acoustic filter **803** (if present) cover the transmit frequency bands. Acoustic filters **805** and **806** are designed so that their driving port reflection coefficients are high (ideally magnitude of one) at the transmit frequency bands. In

another such embodiment, port P3, P1, and P2 may be designated as antenna port, receive port, and transmit port, respectively. In this embodiment, the pass-bands of acoustic filters 805 and 806 cover the transmit frequency bands while the pass-bands of acoustic filter 803 (if present) cover the receive frequency bands. Acoustic filters 805 and 806 are designed so that their driving port reflection coefficients are high (ideally magnitude of one) at the receive frequency bands. In all such embodiments, port P4 may be terminated to appropriate impedance (either in acoustic or electromagnetic domain) or be used to monitor various features and non-idealities of the four-port acoustic network.

FIG. 9 shows an embodiment of the present disclosure. The 3-port acoustic network 900 operates on electromagnetic signals applied at ports P1, P2, and P3. Electromagnetic signals applied to the 3 ports are converted to acoustic signals through transducers 901, 902, 908. The main operations of the 3-port acoustic network 900 occur in acoustic domain using acoustic filters 903, 905, 906, acoustic hybrid couplers 904, 907, and acoustic termination 909. Acoustic filters 905 and 906 have the same frequency response and may be constructed to be identical. Acoustic filter 903 has a different frequency response when compared with acoustic filters 905 and 906. Acoustic hybrid couplers 904, 907 split the signal applied to any of their inputs on either side into two signals with nominally equal amplitude and 90° phase different on the other side. The two ports on the same side of acoustic hybrid couplers are nominally isolated. Nominally, the acoustic termination 909 absorbs the incident acoustic wave and prohibits acoustic reflections. It is possible that the electromagnetic-acoustic transduction at the ports is embedded within the acoustic filters and acoustic hybrid couplers. Acoustic filter 903 may be omitted in some implementations. Ports P1 and P2 of the 3-port acoustic network 900 are nominally isolated irrespective of the transfer functions of the acoustic filters. The transfer function between ports P2 and P3 depends on the transfer function of the filters 905 and 906. The transfer function between ports P1 and P3 depends on the transfer function of filter 903 (if present) and the driving point reflection coefficient of the filters 905 and 906. Surface acoustic wave technology or bulk acoustic wave technology may be used for any of the acoustic components 903, 904, 905, 906, or 907. Any of these acoustic components may include other passive components such as inductors and capacitors in their realizations.

In one embodiment, the 3-port acoustic network 900 may be used in an FDD communication system. In one such embodiment, port P3, P1, and P2 may be designated as antenna port, transmit port, and receive port, respectively. In this embodiment, the pass-bands of acoustic filters 905 and 906 cover the receive frequency bands while the pass-bands of acoustic filter 903 (if present) cover the transmit frequency bands. Acoustic filters 905 and 906 are designed so that their driving port reflection coefficients are high (ideally magnitude of one) at the transmit frequency bands. In another such embodiment, port P3, P1, and P2 may be designated as antenna port, receive port, and transmit port, respectively. In this embodiment, the pass-bands of acoustic filters 905 and 906 cover the transmit frequency bands while the pass-bands of acoustic filter 903 (if present) cover the receive frequency bands. Acoustic filters 905 and 906 are designed so that their driving port reflection coefficients are high (ideally magnitude of one) at the receive frequency bands.

FIG. 10 shows an embodiment of the present disclosure. The 4-port acoustic network 1000 operates on electromagnetic signals applied at ports P1, P2, P3, and P4. The main operations of the 4-port acoustic network 1000 occur in acoustic domain using acoustic filters 1001, 1003, 1004 and acoustic hybrid couplers 1002, 1005. Acoustic filters 1003 and 1004 include acoustic resonators 1007 and 1008 that have the same frequency response and may be constructed to be identical. Acoustic filter 1001 includes acoustic resonators 1006, has a different frequency response when compared with acoustic filters 1003 and 1004, and includes the electromagnetic-acoustic transduction. Acoustic hybrid couplers 1002, 1005 split the signal applied to any of their inputs on either side into two signals with nominally equal amplitude and 90° phase different on the other side. The two ports on the same side of acoustic hybrid couplers are nominally isolated. In this scheme, the electromagnetic-acoustic transduction at the ports is embedded within the acoustic filter 1001 and acoustic hybrid couplers 1002 and 1005. Acoustic filter 1001 may be omitted in some implementations; in such cases, the corresponding electromagnetic-acoustic transduction may be included in the acoustic hybrid coupler 1002. Ports P1 and P2 of the 4-port acoustic network are nominally isolated irrespective of the transfer functions of the acoustic filters. Ports P3 and P4 of the 4-port acoustic network 1000 are nominally isolated irrespective of the transfer functions of the acoustic filters. The transfer function between ports P2 and P3 depends on the transfer function of the filters 1003 and 1004. The transfer function between ports P1 and P3 depends on the transfer function of filter 1001 (if present) and the driving point reflection coefficient of the filters 1003 and 1004. The transfer function between ports P1 and P4 depends on the transfer functions of filters 1001 (if present), 1003, and 1004. The transfer function between ports P2 and P4 depends on the driving port reflection coefficient of filters 1003 and 1004. Surface acoustic wave technology or bulk acoustic wave technology may be used for any of the acoustic components 1001, 1002, 1003, 1004, or 1005. Any of these acoustic components may include other passive components such as inductors and capacitors in their realizations.

FIG. 11 shows an embodiment of the present disclosure. The 4-port acoustic network 1100 operates on electromagnetic signals applied at ports P1, P2, P3, and P4. Electromagnetic signals applied to the 4 ports are converted to acoustic signals through interdigital transducers 1101, 1102, 1108, 1109. The main operations of the 4-port acoustic network 1100 occur in acoustic domain using acoustic filters 1103, 1105, 1106 and acoustic hybrid couplers 1104, 1107. Acoustic filters 1105 and 1106 include acoustic resonators 1111 and 1112 that have the same frequency response and may be constructed to be identical. Acoustic filter 1103 includes acoustic resonators 1110 and has a different frequency response when compared with acoustic filters 1105 and 1106. Some of the acoustic resonators in any of the acoustic filters may be coupled to each other (mechanically, acoustically, or electrically). Acoustic hybrid couplers 1104, 1107 split the signal applied to any of their inputs on either side into two signals with nominally equal amplitude and 90° phase different on the other side. The two ports on the same side of acoustic hybrid couplers are nominally isolated. It is possible that the electromagnetic-acoustic transduction at the ports is embedded within the acoustic filters and acoustic hybrid couplers. In one embodiment, acoustic hybrid couplers may use coupled acoustic waveguides. Acoustic waveguides can be created by combining regions with different acoustic velocities. Various mechanisms may be used to modify the acoustic velocity. For instance, metal strips on a piezoelectric substrate may lead to changes in

acoustic velocity due to mass loading and termination of electric fields associated with the acoustic wave, and as such may be used to create an acoustic waveguide. Proximity of acoustic waveguides may lead to the coupling of acoustic wave between the waveguides. In such a coupled-line acoustic coupler design, the length and spacing of the acoustic waveguides may be selected to realize an acoustic quadrature hybrid coupler. Acoustic waveguides may also be created by selective removal of the piezoelectric substrate (e.g. slot acoustic waveguide). Acoustic filter **1103** may be omitted in some implementations. Ports **P1** and **P2** of the 4-port acoustic network are nominally isolated irrespective of the transfer functions of the acoustic filters. Ports **P3** and **P4** of the 4-port acoustic network are nominally isolated irrespective of the transfer functions of the acoustic filters. The transfer function between ports **P2** and **P3** depends on the transfer function of the filters **1105** and **1106**. The transfer function between ports **P1** and **P3** depends on the transfer function of filter **1103** (if present) and the driving point reflection coefficient of the filters **1105** and **1106**. The transfer function between ports **P1** and **P4** depends on the transfer functions of filters **1103** (if present), **1105**, and **1106**. The transfer function between ports **P2** and **P4** depends on the driving port reflection coefficient of filters **1105** and **1106**.

FIG. **12** shows an embodiment of the present disclosure. The 4-port acoustic network **1200** operates on electromagnetic signals applied at ports **P1**, **P2**, **P3**, and **P4**. Electromagnetic signals applied to the 4 ports are converted to acoustic signals through interdigital transducers **1201**, **1202**, **1208**, **1209**. The main operations of the 4-port network occur in acoustic domain using acoustic filters **1203**, **1205**, **1206** and acoustic hybrid couplers **1204**, **1207**. Acoustic filters **1205** and **1206** are coupled-resonator-based designs using acoustic resonators **1211** and **1212** that have the same frequency response and may be constructed to be identical. Acoustic filter **1203** is a coupled-resonator-based design using acoustic resonators **1210** and has a different frequency response when compared with acoustic filters **1205** and **1206**. Some of the acoustic resonators in any of the acoustic filters may be coupled to each other (mechanically, acoustically, or electrically). Acoustic hybrid couplers **1204**, **1207** split the signal applied to any of their inputs on either side into two signals with nominally equal amplitude and 90° phase different on the other side. The two ports on the same side of acoustic hybrid couplers are nominally isolated. It is possible that the electromagnetic-acoustic transduction at the ports is embedded within the acoustic filters and acoustic hybrid couplers. In one embodiment, acoustic hybrid couplers may use acoustic coupled transmission lines. Acoustic filter **1203** may be omitted in some implementations. Ports **P1** and **P2** of the 4-port acoustic network are nominally isolated irrespective of the transfer functions of the acoustic filters. Ports **P3** and **P4** of the 4-port acoustic network are nominally isolated irrespective of the transfer functions of the acoustic filters. The transfer function between ports **P2** and **P3** depends on the transfer function of the filters **1205** and **1206**. The transfer function between ports **P1** and **P3** depends on the transfer function of filter **1203** (if present) and the driving point reflection coefficient of the filters **1205** and **1206**. The transfer function between ports **P1** and **P4** depends on the transfer functions of filters **1203** (if present), **1205**, and **1206**. The transfer function between ports **P2** and **P4** depends on the driving port reflection coefficient of filters **1205** and **1206**. Any of the acoustic components may include other passive components such as inductors and capacitors in their realizations.

FIG. **13** shows an embodiment of the present disclosure. The 4-port acoustic network **1300** operates on electromagnetic signals applied at ports **P1**, **P2**, **P3**, and **P4**. The main operations of the 4-port acoustic network **1300** occur in acoustic domain using acoustic filters **1301**, **1303**, **1304** and acoustic hybrid couplers **1302**, **1305**. In this embodiment, the interface between the acoustic components **1301**, **1302**, **1303**, **1304**, and **1305** occurs via electromagnetic signals. Electromagnetic-acoustic transduction occurs within each of the acoustic components **1301**, **1302**, **1303**, **1304**, **1305**. Acoustic filters **1303** and **1304** have the same frequency response and may be constructed to be identical. Acoustic filter **1301** has a different frequency response when compared with acoustic filters **1303** and **1304**. Acoustic hybrid couplers **1302**, **1305** split the signal applied to any of their inputs on either side into two signals with nominally equal amplitude and 90° phase different on the other side. The two ports on the same side of acoustic hybrid couplers are nominally isolated. It is possible that the electromagnetic-acoustic transduction at the ports is embedded within the acoustic filters and acoustic hybrid couplers. Acoustic filter **1301** may be omitted in some implementations. Ports **P1** and **P2** of the 4-port acoustic network are nominally isolated irrespective of the transfer functions of the acoustic filters. Ports **P3** and **P4** of the 4-port acoustic network are nominally isolated irrespective of the transfer functions of the acoustic filters. The transfer function between ports **P2** and **P3** depends on the transfer function of the filters **1303** and **1304**. The transfer function between ports **P1** and **P3** depends on the transfer function of filter **1301** (if present) and the driving point reflection coefficient of the filters **1303** and **1304**. The transfer function between ports **P1** and **P4** depends on the transfer functions of filters **1301** (if present), **1303**, and **1304**. The transfer function between ports **P2** and **P4** depends on the driving port reflection coefficient of filters **1303** and **1304**. Surface acoustic wave technology or bulk acoustic wave technology may be used for any of the acoustic components **1301**, **1302**, **1303**, **1304**, or **1305**. Any of these acoustic components may include other passive components such as inductors and capacitors in their realizations.

FIG. **14** shows an embodiment of the present disclosure. The 4-port acoustic network **1400** operates on electromagnetic signals applied at ports **P1**, **P2**, **P3**, and **P4**. The main operations of the 4-port acoustic network **1400** occur in acoustic domain using acoustic filters **1401**, **1403**, **1404** and acoustic hybrid couplers **1402**, **1405**. The interface between acoustic components may occur in acoustic domain or in electromagnetic domain. For instance, acoustic waveguides may be used to couple acoustic waves between acoustic components (in acoustic domain). Electromagnetic-acoustic transducers may be used in such interfaces or embedded within the acoustic components. Acoustic filters **1403** and **1404** have the same frequency response and may be constructed to be identical. Acoustic filter **1401** has a different frequency response when compared with acoustic filters **1403** and **1404**. Acoustic hybrid couplers split the signal applied to any of their inputs on either side into two signals with nominally equal amplitude and 90° phase different on the other side. The two ports on the same side of acoustic hybrid couplers are nominally isolated. It is possible that the electromagnetic-acoustic transduction at the ports is embedded within the acoustic filters and acoustic hybrid couplers. Acoustic filter **1401** may be omitted in some implementations. Ports **P1** and **P2** of the 4-port acoustic network are nominally isolated irrespective of the transfer functions of the acoustic filters. Ports **P3** and **P4** of the 4-port acoustic

network are nominally isolated irrespective of the transfer functions of the acoustic filters. The transfer function between ports P2 and P3 depends on the transfer function of the filters **1403** and **1404**. The transfer function between ports P1 and P3 depends on the transfer function of the filter **1401** (if present) and the driving point reflection coefficient of the filters **1403** and **1404**. The transfer function between ports P1 and P4 depends on the transfer functions of filters **1401** (if present), **1403**, and **1404**. The transfer function between ports P2 and P4 depends on the driving port reflection coefficient of filters **1403** and **1404**. Surface acoustic wave technology or bulk acoustic wave technology may be used for any of the acoustic components **1401**, **1402**, **1403**, **1404**, or **1405**. Any of these acoustic components may include other passive components such as inductors and capacitors in their realizations.

In one embodiment, the 4-port acoustic network **1400** may be used in an FDD communication system. In one such embodiment, port P3, P1, and P2 may be designated as antenna port, transmit port, and receive port, respectively. In this embodiment, the pass-bands of acoustic filters **1403** and **1404** cover the receive frequency bands while the pass-bands of acoustic filter **1401** (if present) cover the transmit frequency bands. Acoustic filters **1403** and **1404** are designed so that their driving port reflection coefficients are high (ideally magnitude of one) at the transmit frequency bands. In another such embodiment, port P3, P1, and P2 may be designated as antenna port, receive port, and transmit port, respectively. In this embodiment, the pass-bands of acoustic filters **1403** and **1404** cover the transmit frequency bands while the pass-bands of acoustic filter **1401** (if present) cover the receive frequency bands. Acoustic filters **1403** and **1404** are designed so that their driving port reflection coefficients are high (ideally magnitude of one) at the receive frequency bands. In all such embodiments, port P4 may be terminated to appropriate impedance (either in acoustic or electromagnetic domain) or be used to monitor various features and non-idealities of the four-port acoustic network.

FIG. **15** shows an embodiment of the present disclosure. The 4-port acoustic network **1500** operates on electromagnetic signals applied at ports P1, P2, P3, and P4. The main operations of the tunable or reconfigurable 4-port acoustic network **1500** occur in acoustic domain using acoustic filters **1501**, **1503**, **1504** and acoustic hybrid couplers **1502**, **1505**. The interface between acoustic components may occur in acoustic domain or in electromagnetic domain. Electromagnetic-acoustic transducers may be used in such interfaces or embedded within the acoustic components. Acoustic filters **1503** and **1504** have the same frequency response and may be constructed to be identical. Acoustic filter **1501** has a different frequency response when compared with acoustic filters **1503** and **1504**. Any one of the acoustic filters **1501**, **1503**, or **1504** may be tunable or reconfigurable. For instance, the transfer function of any of the acoustic filters may be changeable with the application of a stimulus or stimuli such as voltage or current that may be analog or digital. Acoustic hybrid couplers split the signal applied to any of their inputs on either side into two signals with nominally equal amplitude and 90° phase different on the other side. The two ports on the same side of acoustic hybrid couplers are nominally isolated. It is possible that the electromagnetic-acoustic transduction at the ports is embedded within the acoustic filters and acoustic hybrid couplers. Acoustic filter **1501** may be omitted in some implementations. Ports P1 and P2 of the 4-port tunable or reconfigurable acoustic network are nominally isolated irrespective of the

transfer functions of the acoustic filters. Ports P3 and P4 of the 4-port tunable or reconfigurable acoustic network are nominally isolated irrespective of the transfer functions of the acoustic filters. The transfer function between ports P2 and P3 depends on the transfer function of the filters **1503** and **1504**. The transfer function between ports P1 and P3 depends on the transfer function of the filter **1501** (if present) and the driving point reflection coefficient of the filters **1503** and **1504**. The transfer function between ports P1 and P4 depends on the transfer functions of filters **1501** (if present), **1503**, and **1504**. The transfer function between ports P2 and P4 depends on the driving port reflection coefficient of filters **1503** and **1504**. Surface acoustic wave technology or bulk acoustic wave technology may be used for any of the acoustic components **1501**, **1502**, **1503**, **1504**, or **1505**. Any of these acoustic components may include other passive components such as inductors and capacitors in their realizations.

In one embodiment, the 4-port tunable or reconfigurable acoustic network **1500** may be used in an FDD communication system. In one embodiment, the 4-port tunable or reconfigurable acoustic network **1500** may be used in a multi-standard communication system. In one such embodiment, port P3, P1, and P2 may be designated as antenna port, transmit port, and receive port, respectively. In this embodiment, the pass-bands of acoustic filters **1503** and **1504** cover the receive frequency bands while the pass-bands of acoustic filter **1501** (if present) cover the transmit frequency bands. Acoustic filters **1503** and **1504** are designed so that their driving port reflection coefficients are high (ideally magnitude of one) at the transmit frequency bands. In another such embodiment, port P3, P1, and P2 may be designated as antenna port, receive port, and transmit port, respectively. In this embodiment, the pass-bands of acoustic filters **1503** and **1504** cover the transmit frequency bands while the pass-bands of acoustic filter **1501** (if present) cover the receive frequency bands. Acoustic filters **1503** and **1504** are designed so that their driving port reflection coefficients are high (ideally magnitude of one) at the receive frequency bands. In all such embodiments, port P4 may be terminated to appropriate impedance (either in acoustic or electromagnetic domain) or be used to monitor various features and non-idealities of the four-port acoustic network.

Various mechanisms may be used to realize a tunable transfer function in acoustic filters. For instance, a bank of switchable acoustic filters, each with a different frequency response, may be used to realize a tunable acoustic filter. Alternatively, tunable or switchable electromagnetic components such as switched capacitors, switched inductors, variable capacitors (varactors), diodes, etc. may be used in the acoustic filters to enable a tunable transfer function. Alternatively, a tunable or reconfigurable acoustic filter may be constructed from an array of switchable acoustic resonators. The SAW device may be tunable or reconfigurable using micro-electro-mechanical systems (MEMS). Acoustic filter transfer functions may be modified by changing the acoustic wave velocity. Acoustic wave velocity may be modified, for instance, by applying electric field across or modifying the carrier density in a semiconducting piezoelectric substrate. Combination of the aforementioned techniques may be used to realize a tunable filter transfer function.

FIG. **16** shows an embodiment of the present disclosure. The monolithic 4-port network **1600** includes a common substrate **1601** and a number of components **1602**, **1603**, **1604**, **1605**, **1606**, **1607**, **1608**, **1609**, **1610** that are monolithically integrated on the common substrate **1601**. The

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integrated components **1602**, **1603**, **1604**, **1605**, **1606**, **1607**, **1608**, **1609**, and **1610** are primarily acoustic or electro-acoustic components. The electromagnetic-acoustic induction is done within one or more of these components. In one embodiment, integrated components **1602**, **1603**, **1609**, and **1610** may correspond to transducers. In one embodiment, integrated components **1604**, **1606**, and **1607** may correspond to acoustic filters. Integration of acoustic filters on the same substrate leads to better matching over process and temperature variations. In one embodiment, integrated components **1605** and **1608** may correspond to acoustic hybrid couplers. In one embodiment, the common substrate **1601** may be a piezoelectric material including, but not limited to, quartz, lithium niobate, lithium tantalite, lanthanum gallium silicate, zinc oxide, gallium nitride, aluminum nitride, etc. that may be used to create surface acoustic wave devices. In one embodiment, some of the interfaces between the integrated components may be acoustic signals. In one embodiment, the substrate may include multiple layers where each layer is composed of a different material; for instance, the substrate may include a low-cost material for mechanical support at the bottom and a piezoelectric material on the top for the electro-acoustic transduction and/or realization of acoustic devices. In one embodiment, the substrate may include semiconductor material; in such a scenario, in addition to acoustic devices, active electronic devices such as diodes and transistors may be realized on the same substrate. In one embodiment, some of the interfaces between the integrated components may be electromagnetic signals.

In one embodiment, the 4-port network **1600** may be used in an FDD communication system. In one such embodiment, ports P**3**, P**1**, and P**2** may be designated as antenna port, transmit port, and receive port respectively. In another such embodiment, ports P**3**, P**1**, and P**2** may be designated as antenna port, receive port, and transmit port respectively. In all such embodiments, port P**4** may be terminated to appropriate impedance (either in acoustic or electromagnetic domain) or be used to monitor various features and non-idealities of the four-port acoustic network. In one embodiment, the 4-port network **1600** may be based on a surface acoustic wave technology to replace a duplexer that is realized using more expensive bulk acoustic wave technology. In one embodiment, the 4-port network **1600** may be sealed within a package. In such an embodiment, the package may include other components such as inductors and capacitors. In another embodiment, the 4-port network **1600** may be packaged along with other functional devices such as filters, duplexers, switches, amplifiers, and antennas.

FIG. **17** shows an embodiment of the present disclosure. The network **1700** includes a common package **1701** and a number of components **1702**, **1703**, **1704**, and **1705** that are embedded in the common package **1701**. Each of the components **1702**, **1703**, **1704**, and **1705** may be primarily acoustic or electromagnetic. The interface between various components is electromagnetic which may be provided through wires, waveguides, transmission lines, pins, solders, vias, etc. Each of the components **1702**, **1703**, **1704**, and **1705** may be attached to the package through an adhesive material or through solder bumps. In one embodiment, component **1702** may be an acoustic filter. In one embodiment, components **1703** and **1705** may be acoustic hybrid couplers. In one embodiment, component **1704** may include a pair of matched, acoustic filters. Each of the components **1702**, **1703**, **1704**, or **1705** may be based on surface acoustic wave or bulk acoustic wave technologies. It is possible that some of the components **1702**, **1703**, **1704**, or **1705** are placed on top of other components in a stacked configura-

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tion. In one embodiment, the network **1700** may be used in an FDD communication system as a frequency duplexer. In one embodiment, the network **1700** interfaces with the outside world through electromagnetic signals that may be provided through wires, wire-bonds, waveguides, transmission lines, pins, solders, etc. The network **1700** may enable rapid realization of compact high-performance duplexers using commercially available acoustic components **1702**, **1703**, **1704**, or **1705**. In one embodiment, the network **1700** may replace duplexers that are based on bulky dielectric filters such as ceramic filters.

Other embodiments of the disclosure may provide a non-transitory computer readable medium and/or storage medium, and/or a non-transitory machine readable medium and/or storage medium, having stored thereon, a machine code and/or a computer program having at least one code section executable by a machine and/or a computer, thereby causing the machine and/or computer to perform the steps as described herein for all-acoustic duplexers using directional couplers.

Accordingly, aspects of the present disclosure may be realized in hardware, software, or a combination of hardware and software. The present disclosure may be realized in a centralized fashion in at least one computer system or in a distributed fashion where different elements are spread across several interconnected computer systems. Any kind of computer system or other apparatus adapted for carrying out the methods described herein is suited. A typical combination of hardware and software may be a general-purpose computer system with a computer program that, when being loaded and executed, controls the computer system such that it carries out the methods described herein.

Aspects of the present disclosure may also be embedded in a computer program product, which comprises all the features enabling the implementation of the methods described herein, and which when loaded in a computer system is able to carry out these methods. Computer program in the present context means any expression, in any language, code or notation, of a set of instructions intended to cause a system having an information processing capability to perform a particular function either directly or after either or both of the following: a) conversion to another language, code or notation; b) reproduction in a different material form.

While the present disclosure has been described with reference to certain embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted without departing from the scope of the present disclosure. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the present disclosure without departing from its scope. Therefore, it is intended that the present disclosure not be limited to the particular embodiment disclosed, but that the present disclosure will include all embodiments falling within the scope of the appended claims.

What is claimed is:

1. A radio frequency (RF) duplexer, comprising:
   at least a first port, a second port, and a third port; and
   a plurality of acoustic components comprising at least:
     a first acoustic filter that is coupled to the first port;
     a second acoustic filter;
     a third acoustic filter that is substantially similar to the
       second acoustic filter;

a first acoustic quadrature hybrid coupler that is configured to couple signals from the first acoustic filter and the third port to the second acoustic filter and the third acoustic filter; and

a second acoustic quadrature hybrid coupler that is configured to couple signals from the second acoustic filter and the third acoustic filter to the second port,

wherein the third port is a common port to the first port and the second port,

wherein the first port and the second port are isolated, and

wherein a transfer function between the first port and the third port and a transfer function between the second port and the third port have passbands at different frequencies as determined by the first acoustic filter, the second acoustic filter, and the third acoustic filter.

2. The RF duplexer of claim 1, wherein the second acoustic quadrature hybrid coupler is coupled to a fourth port, and the fourth port is coupled to an electrical termination.

3. The RF duplexer of claim 1, wherein the second acoustic quadrature hybrid coupler is coupled to an acoustic termination.

4. The RF duplexer of claim 1, wherein RF signals from one or more of the first port, the second port, and the third port are coupled to the acoustic components in the RF duplexer using interdigital transducers.

5. The RF duplexer of claim 1, wherein one or more of the first acoustic filter, the second acoustic filter, and the third acoustic filter use at least one acoustic resonator.

6. The RF duplexer of claim 1, wherein one or more of the first acoustic filter, the second acoustic filter, and the third acoustic filter include a ladder filter or a transversal filter.

7. The RF duplexer of claim 1, wherein one or both of the first acoustic quadrature hybrid coupler and the second acoustic quadrature hybrid coupler are realized using coupled acoustic waveguides.

8. The RF duplexer of claim 1, wherein the RF duplexer is realized monolithically on a piezoelectric substrate.

9. The RF duplexer of claim 8 wherein the piezoelectric substrate is a semiconductor substrate.

10. The RF duplexer of claim 1, wherein the RF duplexer components are integrated into a single package.

11. The RF duplexer of claim 1, wherein at least one of the acoustic components includes at least one capacitor or at least one inductor.

12. The RF duplexer of claim 1, wherein at least one of the acoustic components can be tuned by applying at least one electrical stimulus.

13. The RF duplexer of claim 1, comprising at least one switchable component in at least one of the acoustic components, wherein a response of the acoustic component includes that the switchable component changes for different states of the switchable component.

14. The RF duplexer of claim 1, wherein the RF duplexer is used in a multi-standard system or a multi-band communication system.

15. The RF duplexer of claim 1, wherein at least one of the acoustic components in the RF duplexer uses surface acoustic waves or bulk acoustic waves.

16. The RF duplexer of claim 1, wherein the first acoustic filter corresponds to frequency bands of a transmitter, and the second and the third acoustic filters correspond to the frequency bands of a receiver.

17. The RF duplexer of claim 1, wherein the first acoustic filter correspond to frequency bands of a receiver, and the second and third acoustic filters correspond to the frequency bands of a transmitter.

18. The RF duplexer of claim 1, wherein one or more of the first acoustic filter, the second acoustic filter, and the third acoustic filter comprise multiple passbands.

19. The RF duplexer of claim 1, wherein the radio frequency duplexer is configured to support cellular wireless communications.

20. The RF duplexer of claim 1, comprising electrical components that improve one or more of:

an impedance matching of one or more of the first port, the second port, and the third port;

an isolation between the first port and the second port; and

a rejection in certain frequencies in the transfer function between any pair of the first port, the second port, and the third port.

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