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(54) **RADIO FREQUENCY MODULES**

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Related U.S. Application Data

(63) Continuation of application No. 15/916,571, filed on Mar. 9, 2018, now Pat. No. 10,515,924.

(60) Provisional application No. 62/469,723, filed on Mar. 10, 2017, provisional application No. 62/573,524, filed on Oct. 17, 2017.

Publication Classification

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H01L 23/66 (2006.01)
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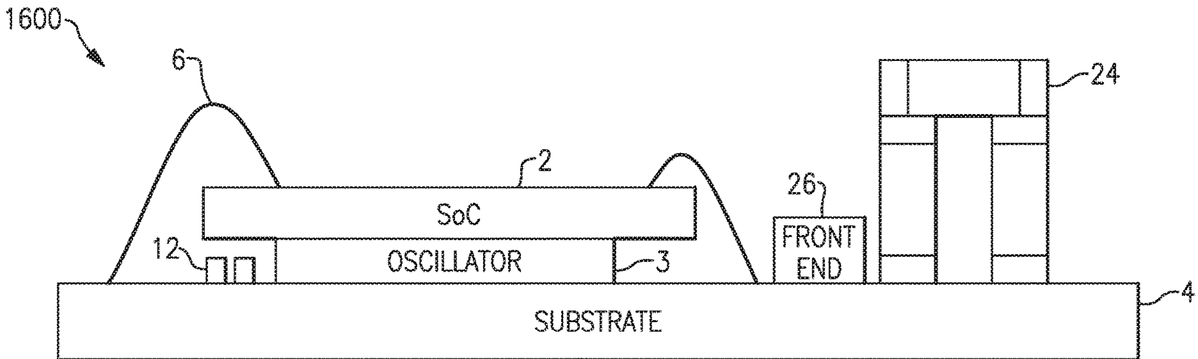
H04B 1/40 (2006.01)
H01L 25/18 (2006.01)

(52) **U.S. Cl.**
CPC ***H01L 24/73*** (2013.01); ***H01L 23/66*** (2013.01); ***H01L 23/552*** (2013.01); ***H04B 1/40*** (2013.01); ***H01L 24/48*** (2013.01); *H01L 23/49805* (2013.01); *H01L 2223/6677* (2013.01); *H01L 2924/3025* (2013.01); *H01L 2224/73257* (2013.01); *H01L 2924/00014* (2013.01); ***H01L 25/18*** (2013.01)

(57) **ABSTRACT**

Packaged modules for use in wireless devices are disclosed. A substrate supports integrated circuit die including at least a portion of a baseband system and a front end system, an oscillator assembly, and an antenna. The oscillator assembly includes an enclosure to enclose the oscillator and conductive pillars formed at least partially within a side of the enclosure to conduct signals between the top and bottom surfaces of the oscillator assembly. Components can be vertically integrated to save space and reduce trace length. Vertical integration provides an overhang volume that can include discrete components. Radio frequency shielding and ground planes within the substrate shield the front end system and antenna from radio frequency interference. Stacked filter assemblies include passive surface mount devices to filter radio frequency signals.



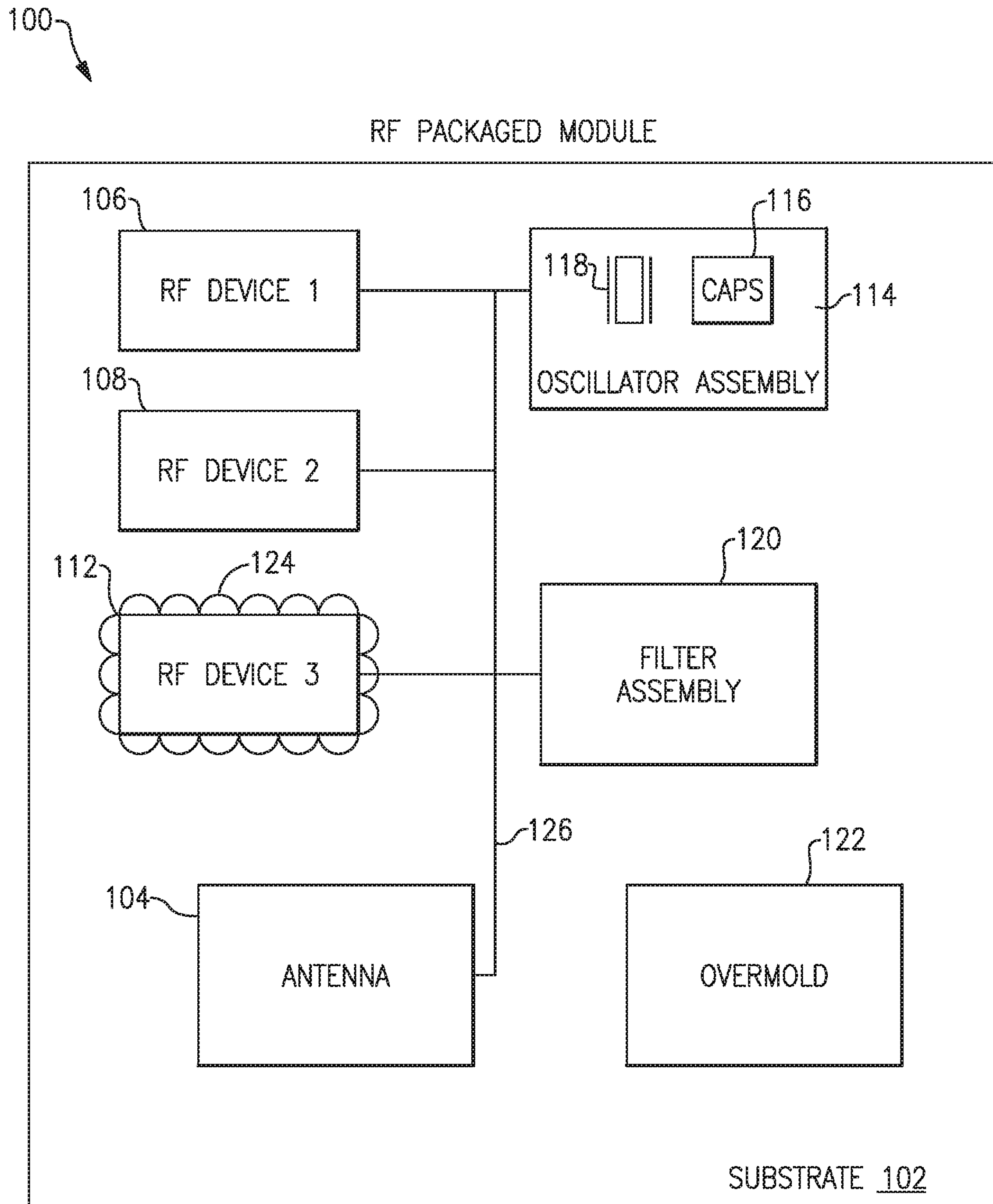


FIG.1

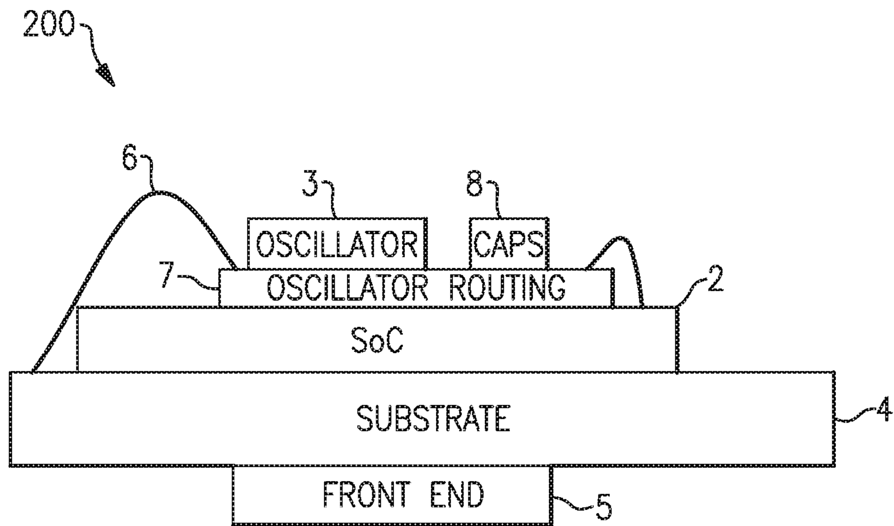


FIG.2

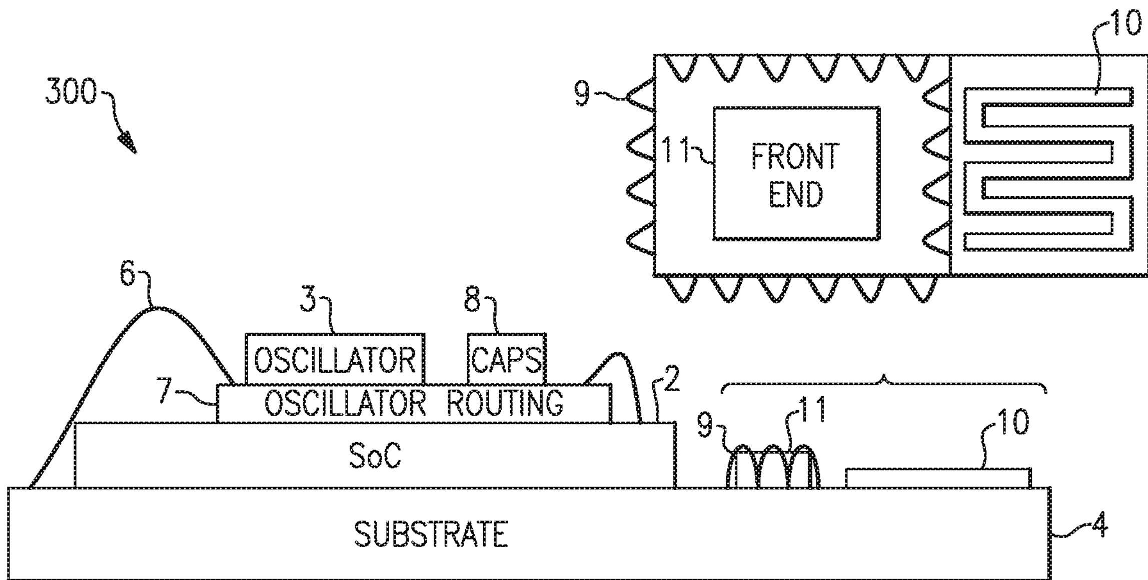


FIG.3

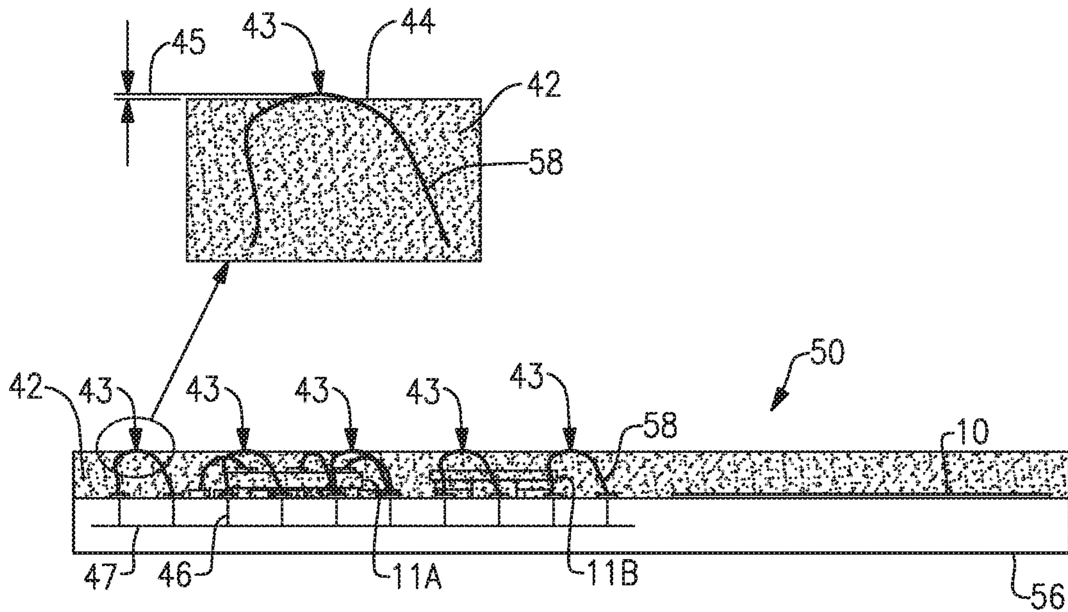


FIG.3A

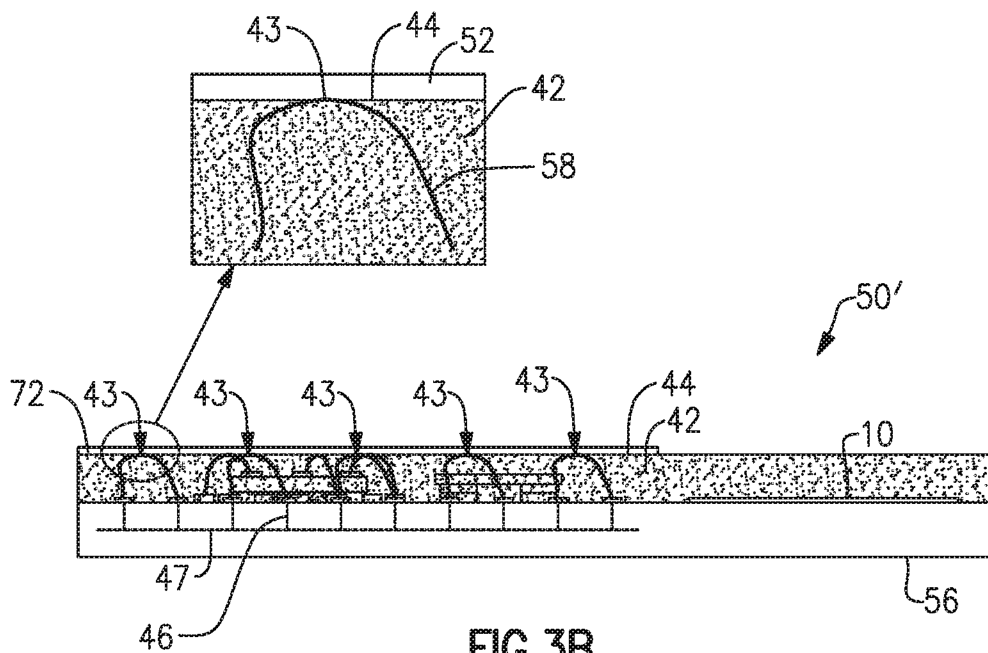


FIG.3B

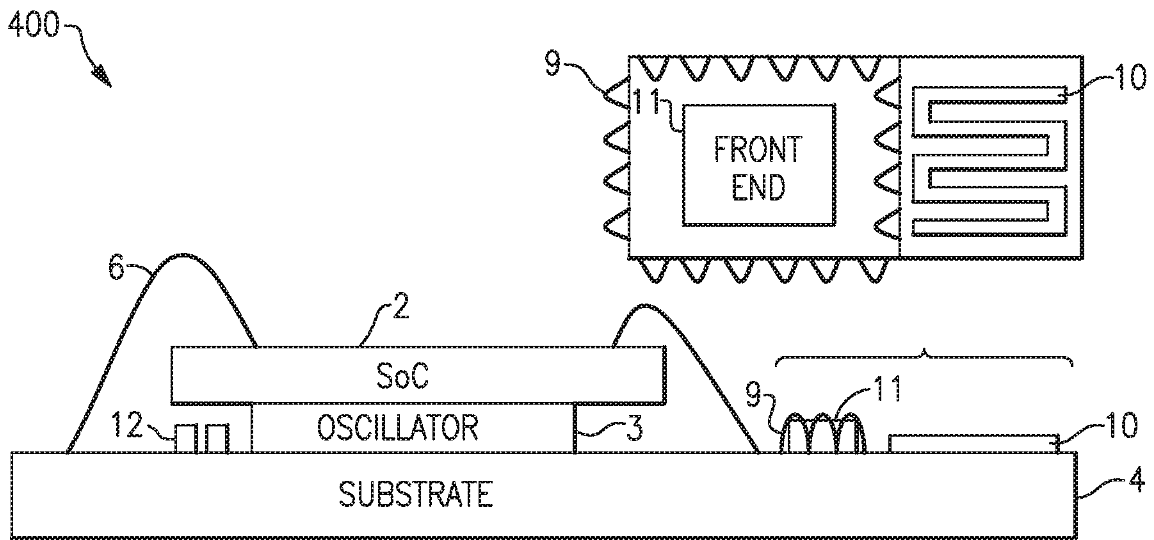


FIG.4

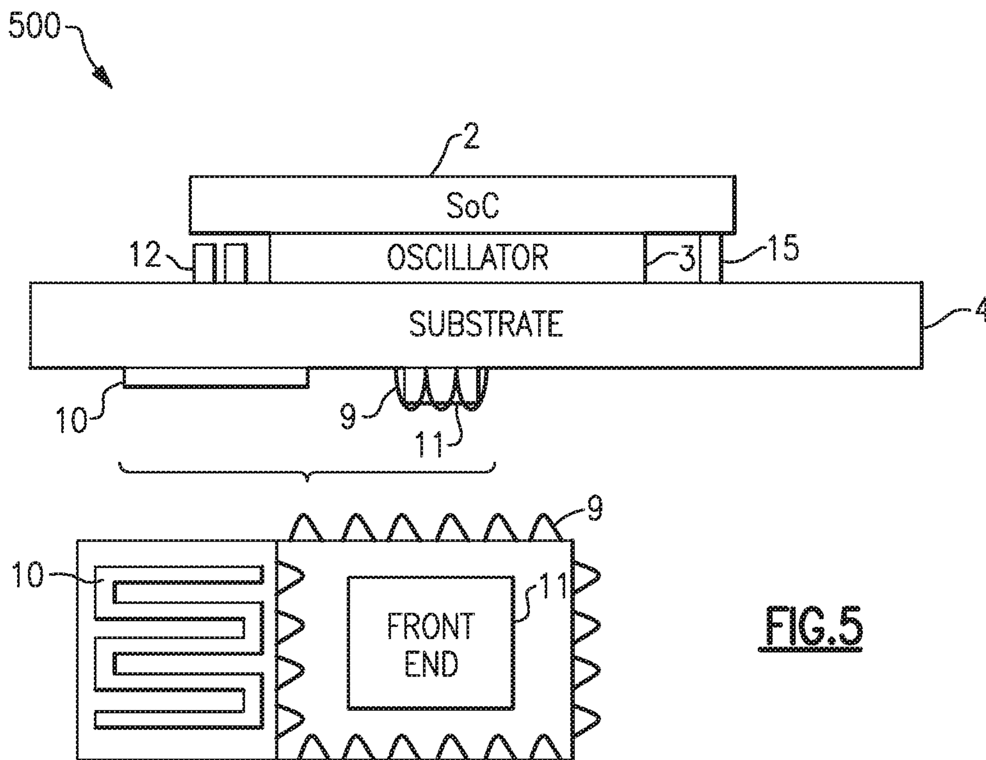


FIG.5

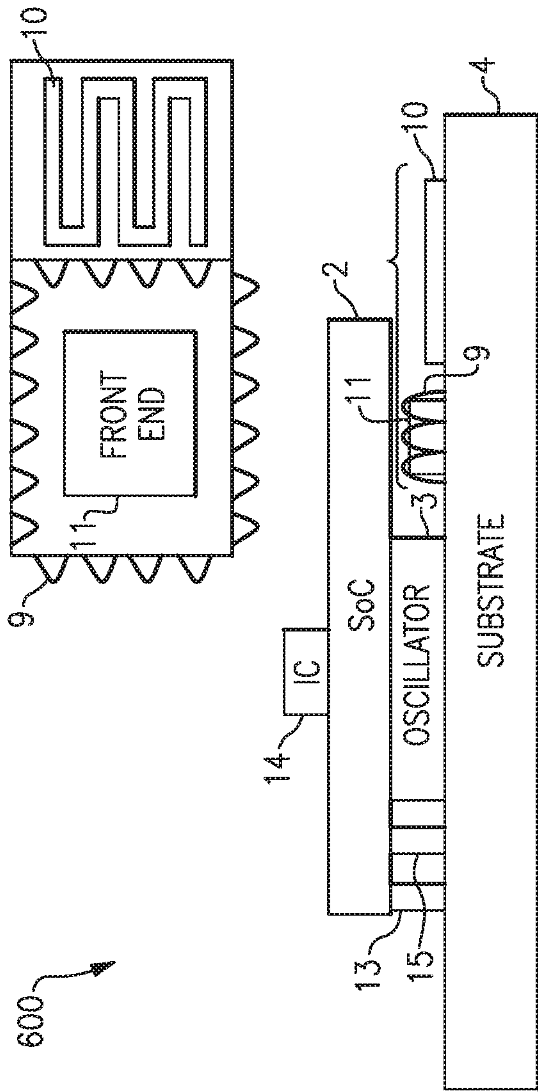


FIG.6

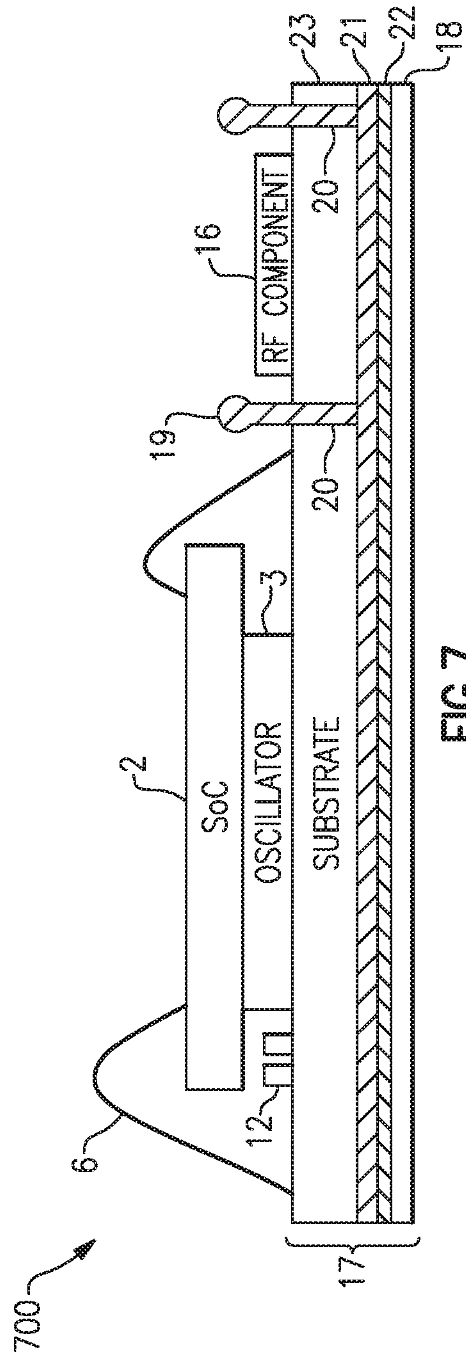


FIG.7

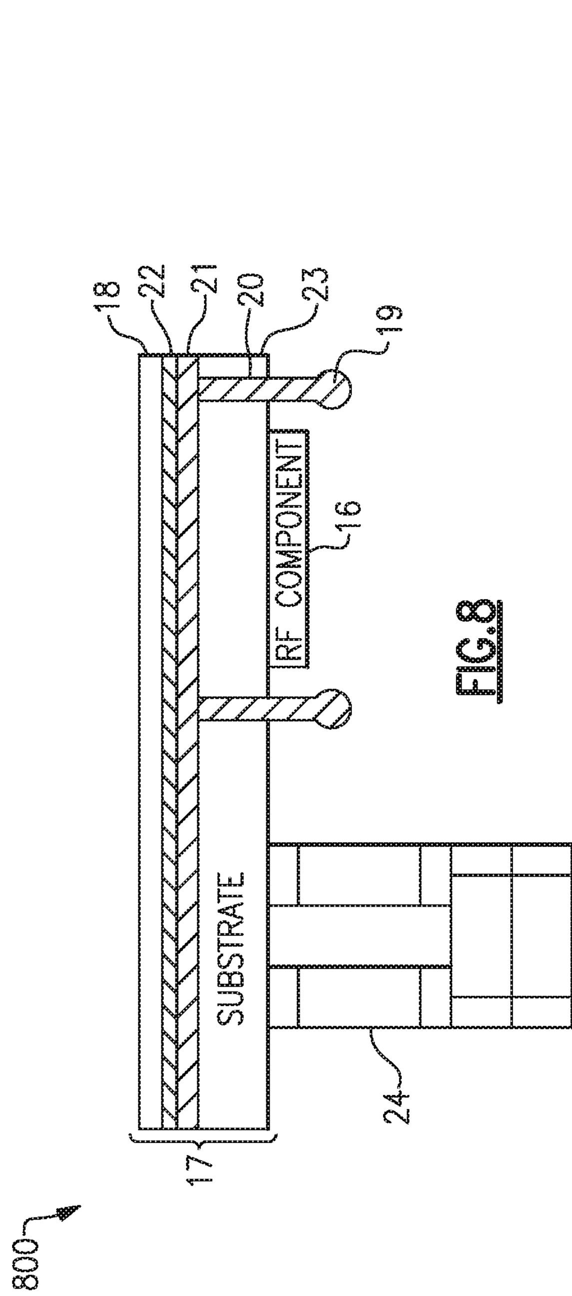


FIG.8

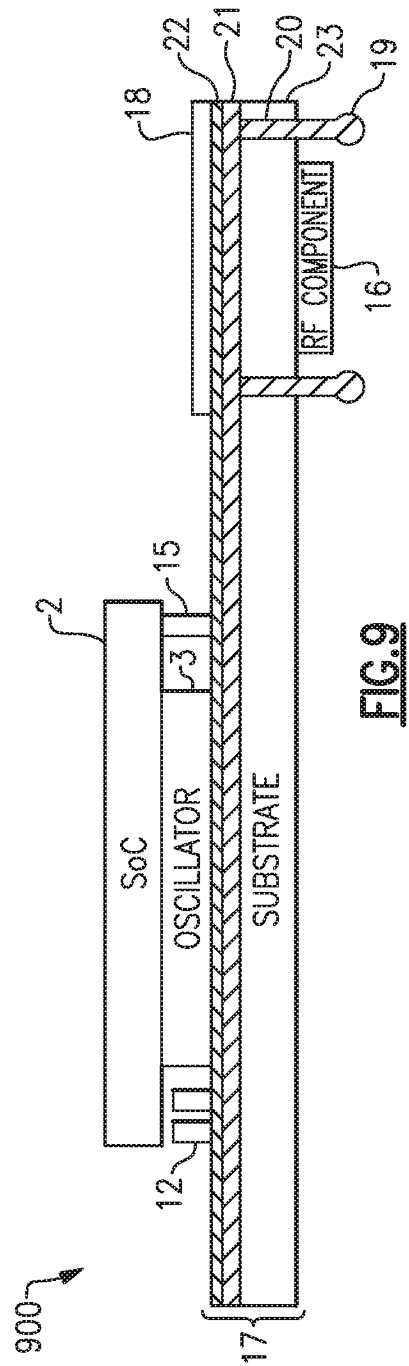


FIG.9

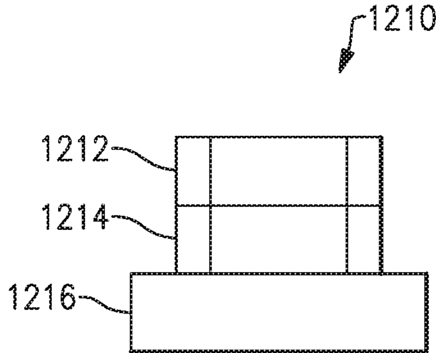


FIG.8A1

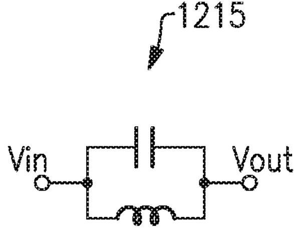


FIG.8A2

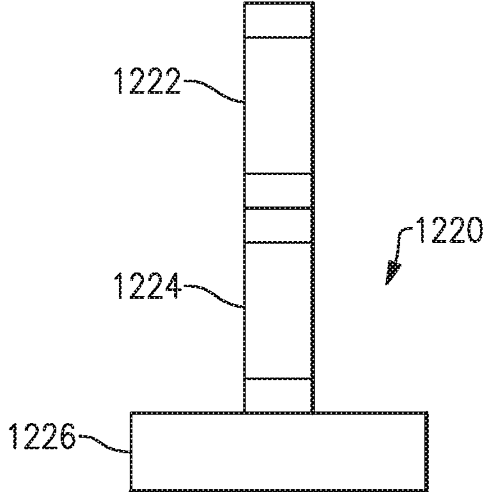


FIG.8B1

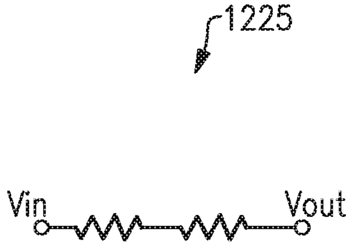


FIG.8B2

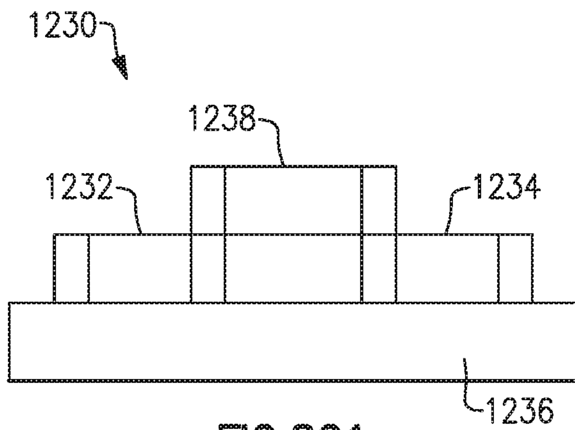


FIG.8C1

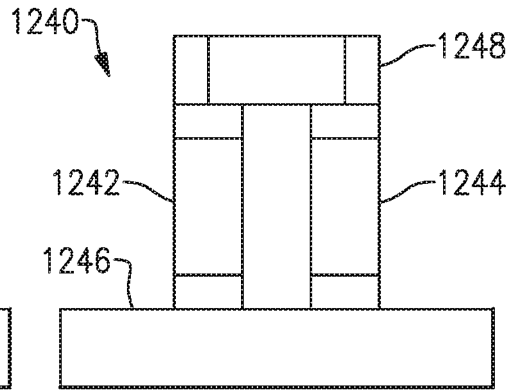


FIG.8C2

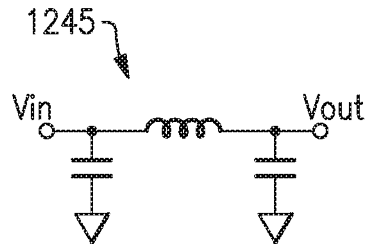


FIG.8C3

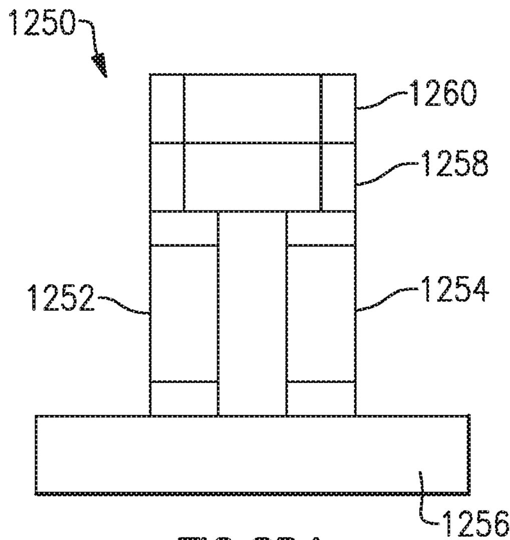


FIG.8D1

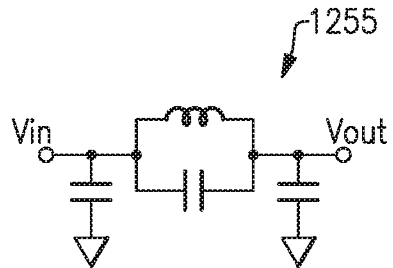


FIG.8D2

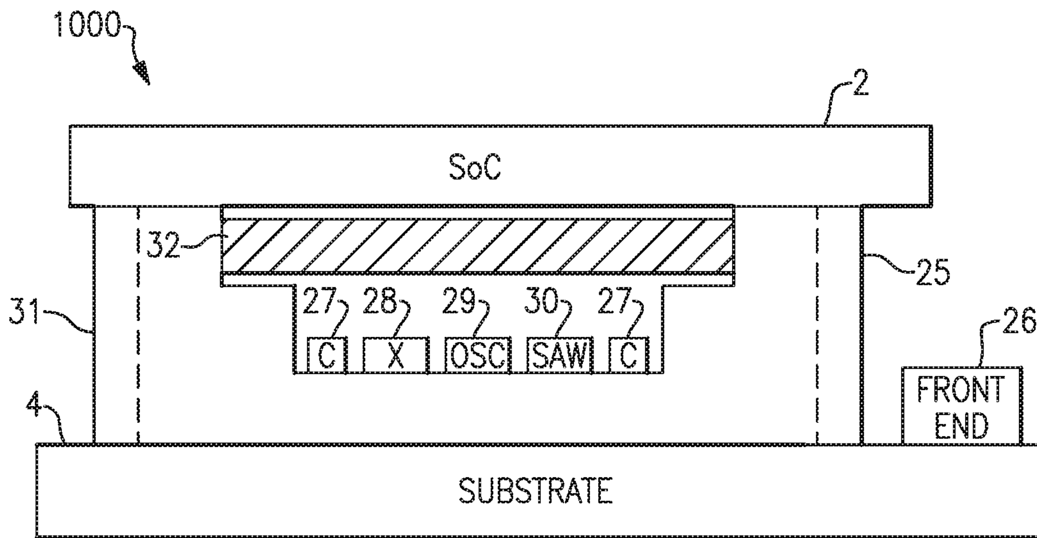


FIG.10

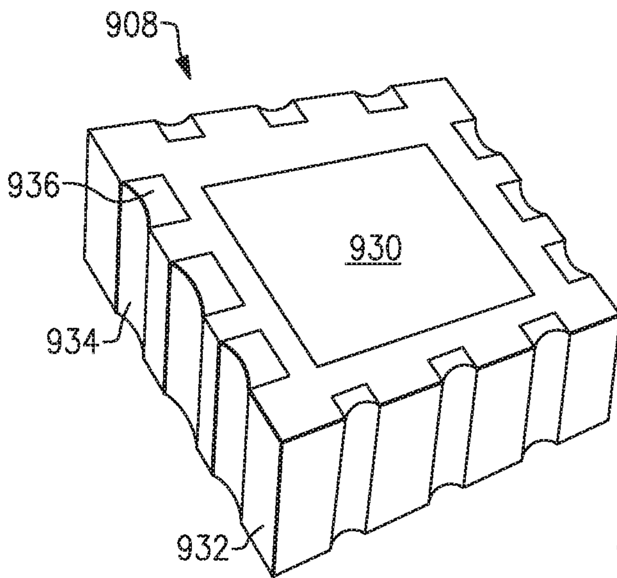


FIG.10A1

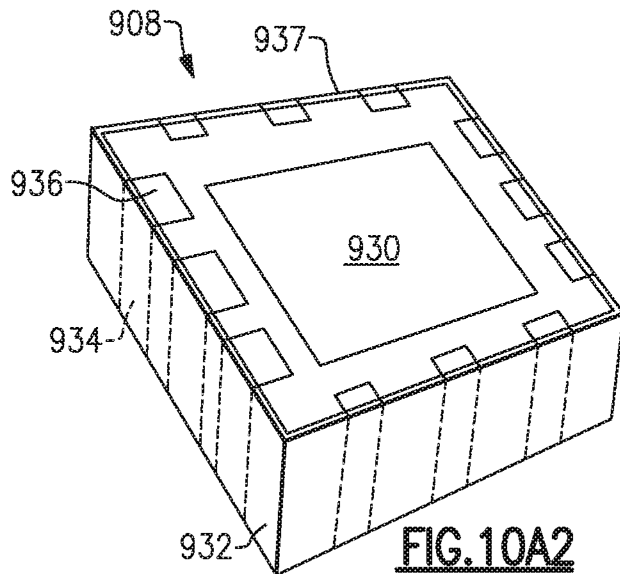


FIG.10A2

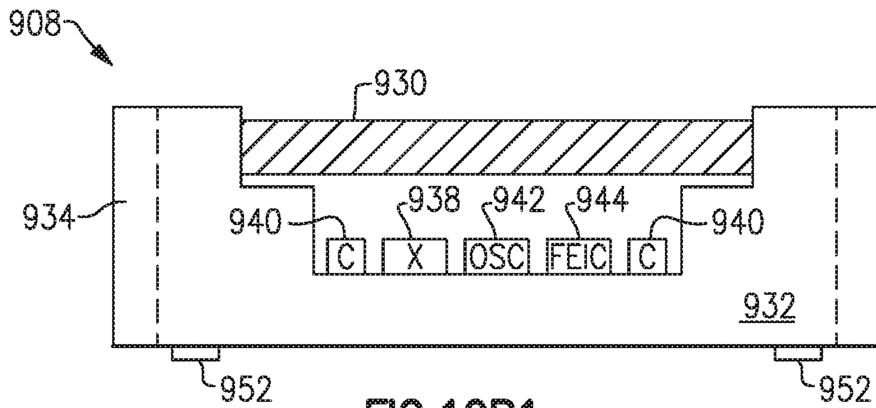


FIG.10B1

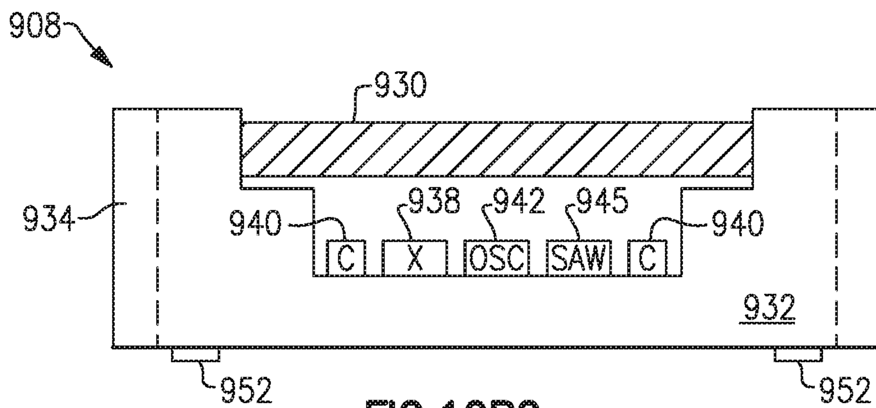


FIG.10B2

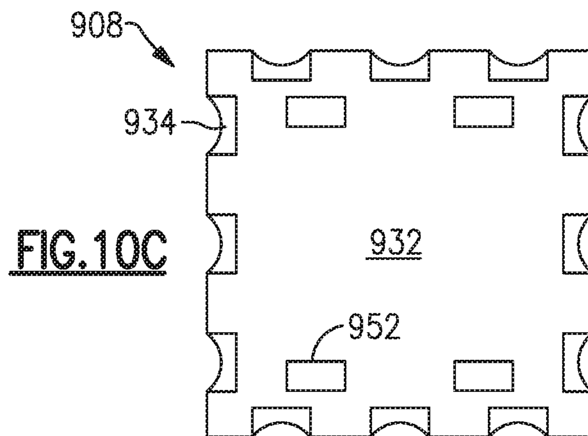


FIG.10C

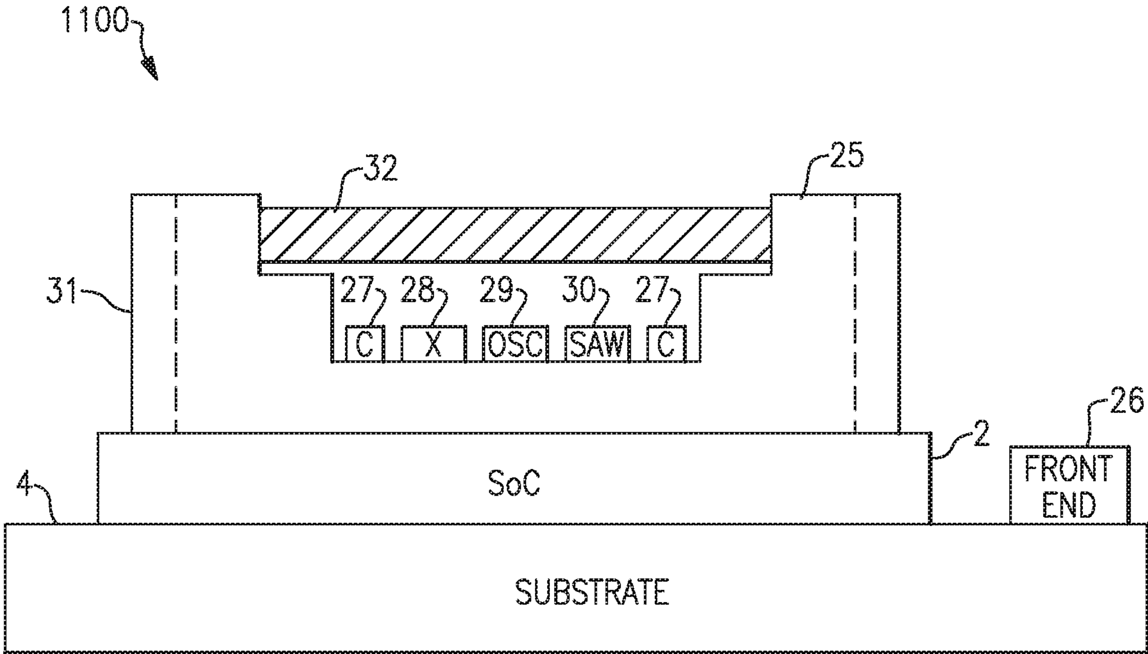


FIG.11

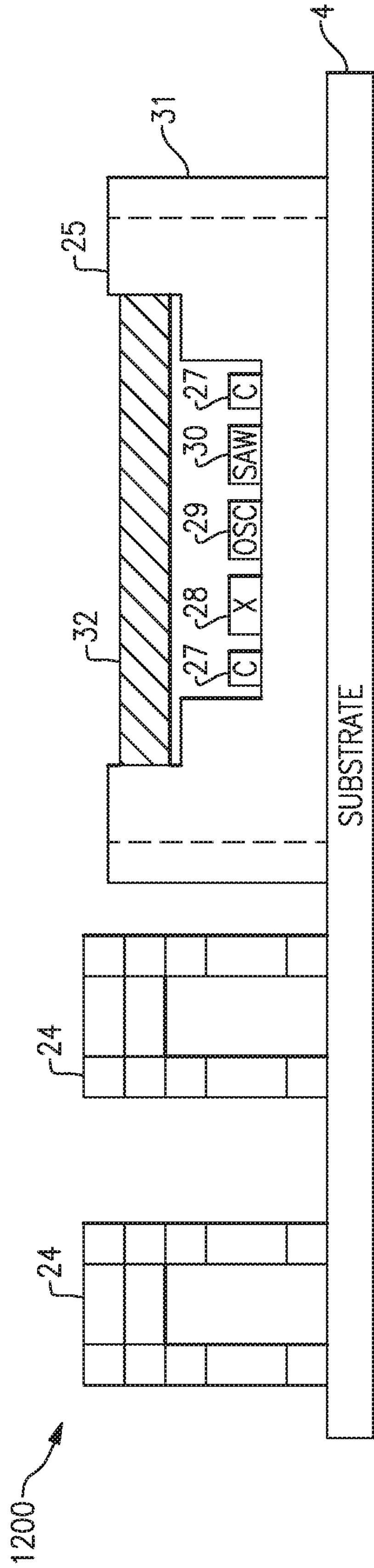


FIG. 12

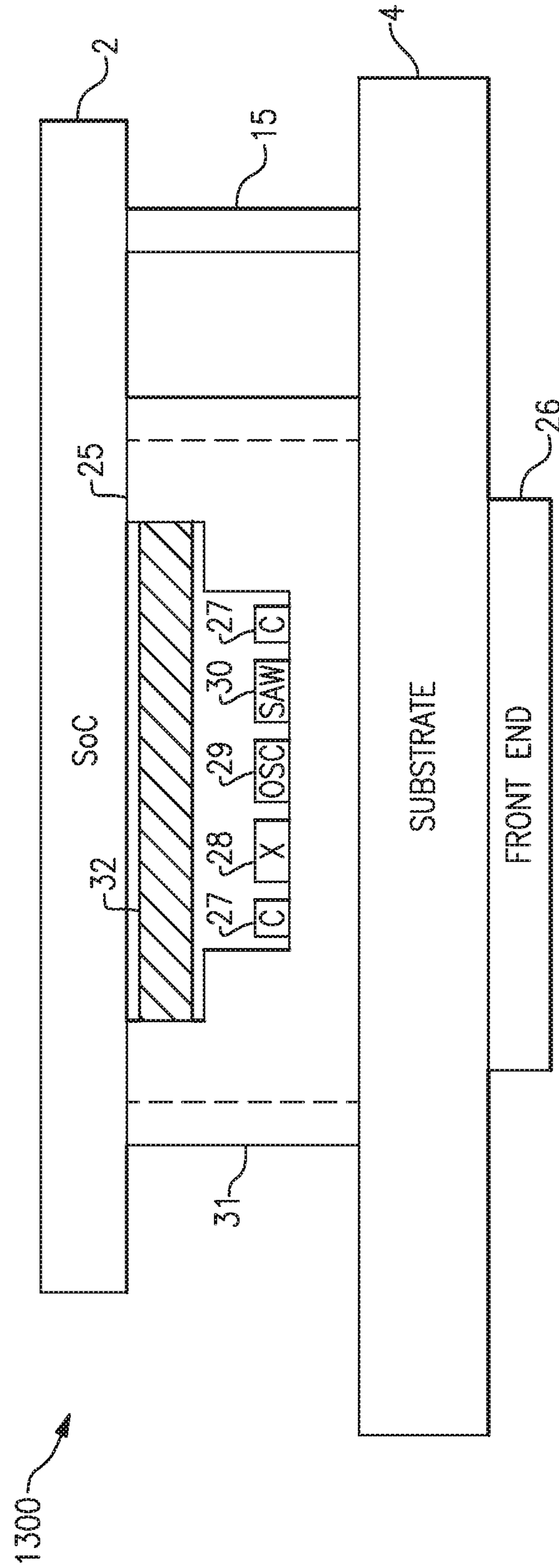


FIG. 13

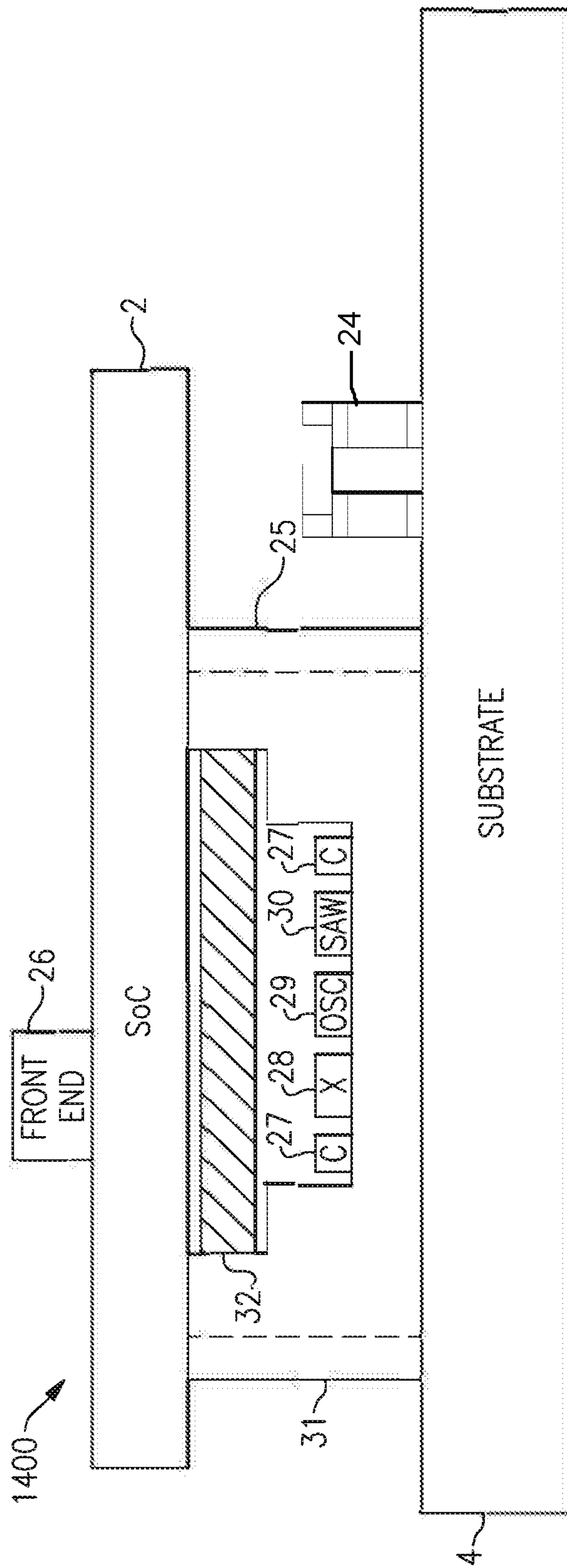


FIG.14

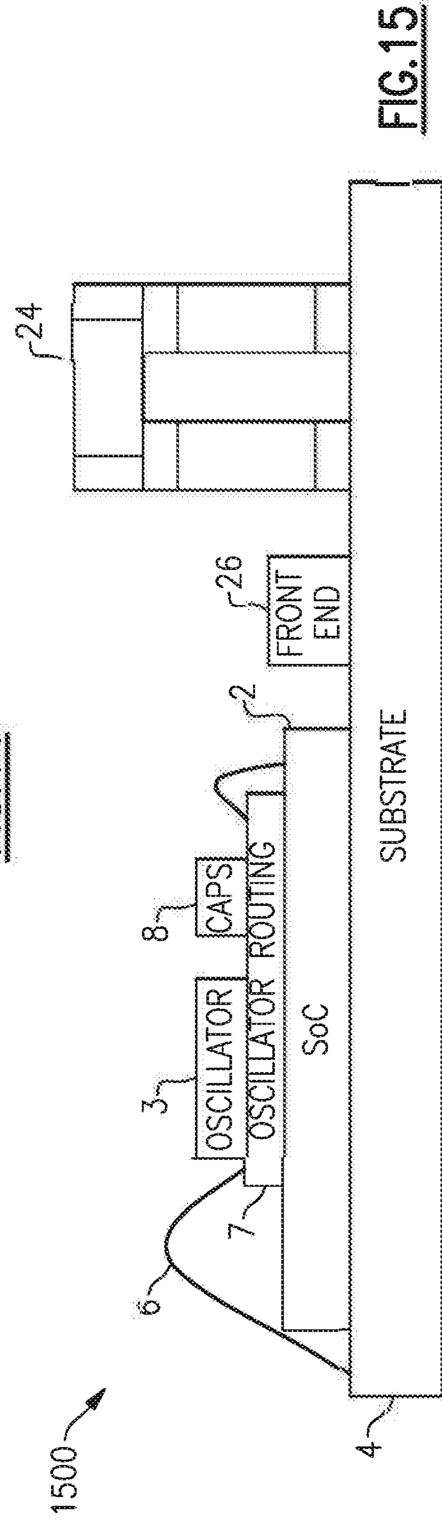


FIG.15

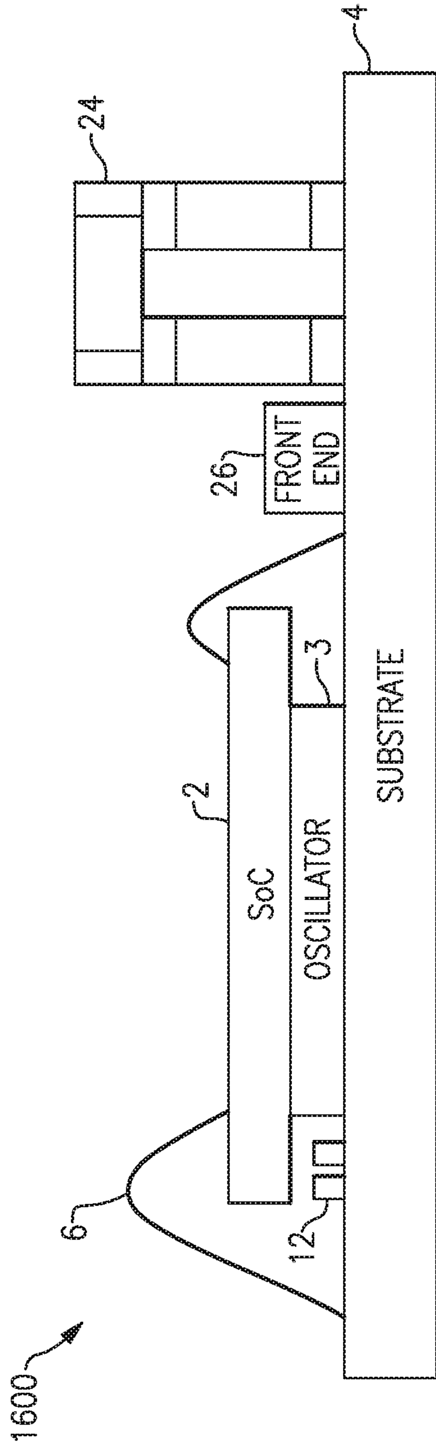


FIG.16

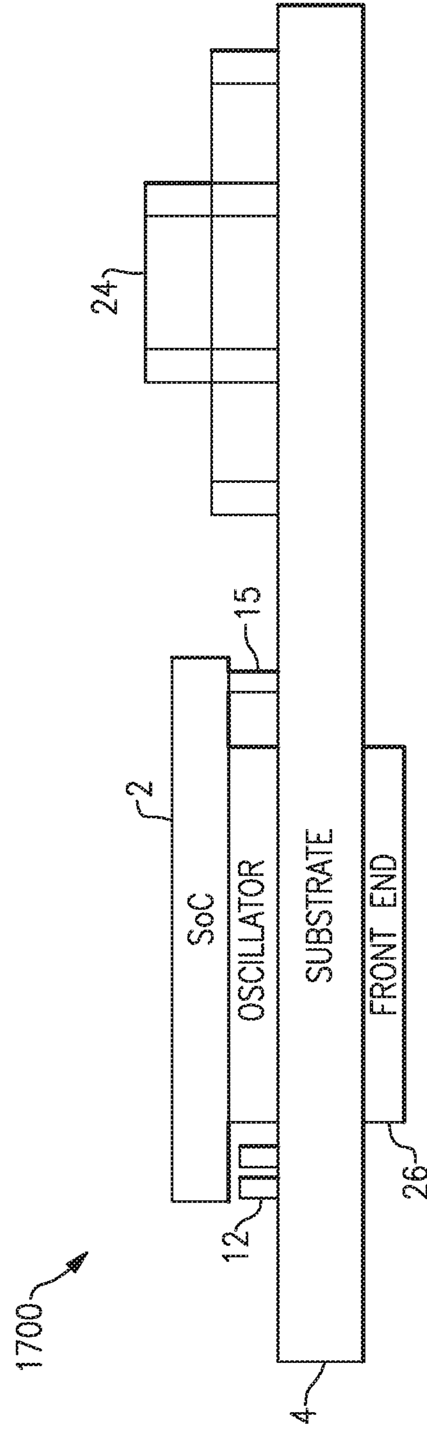


FIG.17

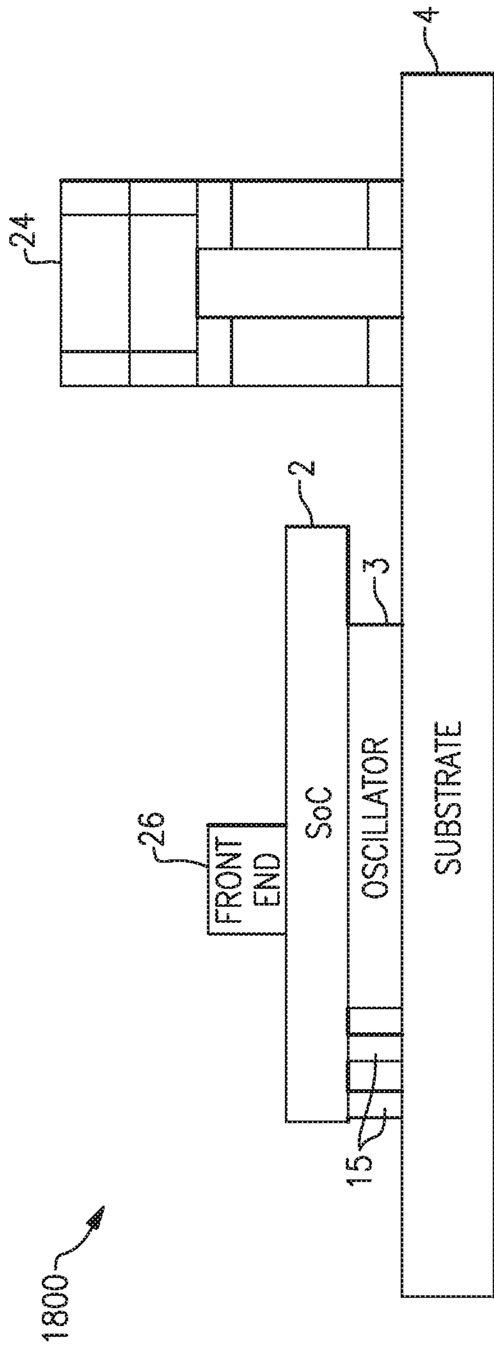


FIG.18

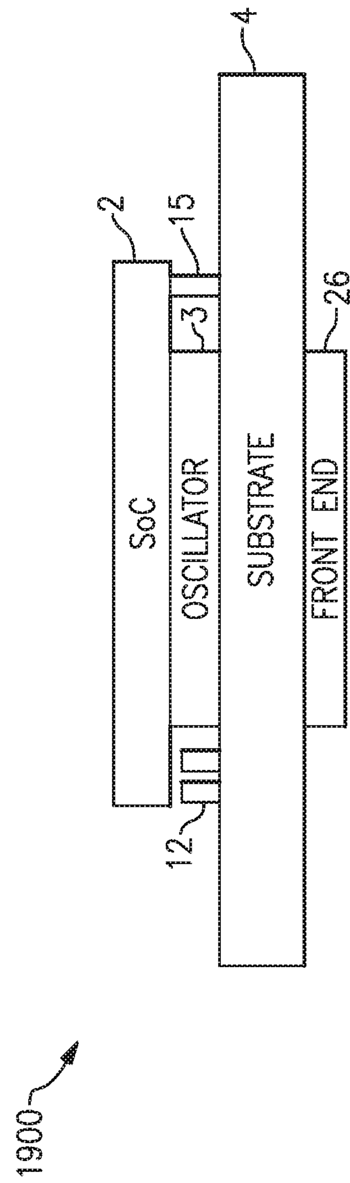


FIG.19

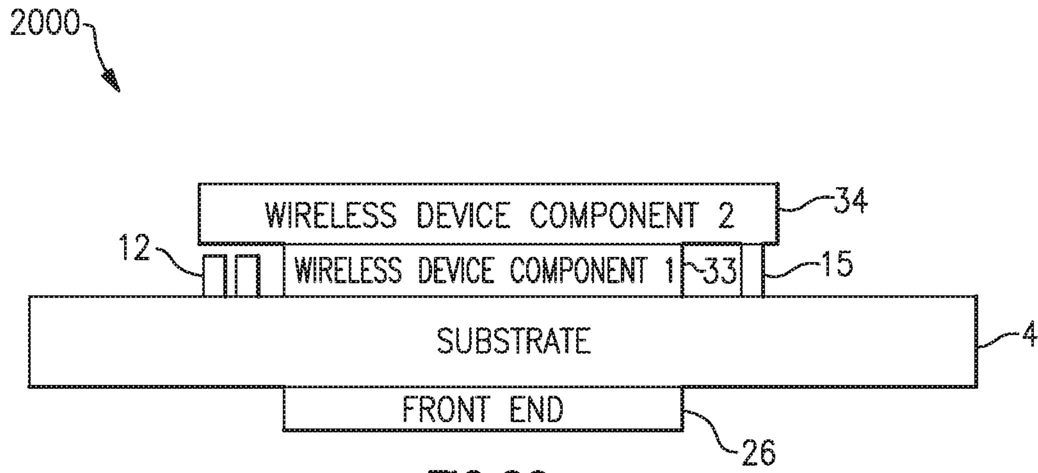


FIG.20

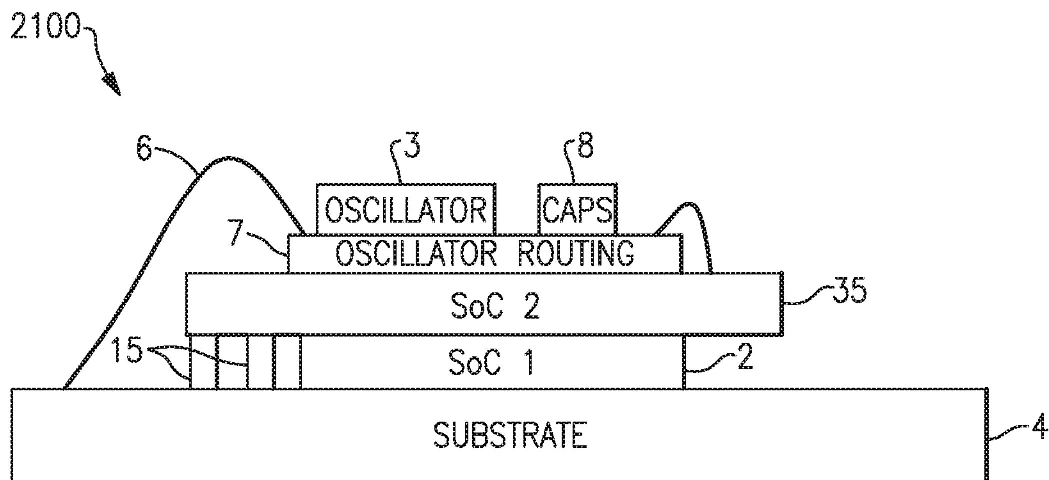


FIG.21

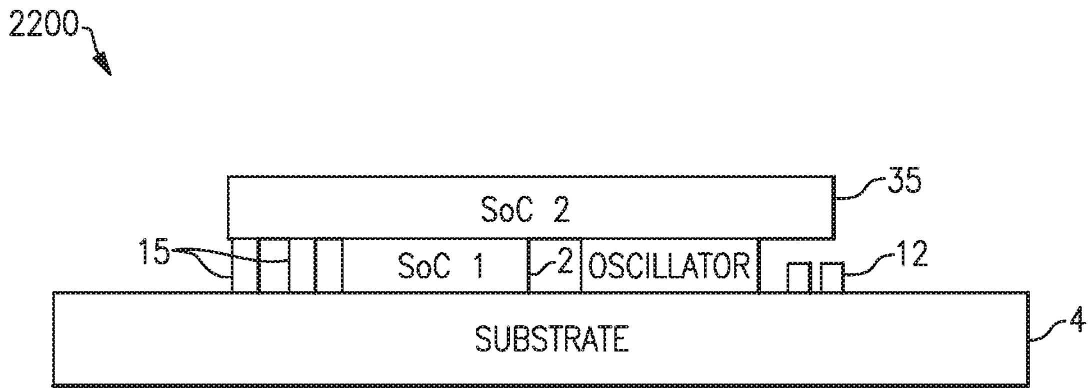


FIG.22

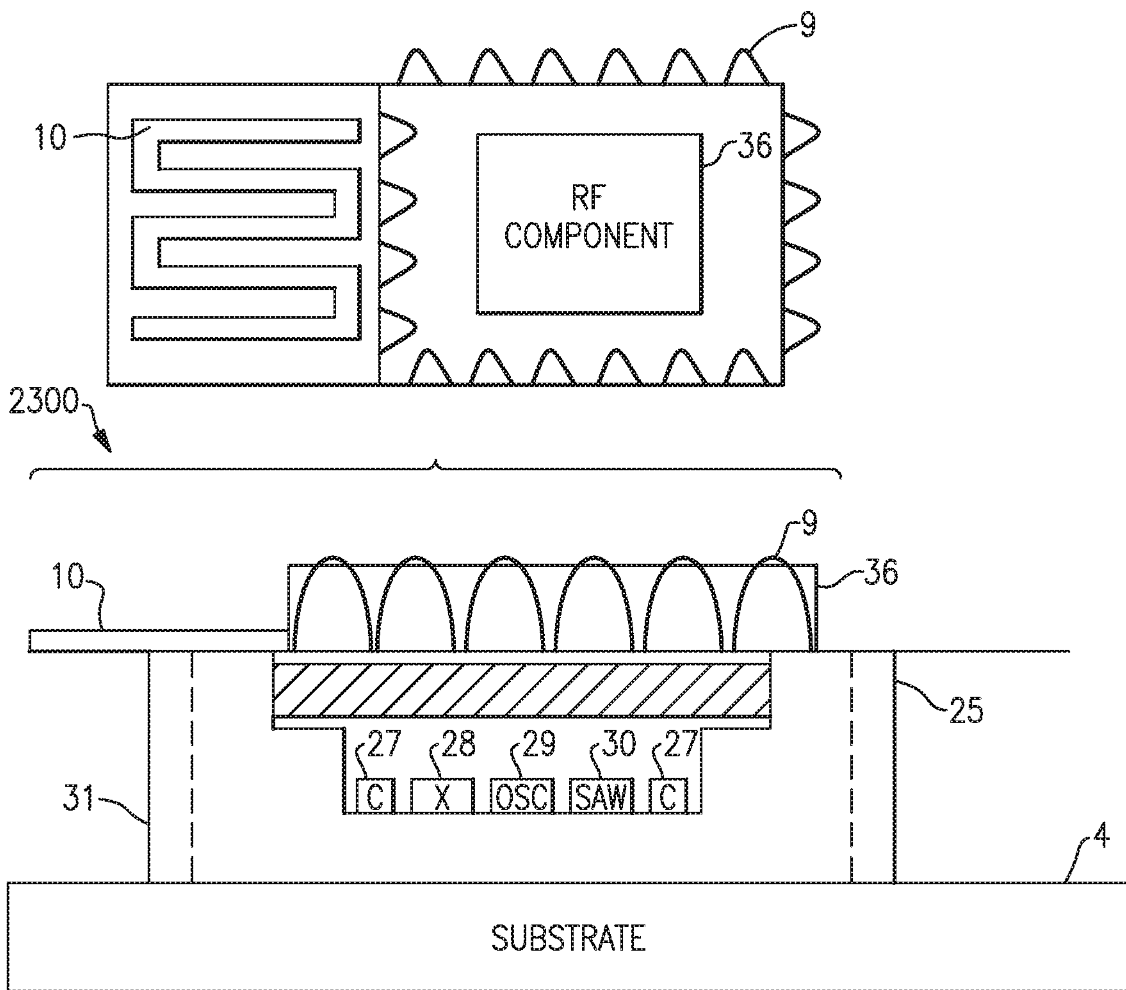


FIG.23

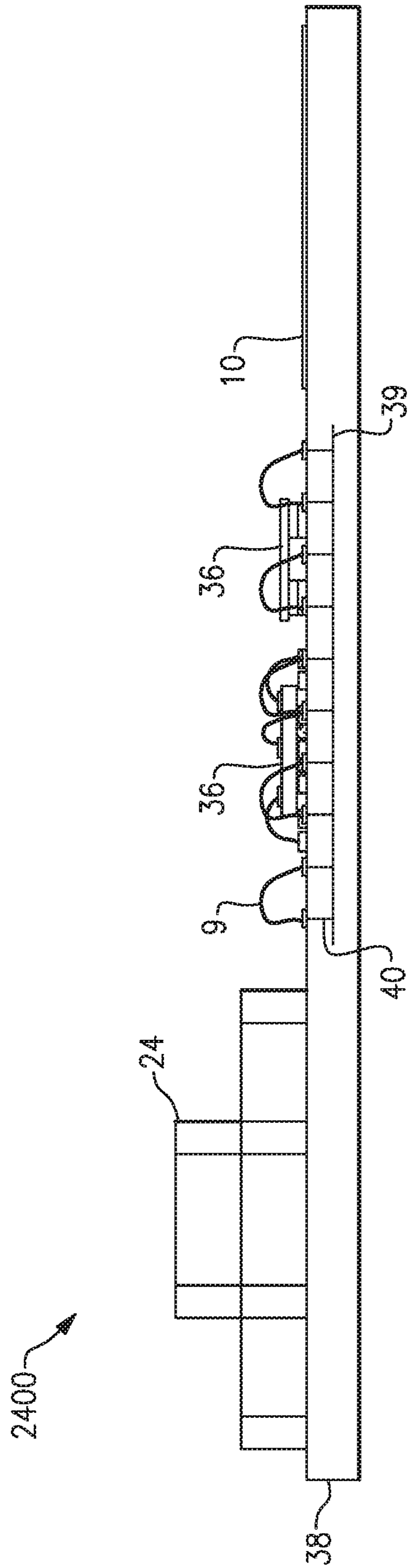


FIG.24

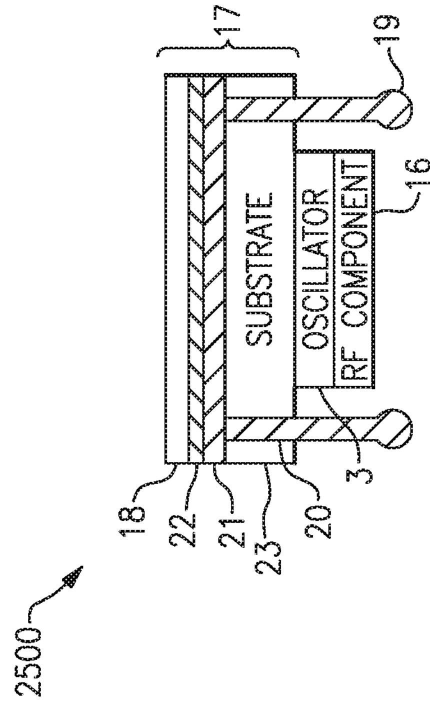


FIG.25

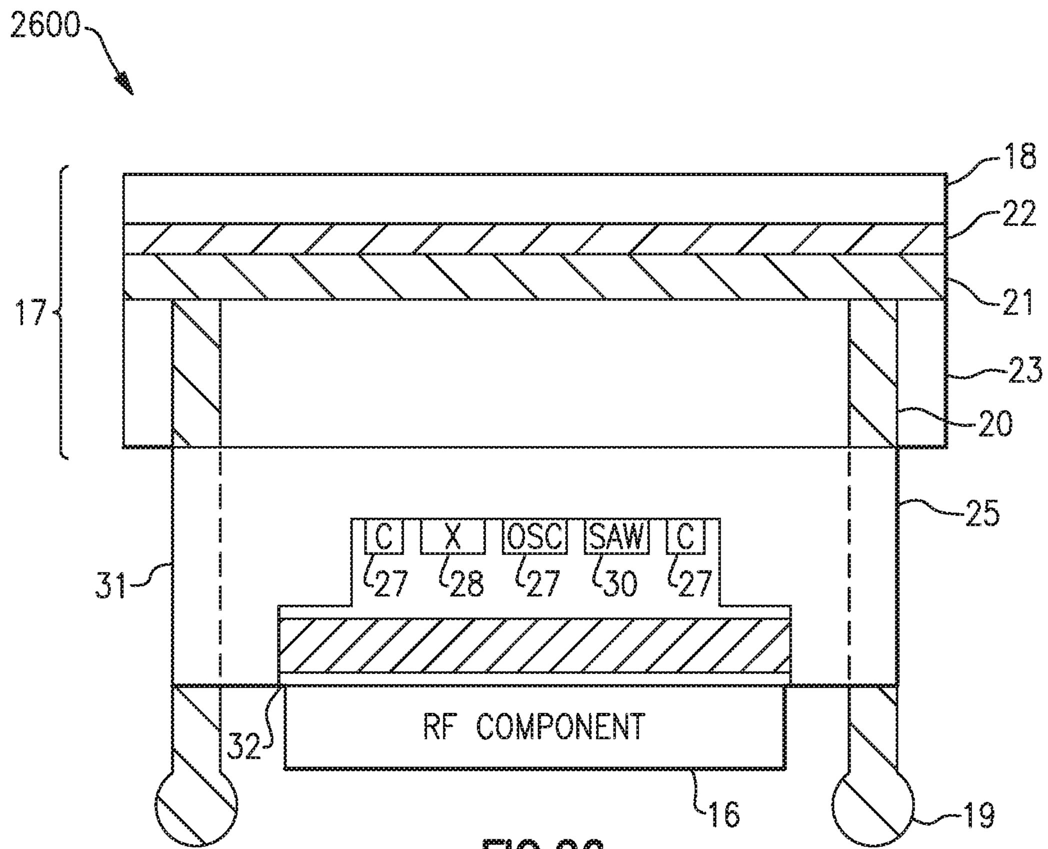


FIG.26

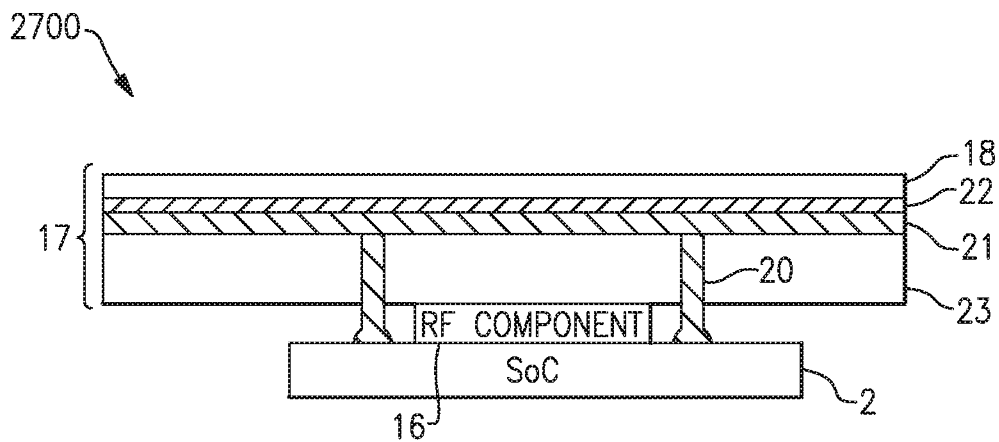


FIG.27

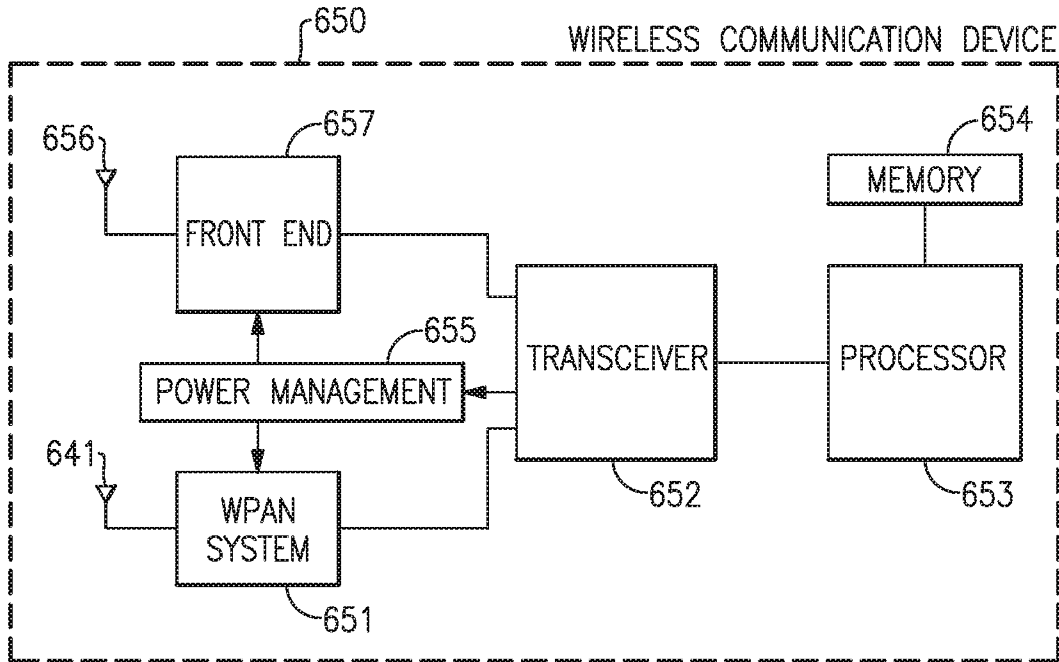


FIG.28A

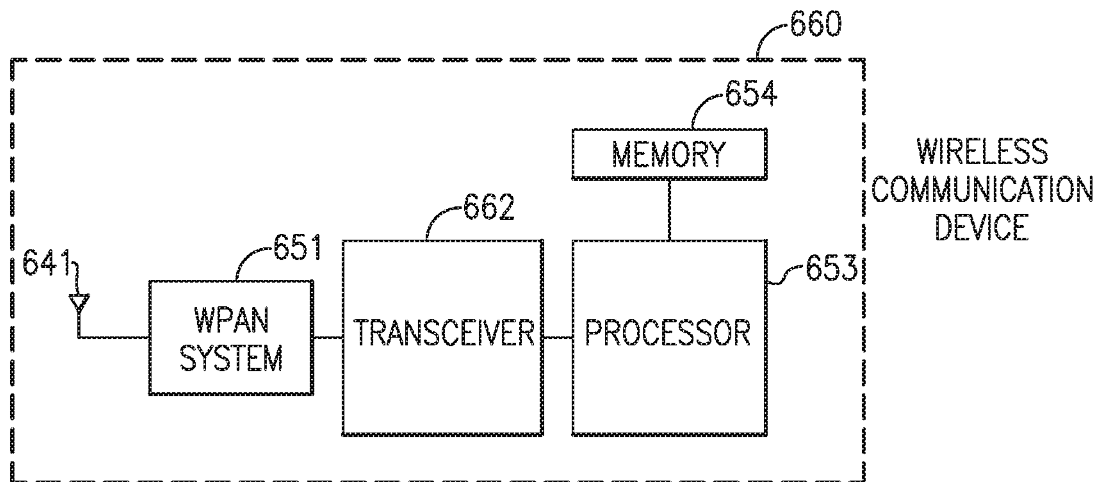


FIG.28B

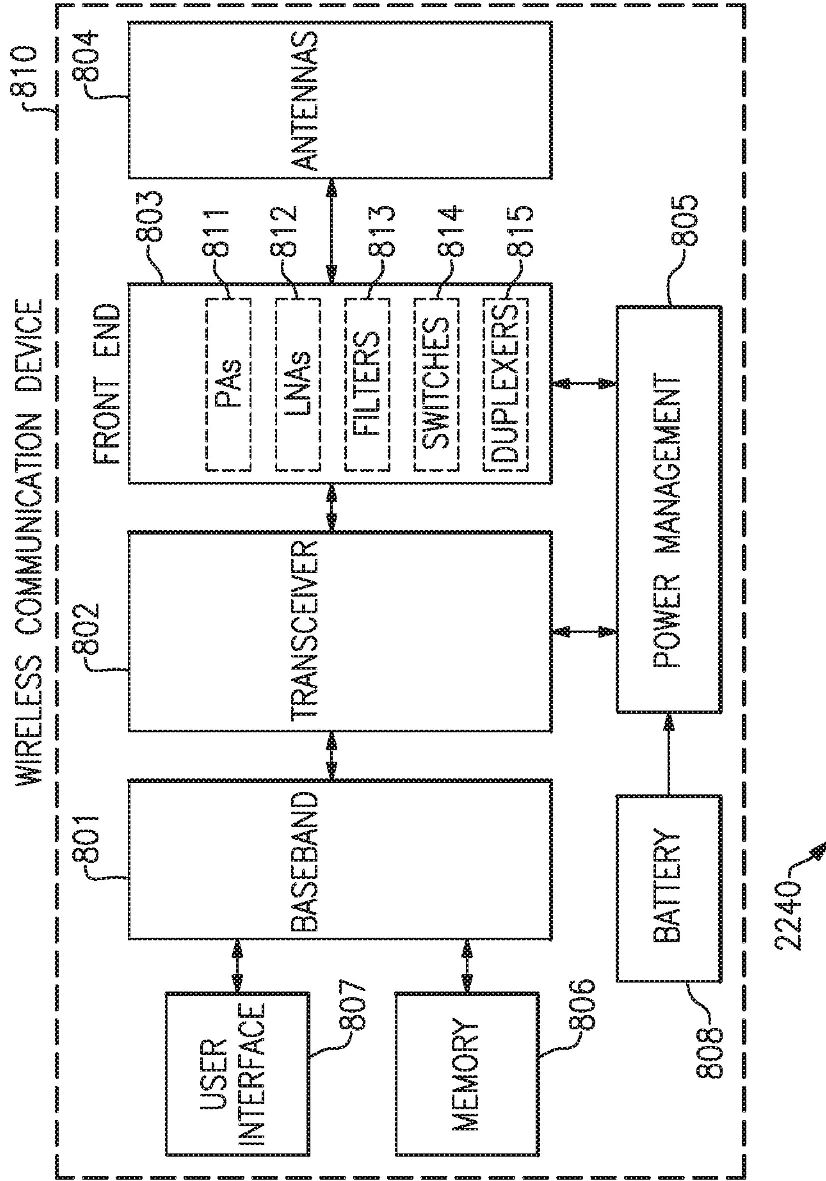


FIG.29A

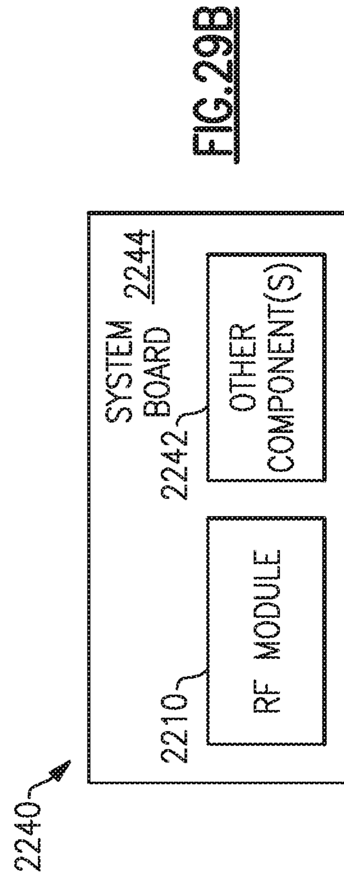


FIG.29B

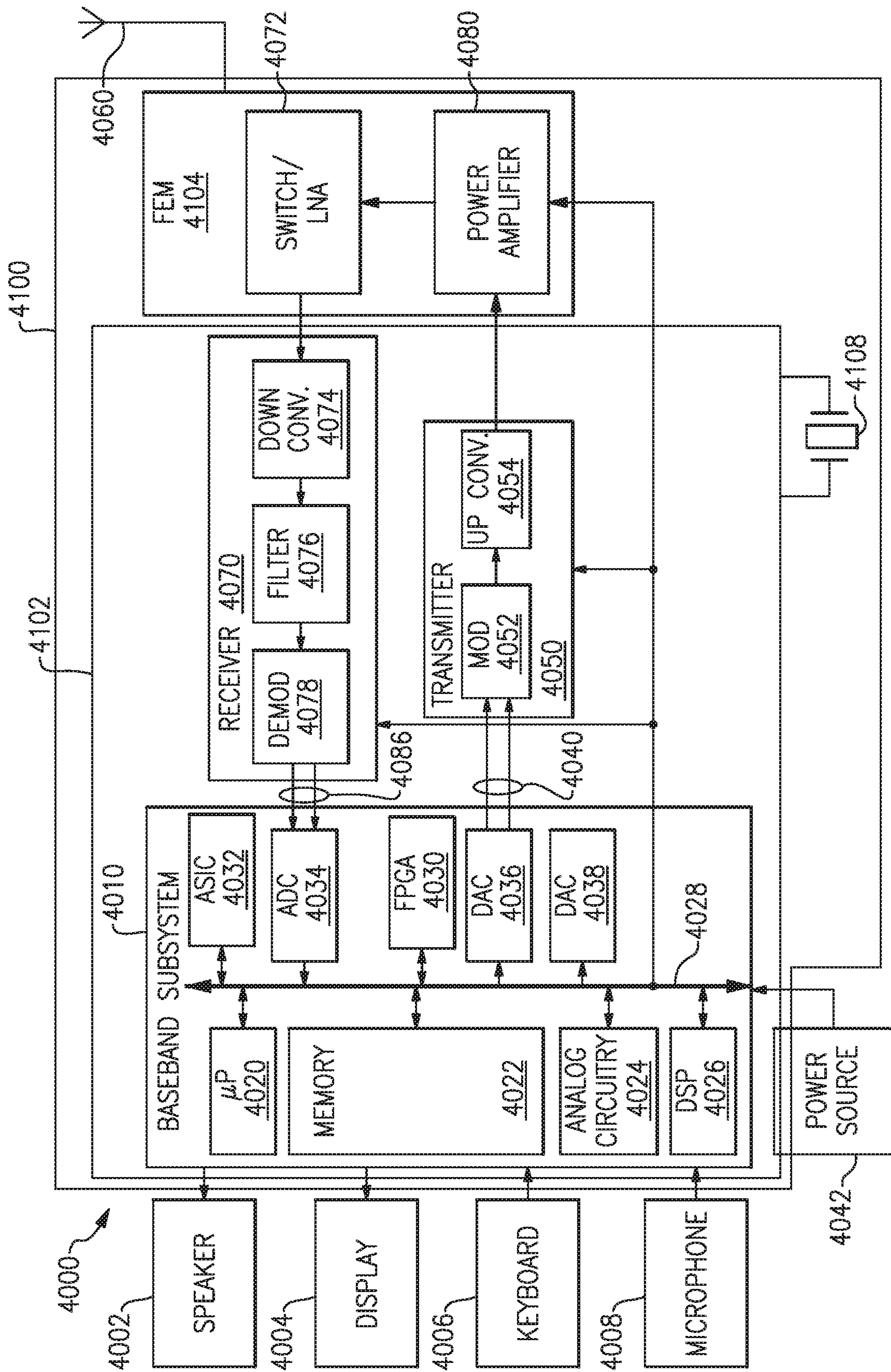


FIG.30

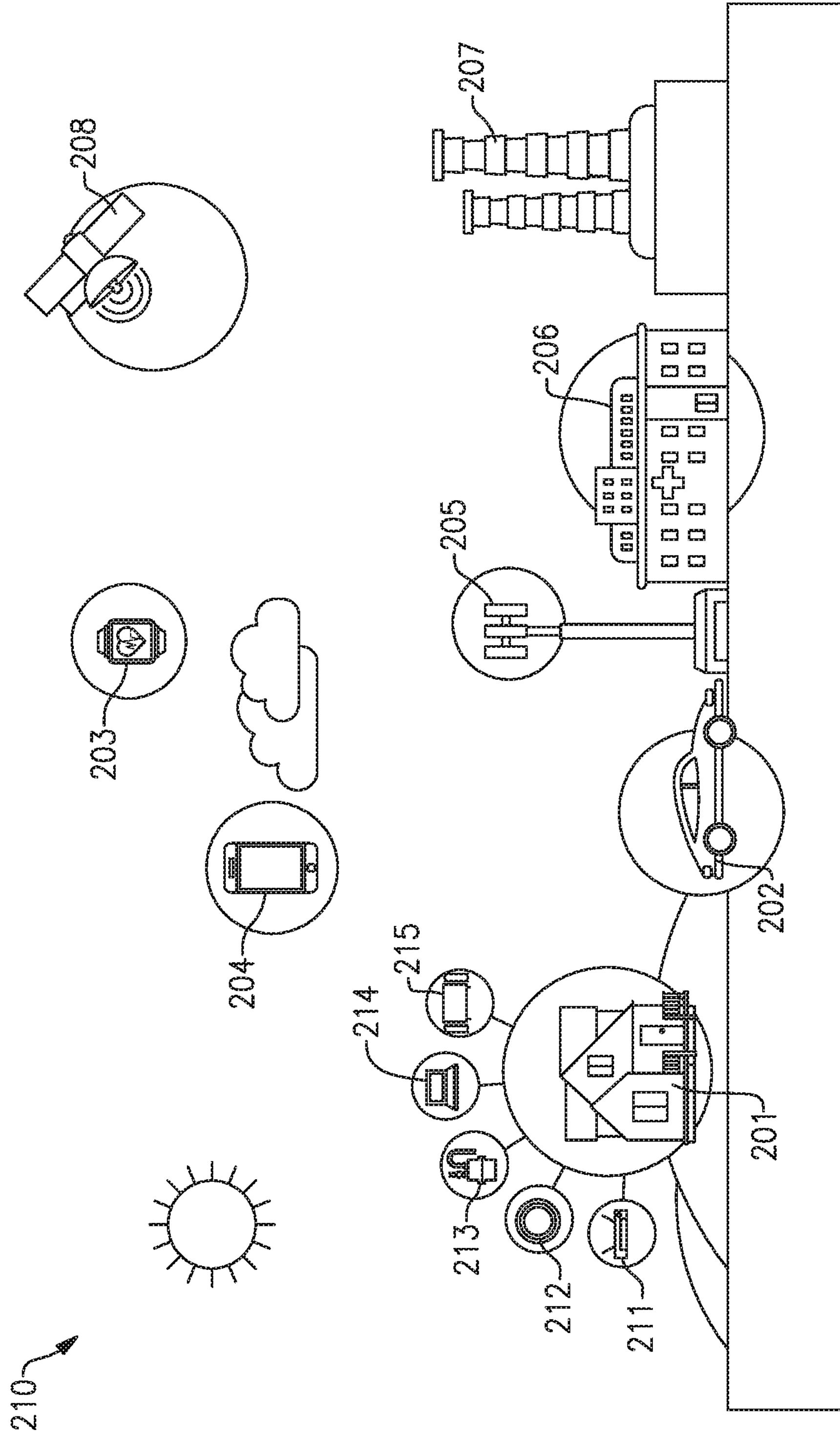


FIG.31

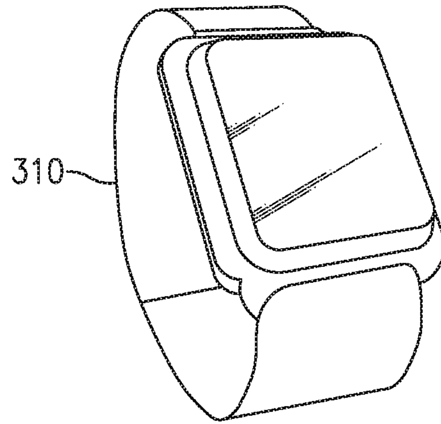


FIG.32A

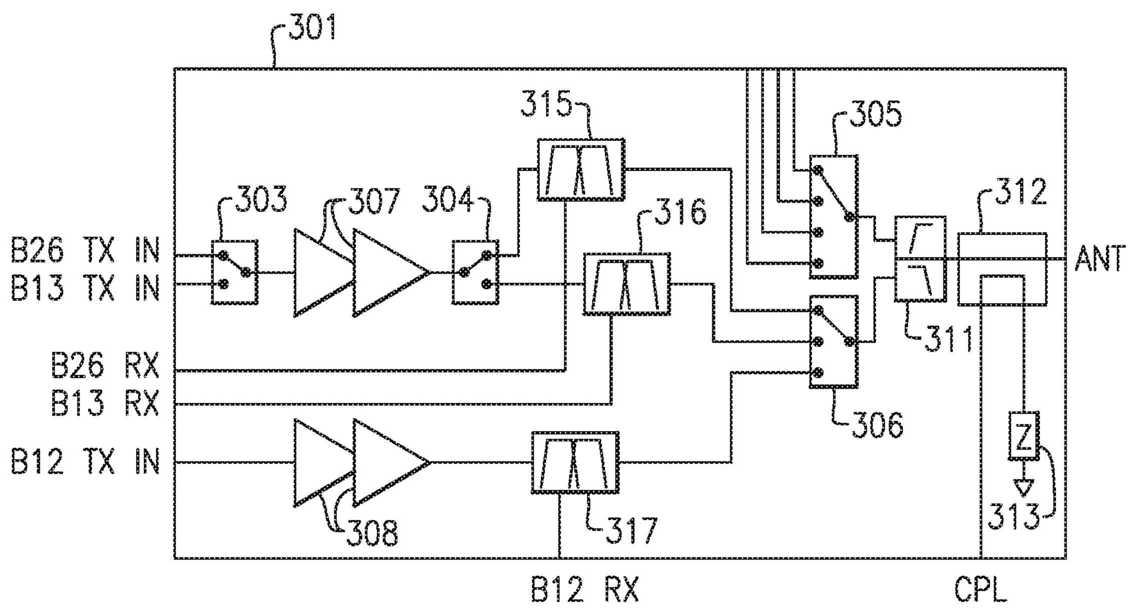


FIG.32B

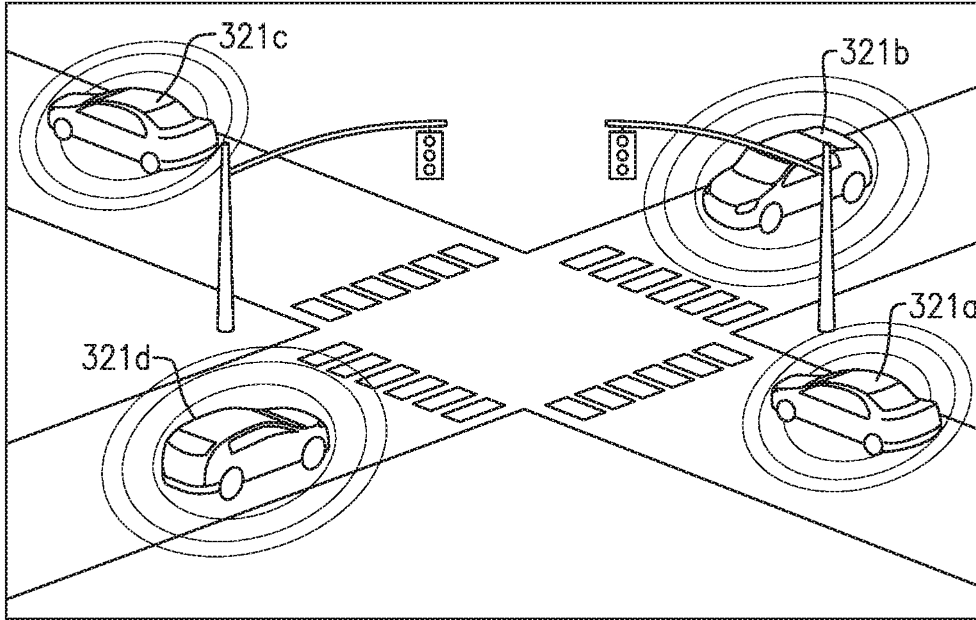


FIG.33A

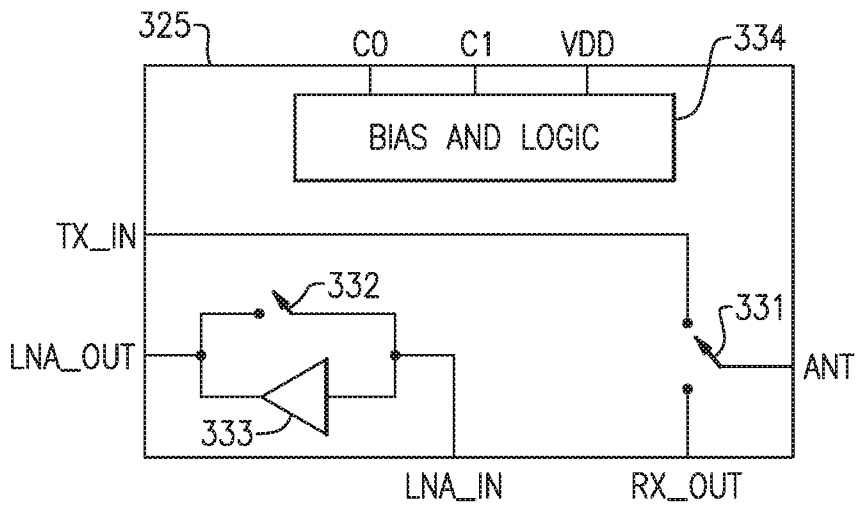


FIG.33B

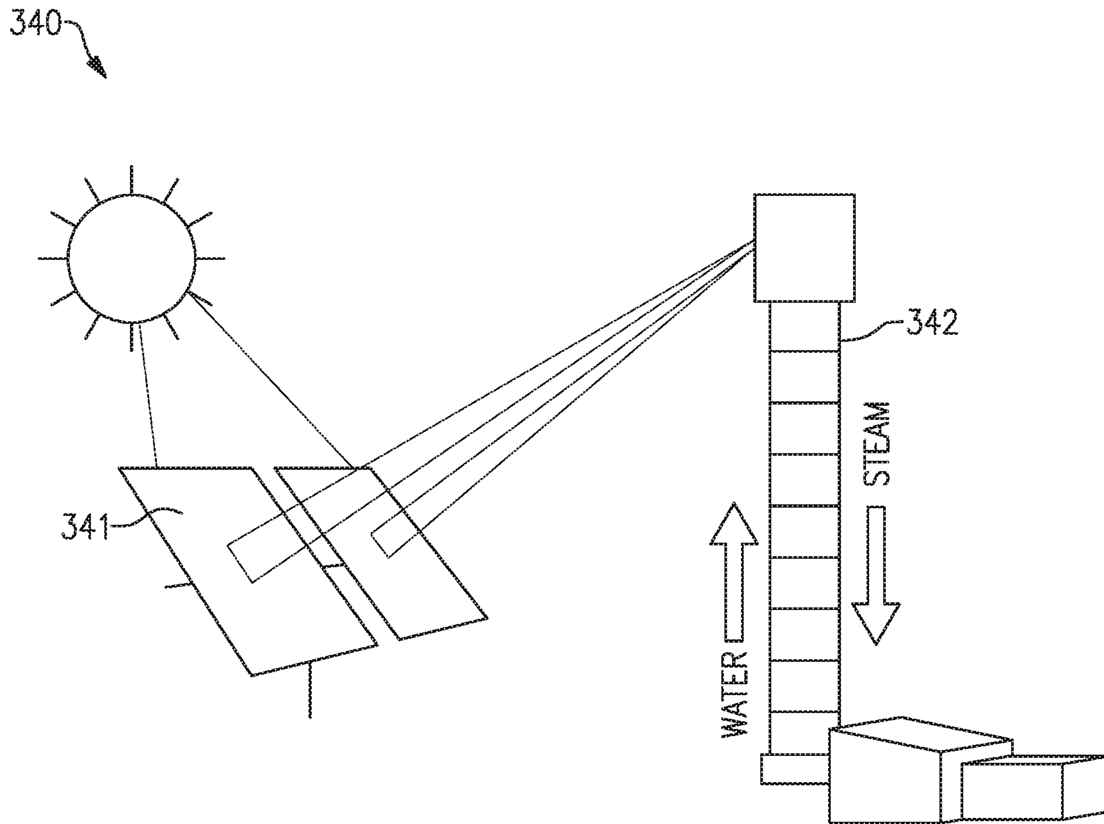


FIG.34A

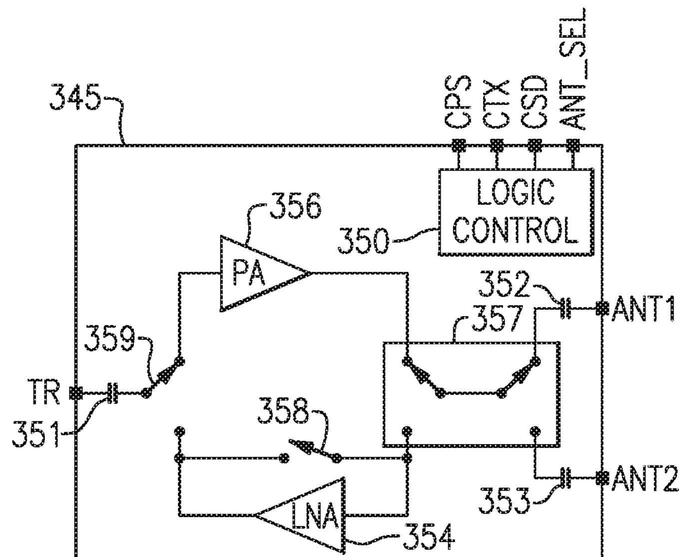


FIG.34B

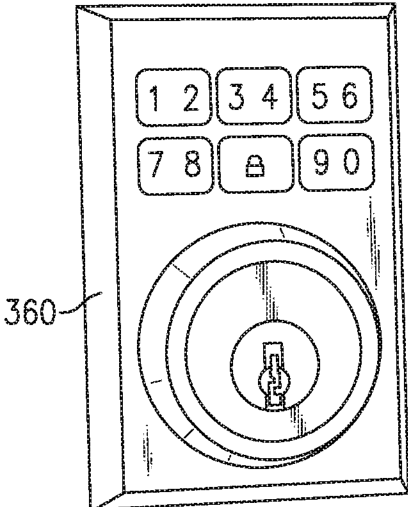


FIG.35A

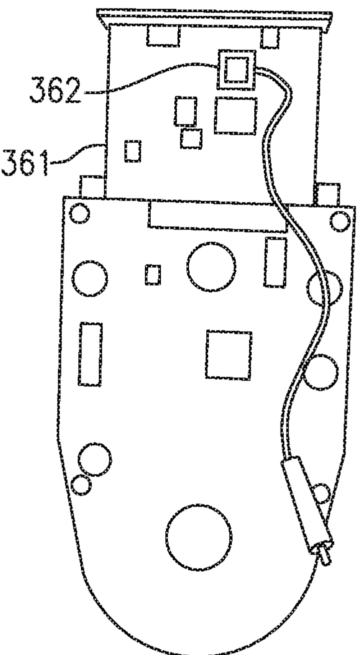


FIG.35B

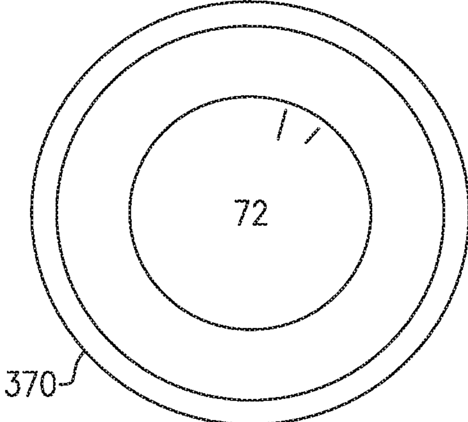


FIG.36A

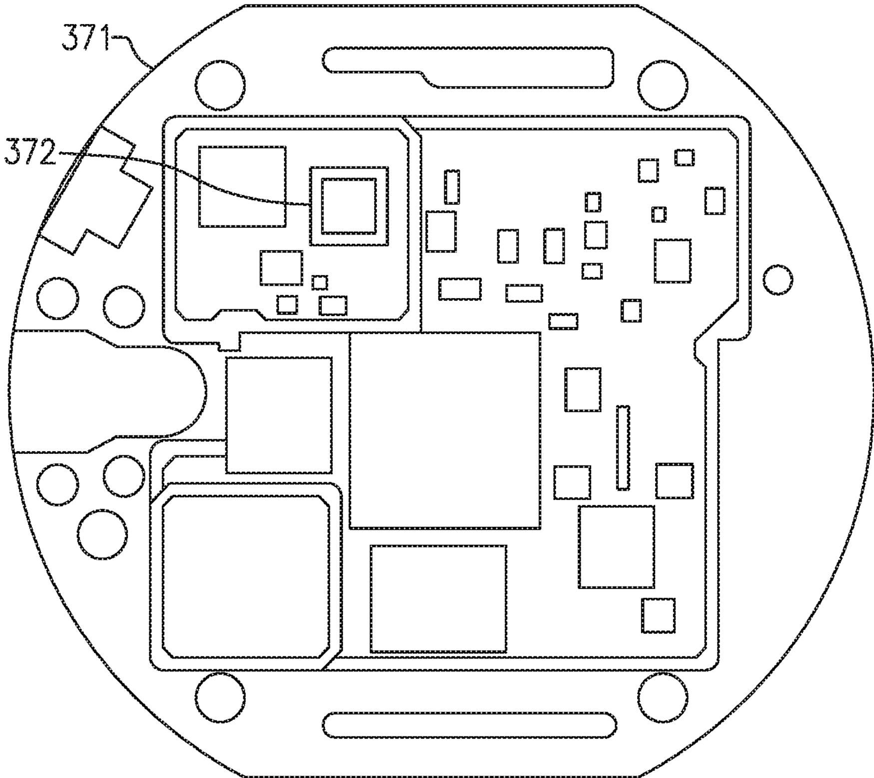


FIG.36B

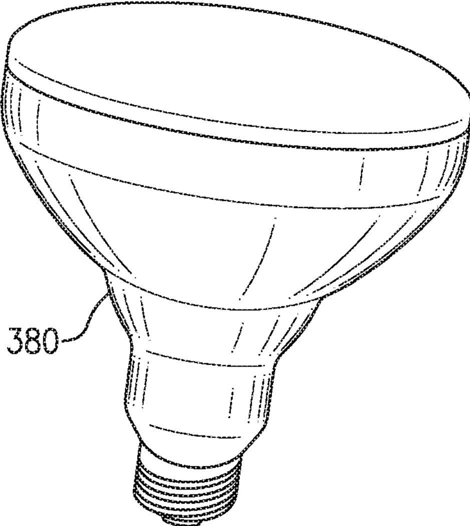


FIG.37A

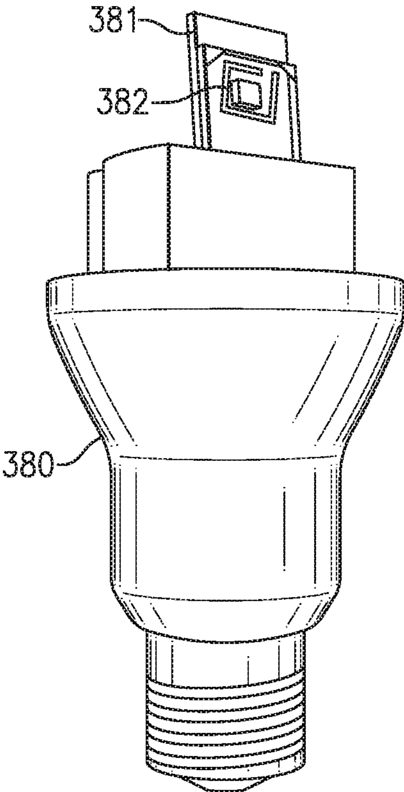


FIG.37B

RADIO FREQUENCY MODULES

INCORPORATION BY REFERENCE TO ANY PRIORITY APPLICATIONS

[0001] Any and all applications for which a foreign or domestic priority claim is identified in the Application Data Sheet as filed with the present application are hereby incorporated by reference under 37 CFR 1.57.

[0002] This application claims the benefit of priority under 35 U.S.C. § 119(e) of U.S. Provisional Patent Application No. 62/469,723, titled RADIO FREQUENCY MODULES, filed Mar. 10, 2017 and U.S. Provisional Patent Application No. 62/573,524, titled RADIO FREQUENCY MODULES, filed Oct. 17, 2017. The disclosures of each of these priority applications are hereby incorporated by reference in their entireties herein.

BACKGROUND

Field

[0003] Embodiments of the invention relate to electronic systems, and in particular, to radio frequency (RF) electronics.

Description of Related Technology

[0004] A radio frequency electronic system can process radio frequency signals in a frequency range from about 30 kilohertz (kHz) to 300 gigahertz (GHz), such as in a range from about 450 megahertz (MHz) to 6 GHz. A front end system is an example of a radio frequency electronic system. A front end system can be referred to as a radio frequency front end system. A radio frequency electronic system can include radio frequency modules.

[0005] Some or all of a front end system can be embodied in a radio frequency module. A packaged semiconductor module is an example of a radio frequency module. Packaged semiconductor modules can include integrated shielding technology within a package. A shielding structure can be formed around a radio frequency component of a front end system. The shielding structure can shield the radio frequency component from electromagnetic radiation that is external to the shielding structure. The shielding structure can shield circuit elements external to the shielding structure from electromagnetic radiation emitted by the radio frequency component. As more components are being integrated together with each other in a radio frequency module, shielding components from each other in a compact and efficient manner can be challenging.

[0006] A system in a package (SiP) can include integrated circuits and/or discrete components within a common package. Some or all of a front end system can be implemented in a SiP. An example SiP can include a system-on-a-chip (SoC), an oscillator assembly comprising a crystal, for example, for clocking purposes, and a front-end module (FEM) that includes a front end system. In certain SiPs, a SoC and a crystal can consume a relatively large amount of physical area. This can create a relatively large footprint for the SiP. Also, long oscillator routing paths add parasitic capacitance, which can adversely affect the ability for the oscillator to start oscillating at power up.

SUMMARY

[0007] Packaged modules for use in wireless devices are disclosed. In some embodiments, a substrate supports integrated circuit die including at least a portion of a baseband system and a front end system, an oscillator assembly, and an antenna. In some embodiments, the oscillator assembly includes an enclosure to enclose the oscillator and conductive pillars formed at least partially within a side of the enclosure to conduct signals between the top and bottom surfaces of the oscillator assembly. In some embodiments, components can be vertically integrated to save space and reduce trace length. In some embodiments, vertical integration provides an overhang volume that can include discrete components. In some embodiments, radio frequency shielding and ground planes within the substrate shield the front end system and antenna from radio frequency interference. In some embodiments, stacked filter assemblies include passive surface mount devices to filter radio frequency signals

[0008] In certain embodiments, the disclosure relates to a packaged module for use in a wireless communication device. The packaged module comprises a first die supported by a substrate, an oscillator assembly configured to provide a clock signal for use by circuitry on the first die, where the oscillator assembly is supported by the substrate and disposed between the first die and the substrate, and a stacked filter assembly supported by the substrate. The stacked filter assembly includes a plurality of passive components, where at least one passive component is in direct communication with the substrate and at least another passive component spaced from the substrate by the at least one passive component that is in the direct communication with the substrate.

[0009] In an embodiment, the oscillator assembly includes a crystal, a conductive pillar, and an enclosure configured to enclose the crystal, the conductive pillar formed at least partially within a side of the enclosure and extending from a top surface to a bottom surface of the enclosure. In another embodiment, at least a first overhanging portion of the first die extending beyond at least a portion of the periphery of the oscillator assembly. In a further embodiment, the stacked filter assembly is disposed between the at least the first overhanging portion of the first die and the substrate. In a yet further embodiment, the packaged module further comprises supports positioned between the at least a first overhanging portion of the first die and the substrate to provide support for the at least a first overhanging portion of the first die.

[0010] In an embodiment, the substrate is a multi-layer substrate having a first side and a second side opposite to the first side, the multi-layer substrate including a ground plane. In another embodiment, the packaged module further comprises an antenna on the first side of the multi-layer substrate, and a second die supported by the multi-layer substrate and including at least a radio frequency component, where the second die is disposed on the second side of the multi-layer substrate such that the ground plane is positioned between the antenna and the radio frequency component. In a further embodiment, the packaged module further comprises a radio frequency shielding structure extending above the substrate, a second die supported by the substrate and in an interior of the radio frequency shielding structure, where the second die includes a radio frequency component, and an antenna supported by the substrate external to the radio frequency shielding structure. In a yet further embodiment, the packaged module further comprises a second die, where

the first die, the oscillator assembly and the stacked filter assembly are disposed on a first side of the substrate, the second die disposed on a second side of the substrate opposite of the first side.

[0011] In an embodiment, the packaged module further comprises a second die, where the first die includes at least a portion of a baseband system and the second die includes at least a portion of a radio frequency front end system. In another embodiment, the first die and the oscillator assembly are disposed on a first side of the substrate, and the stacked filter assembly is disposed on a second side of the substrate opposite of the first side. In a further embodiment, the stacked filter assembly is configured as a filter circuit that is in communication with radio frequency receiver circuitry on the first die.

[0012] In certain embodiments, the disclosure relates to a system board assembly comprising a system board and a radio frequency module supported by the system board. The radio frequency module includes a first die supported by a substrate, an oscillator assembly configured to provide a clock signal for use by the first die, where the oscillator assembly is supported by the substrate and disposed between the first die and the substrate, and a stacked filter assembly supported by the substrate, where the stacked filter assembly includes a plurality of passive components, where at least one passive component is in direct communication with the substrate and at least another passive component spaced from the substrate by the at least one passive component that is in the direct communication with the substrate. The system board assembly further comprises one or more components including at least one of radio frequency circuitry, baseband processor, and memory supported by the system board and connectivity to provide signal interconnections between the radio frequency module and the one or more components.

[0013] In an embodiment, the oscillator assembly includes a crystal, a conductive pillar, and an enclosure configured to enclose the crystal, where the conductive pillar formed at least partially within a side of the enclosure and extending from a top surface to a bottom surface of the enclosure. In another embodiment, the radio frequency module further includes a radio frequency shielding structure extending above the substrate and a second die supported by the substrate and disposed in an interior of the radio frequency shielding structure. In a further embodiment, the radio frequency module further includes an antenna supported by the substrate external to the radio frequency shielding structure.

[0014] In certain embodiments, the disclosure relates to a wireless communication device comprising an antenna configured to receive and transmit radio frequency signals and a radio frequency module. The radio frequency module includes a first die supported by a substrate, where the first die includes at least a portion of a radio frequency front end system that is in communication with the antenna, an oscillator assembly configured to provide a clock signal for use by the first die, where the oscillator assembly is supported by the substrate and disposed between the first die and the substrate, and a stacked filter assembly supported by the substrate, where the stacked filter assembly includes a plurality of passive components, where at least one passive component is in direct communication with the substrate and at least another passive component spaced from the substrate by the at least one passive component that is in the direct communication with the substrate.

[0015] In an embodiment, the radio frequency module further includes a second die, where the oscillator assembly and the stacked filter assembly are disposed on a first side of the substrate, and the second die is disposed on a second side of the substrate opposite of the first side. In another embodiment, the second die includes at least a portion of a baseband system. In a further embodiment, the plurality of passive components includes surface mount passive components.

[0016] In certain embodiments, the disclosure relates to a packaged module for use in a wireless communication device that comprises a first die supported by a substrate and includes at least a microprocessor and one or more of radio frequency transmitter circuitry and radio frequency receiver circuitry and a oscillator assembly supported by the substrate. The first die is disposed between the oscillator assembly and the substrate. The packaged module further comprises a second die supported by the substrate and implementing at least a portion of a radio frequency front end including a radio frequency power amplifier. The substrate is disposed between the first die and the second die. In some embodiments, the packaged module further comprises an overmold enclosing the first die and the oscillator assembly. A wireless communication device can include the packaged module. A system board assembly can include the packaged module.

[0017] In certain embodiments, the disclosure relates to a packaged radio frequency module that comprises a radio frequency shielding structure extending above a package substrate and a first die supported by the package substrate and in an interior of the radio frequency shielding structure. The first die includes a radio frequency component. The radio frequency module further comprises an antenna supported by the package substrate external to the radio frequency shielding structure and an oscillator assembly supported by the package substrate. The first die is disposed between the oscillator assembly and the package substrate. In some embodiments, the packaged radio frequency module further comprises an overmold enclosing the first die, the oscillator assembly, and the antenna. A wireless communication device can include the packaged radio frequency module. A system board assembly can include the packaged radio frequency.

[0018] In certain embodiments, the present disclosure relates to a packaged radio frequency module that comprises a frequency shielding structure extending above a package substrate, and a first die supported by the package substrate and in an interior of the radio frequency shielding structure, where the first die includes a radio frequency component. The packaged radio frequency module further comprises an antenna supported by the package substrate external to the radio frequency shielding structure and an oscillator assembly supported by the package substrate, where the oscillator assembly is disposed between the first die and the package substrate. In some embodiments, packaged radio further comprises an overmold enclosing the first die, the oscillator assembly, and the antenna. A wireless communication device can include the packaged radio frequency module. A system board assembly can include the packaged radio frequency module.

[0019] In certain embodiments, the present disclosure relates to a packaged radio frequency module for use in a wireless communication device that comprises a radio fre-

quency shielding structure extending above a package substrate, a first integrated circuit die supported by the package substrate and in an interior of the radio frequency shielding structure, an antenna supported by the package substrate external to the radio frequency shielding structure, and a second integrated circuit die supported by the package substrate. The package substrate is disposed between the first integrated circuit die and the second integrated circuit die. In some embodiments, the first integrated circuit die implements at least a portion of a radio frequency front end including a radio frequency power amplifier and the second integrated circuit die implements at least a portion of a radio frequency baseband subsystem. In some embodiments, the packaged radio frequency further comprises an overmold enclosing the first integrated circuit die and the antenna. A wireless communication device can include the packaged radio frequency module. A system board assembly can include the packaged radio frequency module.

[0020] In certain embodiments, the present disclosure relates to a packaged radio frequency module for use in a wireless communication device that comprises a radio frequency shielding structure extending above a package substrate, a first wireless device component supported by the package substrate and in an interior of the radio frequency shielding structure, an antenna supported by the package substrate external to the radio frequency shielding structure, and a second wireless device component supported by and spaced from the package substrate. The first wireless device component is between the second wireless device component and a first surface of the package substrate. At least a first overhanging portion of the second wireless device component extends beyond at least a portion of the periphery of the first wireless device component. In some embodiments, the first wireless device component includes a radio frequency component. In some embodiments, the packaged radio frequency module further comprises an overmold enclosing the first wireless device component, the antenna, and the second wireless device component. A wireless communication device can include the packaged radio frequency module. A system board assembly can include the packaged radio frequency module.

[0021] In certain embodiments, the present disclosure relates to a packaged radio frequency module for use in a wireless communication device that comprises a multi-layer substrate having a first side and a second side opposite to the first side. The multi-layer substrate includes a ground plane. The packaged radio frequency module further comprises an antenna on the first side of the multi-layer substrate, and a first die supported by the multi-layer substrate and includes at least a radio frequency component. The first die is disposed on the second side of the multi-layer substrate such that the ground plane is positioned between the antenna and the radio frequency component. The packaged radio frequency module further comprises an oscillator assembly supported by the multi-layer substrate and disposed on the second side of the multi-layer substrate such that the first die is positioned between the oscillator assembly and the second side of the multi-layer substrate, and conductive features disposed around the radio frequency component and electrically connected to the ground plane. In some embodiments, the packaged radio frequency module further comprises an overmold enclosing the first die, the oscillator assembly, and a microprocessor. In some embodiments, the conductive features and the ground plane are configured to provide shielding for the radio frequency component. The wireless communication device can include the packaged radio frequency module. A system board assembly can include the packaged radio frequency module.

[0022] In certain embodiments, the present disclosure relates to a radio frequency module comprising a multi-layer substrate having a first side and a second side opposite to the first side, where the multi-layer substrate includes a ground plane, an antenna on the first side of the multi-layer substrate, a first die supported by the multi-layer substrate and including at least radio frequency receiver circuitry disposed on the second side of the multi-layer substrate such that the ground plane is positioned between the antenna and the radio frequency receiver circuitry, conductive features disposed around the radio frequency receiver circuitry and electrically connected to the ground plane, and a stacked filter assembly is supported by the multi-layer substrate and configured as a filter circuit that is in communication with the radio frequency receiver circuitry, where the stacked filter assembly is disposed on the second side of the multi-layer substrate. In some embodiments, the first die further includes a microprocessor. In some embodiments, the conductive features and the ground plane are configured to provide shielding for the radio frequency receiver circuitry. In some embodiments, the stacked filter assembly includes a plurality of passive components. In some embodiments, each passive component of the plurality of passive components is packaged as a surface mount device. In some embodiments, at least one passive component is in direct communication with the second side of the multi-layer substrate and at least another passive component supported above the second side of the multi-layer substrate by the at least one passive component that is in the direct communication with the second side of the multi-layer substrate. In some embodiments, the radio frequency module further comprises an overmold enclosing the first die and the stacked filter assembly. A wireless communication device can include the radio frequency module. A system board assembly can include the radio frequency module.

[0023] In certain embodiments, the present disclosure relates to a radio frequency module that comprises a multi-layer substrate having a first side and a second side opposite to the first side, where the multi-layer substrate including a ground plane, an antenna on the first side of the multi-layer substrate, a first integrated circuit die supported by the multi-layer substrate and implementing a radio frequency power amplifier, where the first integrated circuit die is disposed on the second side of the multi-layer substrate such that the ground plane is positioned between the antenna and the radio frequency power amplifier, and conductive features disposed around at least the radio frequency power amplifier and electrically connected to the ground plane, where a second integrated circuit die supported by the multi-layer substrate is disposed on the first side of the multi-layer substrate. In some embodiments, at least a portion of a radio frequency front end includes the radio frequency power amplifier. In some embodiments, the conductive features and the ground plane are configured to provide shielding for the radio frequency power amplifier. In some embodiments, the second integrated circuit die implements at least a portion of a radio frequency baseband subsystem. In some embodiments, the radio frequency module further comprises an overmold enclosing the second integrated circuit die and the antenna. The wireless communication device can include the

radio frequency module. A system board assembly can include the radio frequency module.

[0024] In certain embodiments, the present disclosure relates to a packaged module for use in a wireless communication device that comprises a first die supported by a substrate, and an oscillator assembly configured to provide a clock signal for use in the first die, where the oscillator assembly is supported by the substrate and disposed between the first die and the substrate, where the oscillator assembly includes a crystal, a conductive pillar, and an enclosure configured to enclose the crystal, the conductive pillar formed at least partially within a side of the enclosure and extending from a top surface to a bottom surface of the enclosure. In some embodiments, the first die includes at least a microprocessor and one or more of radio frequency transmitter circuitry and radio frequency receiver circuitry. In some embodiments, the clock signal is provided for use in the at least one of the microprocessor and the one or more of the radio frequency transmitter circuitry and the radio frequency receiver circuitry. In some embodiments, the oscillator assembly further includes an input terminal configured to receive a first signal and an output terminal configured to output the clock signal, where the conductive pillar is configured to conduct a third signal distinct from the first signal and the clock signal. In some embodiments, the packaged module further comprises an overmold enclosing the first die and the oscillator assembly. The wireless communication device can include the packaged module. A system board assembly can include the packaged module.

[0025] In certain embodiments, the present disclosure relates to a packaged module for use in a wireless communication device that comprises a first die supported by a substrate, and a oscillator assembly configured to provide a clock signal for use in the first die, where the oscillator assembly is supported by the substrate, where the first die is disposed between the oscillator assembly and the substrate, where the oscillator assembly includes a crystal, a conductive pillar, and an enclosure configured to enclose the crystal, and where the conductive pillar is formed at least partially within a side of the enclosure and extending from a top surface to a bottom surface of the enclosure. In some embodiments, the first die includes at least a microprocessor and one or more of radio frequency transmitter circuitry and radio frequency receiver circuitry. In some embodiments, the clock signal is provided for use in the at least one of the microprocessor and the one or more of the radio frequency transmitter circuitry and the radio frequency receiver circuitry. In some embodiments, the oscillator assembly further includes an input terminal configured to receive a first signal and an output terminal configured to output the clock signal, where the conductive pillar is configured to conduct a third signal distinct from the first signal and the clock signal. In some embodiments, the packaged module further comprises an overmold enclosing the first die and the oscillator assembly. The wireless communication device can include the packaged module. A system board assembly can include the packaged module.

[0026] In certain embodiments, the present disclosure relates to a packaged module for use in a wireless communication device that comprises a first die supported by a substrate, an oscillator assembly configured to provide a clock signal for use the first die, where the oscillator assembly is supported by the substrate and disposed between the first die and the substrate, where the oscillator assembly includes a crystal, a conductive pillar, and an enclosure configured to enclose the crystal, where the conductive pillar is formed at least partially within a side of the enclosure and extending from a top surface to a bottom surface of the enclosure, and a stacked filter assembly supported by the substrate. The stacked filter assembly includes a plurality of passive components, where at least one passive component is in direct communication with the substrate and at least another passive component supported above the substrate by the at least one passive component that is in the direct communication with the substrate. In some embodiments, the first die includes at least one of the microprocessor and the radio frequency receiver circuitry. In some embodiments, the clock signal is provided for use in the at least one of the microprocessor and the radio frequency receiver circuitry. In some embodiments, the stacked filter assembly is configured as a filter circuit that is in communication with the radio frequency receiver circuitry. In some embodiments, the oscillator assembly further includes an input terminal configured to receive a first signal and an output terminal configured to output the clock signal, where the conductive pillar is configured to conduct a third signal distinct from the first signal and the clock signal. In some embodiments, each passive component of the plurality of passive components is packaged as a surface mount device. In some embodiments, the packaged module further comprises an overmold enclosing the first die, the oscillator assembly, and the stacked filter assembly. The wireless communication device can include the packaged module. A system board assembly can include the packaged module.

[0027] In certain embodiments, the present disclosure relates to a packaged module for use in a wireless communication device that comprises a first integrated circuit die supported by a substrate, where an oscillator assembly configured to provide a clock signal to the first integrated circuit die, where the oscillator assembly is supported by the substrate and disposed between the first integrated circuit die and the substrate, where the oscillator assembly includes a crystal, a conductive pillar, and an enclosure configured to enclose the crystal, where the conductive pillar is formed at least partially within a side of the enclosure and extending from a top surface to a bottom surface of the enclosure, and a second integrated circuit die supported by the substrate, where the substrate is disposed between the first integrated circuit die and the second integrated circuit die. In some embodiments, the first integrated circuit die implements at least a portion of a radio frequency baseband subsystem. In some embodiments, the clock signal is provided for the at least a portion of the radio frequency baseband subsystem. In some embodiments, the oscillator assembly further includes an input terminal configured to receive a first signal and an output terminal configured to output the clock signal, where the conductive pillar configured to conduct a third signal distinct from the first signal and the clock signal. In some embodiments, the second integrated circuit die implements at least a portion of a radio frequency front end including a radio frequency power amplifier. In some embodiments, the packaged module further comprises an overmold enclosing the first integrated circuit die and the oscillator assembly. The wireless communication device can include the packaged module. A system board assembly can include the packaged module.

[0028] In certain embodiments, the present disclosure relates to a packaged module for use in a wireless commu-

nication device that comprises a first wireless device component supported by a substrate, a second wireless device component supported by and spaced from the substrate, where the first wireless device component is between the second wireless device component and the substrate, where at least a first overhanging portion of the second wireless device component extends beyond at least a portion of the periphery of the first wireless device component, and an oscillator assembly supported by the substrate and disposed between the at least the first overhanging portion of the second wireless device component and the substrate. The oscillator assembly includes a crystal, a conductive pillar, and an enclosure configured to enclose the crystal, where the conductive pillar is formed at least partially within a side of the enclosure and extending from a top surface to a bottom surface of the enclosure. In some embodiments, the oscillator assembly further includes an input terminal configured to receive a first signal and an output terminal configured to output a second signal, where the conductive pillar is configured to conduct a third signal distinct from the first and second signals. In some embodiments, the packaged assembly further comprises an overmold enclosing the first wireless device component, the second wireless device component, and the oscillator assembly. The wireless communication device can include the packaged module. A system board assembly can include the packaged module.

[0029] In certain embodiments, the present disclosure relates to a packaged module for use in a wireless communication device that comprises a first die supported by a substrate, a stacked filter assembly supported by the substrate, where the stacked filter assembly includes a plurality of passive components, where at least one passive component is in direct communication with the substrate and at least another passive component supported above the substrate by the at least one passive component that is in the direct communication with the substrate, and a oscillator assembly supported by the substrate, where the first die is disposed between the oscillator assembly and the substrate. In some embodiments, the first die includes at least a microprocessor and radio frequency receiver circuitry. In some embodiments, the stacked filter assembly is configured as a filter circuit that is in communication with the radio frequency receiver circuitry. In some embodiments, each passive component of the plurality of passive components is packaged as a surface mount device. In some embodiments, the packaged module further comprises an overmold enclosing the first die, the stacked filter assembly, and the oscillator assembly. The wireless communication device can include the packaged module. A system board assembly can include the packaged module.

[0030] In certain embodiments, the present disclosure relates to a packaged module for use in a wireless communication device that comprises a first die supported by a substrate, a stacked filter assembly supported by the substrate and including a plurality of passive components, where at least one passive component is in direct communication with the substrate and at least another passive component supported above the substrate by the at least one passive component that is in the direct communication with the substrate, and a oscillator assembly supported by the substrate and disposed between the first die and the substrate. In some embodiments, the first die includes at least a microprocessor and radio frequency receiver circuitry. In some embodiments, the stacked filter assembly is configured as a filter circuit that is in communication with the radio frequency receiver circuitry. In some embodiments, each passive component of the plurality of passive components is packaged as a surface mount device. In some embodiments, the packaged module further comprises an overmold enclosing the first die, the stacked filter assembly, and the oscillator assembly. The wireless communication device can include the packaged module. A system board assembly can include the packaged module.

[0031] In certain embodiments, the present disclosure relates to a packaged module for use in a wireless communication device that comprises a first die supported by a substrate, a stacked filter assembly supported by the substrate, where the stacked filter assembly includes a plurality of passive components, where at least one passive component is in direct communication with the substrate and at least another passive component is supported above the substrate by the at least one passive component that is in the direct communication with the substrate, and a second die supported by the substrate, where the substrate disposed between the first die and the second die. In some embodiments, the first die includes at least a microprocessor and radio frequency receiver circuitry. In some embodiments, the stacked filter assembly is configured as a filter circuit that is in communication with the radio frequency receiver circuitry. In some embodiments, the second die implements at least a portion of a radio frequency front end including a radio frequency power amplifier. In some embodiments, each passive component of the plurality of passive components is packaged as a surface mount device. In some embodiments, the packaged module further comprises an overmold enclosing the first die and the stacked filter assembly. The wireless communication device can include the packaged module. A system board assembly can include the packaged module.

[0032] In certain embodiments, the present disclosure relates to a packaged module for a radio frequency wireless device that comprises a first wireless device component supported by a substrate and includes at least a microprocessor and radio frequency receiver circuitry, a second wireless device component supported by and spaced from the substrate, where the first wireless device component is between the second wireless device component and the substrate, where at least a first overhanging portion of the second wireless device component extending beyond at least a portion of the periphery of the first wireless device component, and a stacked filter assembly supported by the substrate and configured as a filter circuit that is in communication with the radio frequency receiver circuitry. The stacked filter assembly includes a plurality of passive components, where at least one passive component is in direct communication with the substrate, where the stacked filter assembly is disposed between the at least a first overhanging portion and the substrate. In some embodiments, each passive component of the plurality of passive components is packaged as a surface mount device. In some embodiments, at least another passive component is supported above the substrate by the at least one passive component that is in the direct communication with the substrate. In some embodiments, the packaged module further comprises an overmold enclosing the first wireless device component, the second wireless device component, and the stacked filter assembly.

The radio frequency wireless device can include the packaged module. A system board assembly can include the packaged module.

[0033] In certain embodiments, the present disclosure relates to a packaged module for use in a wireless communication device that comprises a first die supported by a substrate and includes at least one of a microprocessor, radio frequency transmitter circuitry, and radio frequency receiver circuitry, a oscillator assembly configured to provide a timing signal for use in the first die, where the oscillator assembly is supported by the substrate and is disposed between the first die and the substrate, and a second die supported by the substrate and implementing at least a portion of a radio frequency front end including a radio frequency power amplifier. The substrate is disposed between the first die and the second die. In some embodiments, the packaged module further comprises an overmold enclosing the first die and the oscillator assembly. The wireless communication device can include the packaged module. A system board assembly can include the packaged module.

[0034] In certain embodiments, the present disclosure relates to a packaged module for use in a radio frequency wireless device that comprises a first wireless device component supported by a substrate, a second wireless device component supported by and spaced from the substrate and implementing at least a portion of a radio frequency baseband subsystem, where the first wireless device component is positioned between the second wireless device component and the substrate, where at least a first overhanging portion of the second wireless device component extending beyond at least a portion of the periphery of the first wireless device component, and a third wireless device component supported by the substrate and implementing at least a portion of a radio frequency front end including a radio frequency power amplifier. The substrate is disposed between the second wireless device component and the third wireless device component. In some embodiments, the packaged module further comprises an overmold enclosing the first wireless device component and the second wireless device component. The radio frequency wireless device can include the packaged module. A system board assembly can include the packaged module.

[0035] In certain embodiments, the present disclosure relates to a packaged module for use in a wireless communication device that comprises a first wireless device component supported by a substrate, a second wireless device component supported by and spaced from the substrate, where the first wireless device component is between the second wireless device component and the substrate, where at least a first overhanging portion of the second wireless device component extends beyond at least a portion of the periphery of the first wireless device component, and a oscillator assembly supported by the substrate. The first wireless device component and the second wireless device component are disposed between the oscillator assembly and the substrate. In some embodiments, the packaged module further comprises an overmold enclosing the first wireless device component, the second wireless device component, and the oscillator assembly. The wireless communication device can include the packaged module. A system board assembly can include the packaged module.

[0036] In certain embodiments, the present disclosure relates to a packaged module for use in a wireless communication device that comprises a first wireless device component supported by a substrate, a second wireless device component supported by and spaced from the substrate, where the first wireless device component is positioned between the second wireless device component and the substrate, where at least a first overhanging portion of the second wireless device component extending beyond at least a portion of the periphery of the first wireless device component, and a oscillator assembly supported by the substrate. The oscillator assembly is disposed within the at least the first overhanging portion of the second wireless device component and between the second wireless device component and the substrate. In some embodiments, the packaged module further comprises an overmold enclosing the first wireless device component, the second wireless device component, and the oscillator assembly. The wireless communication device can include the packaged module. A system board assembly can include the packaged module.

[0037] In certain embodiments, the present disclosure relates to a packaged radio frequency module for use in a wireless communication device that comprises a radio frequency shielding structure extending above a package substrate, a first die supported by the package substrate and in an interior of the radio frequency shielding structure, where the first die including a radio frequency component, an antenna supported by the package substrate external to the radio frequency shielding structure, and a oscillator assembly supported by the package substrate and disposed between the first die and the package substrate. The oscillator assembly includes a crystal, a conductive pillar, and an enclosure configured to enclose the crystal, where the conductive pillar is formed at least partially within a side of the enclosure and extending from a top surface to a bottom surface of the enclosure. In some embodiments, the packaged radio frequency module further comprises an overmold enclosing the first die, the oscillator assembly, and the antenna. In some embodiments, the oscillator assembly further includes an input terminal configured to receive a first signal, an output terminal configured to output a second signal, and the conductive pillar is configured to conduct a third signal distinct from the first and second signals. The wireless communication device can include the packaged radio frequency module. A system board assembly can include the packaged radio frequency module.

[0038] In certain embodiments, the present disclosure relates to a packaged radio frequency module for use in a wireless communication device that comprises a radio frequency shielding structure extending above a package substrate, a first die supported by the package substrate and in an interior of the radio frequency shielding structure, where the first die includes radio frequency receiver circuitry, an antenna supported by the package substrate external to the radio frequency shielding structure, and a stacked filter assembly supported by the package substrate and configured as a filter circuit that is in communication with the radio frequency receiver circuitry. The stacked filter assembly includes a plurality of passive components, where at least one passive component is in direct communication with the package substrate and at least another passive component is supported above the package substrate by the at least one passive component that is in the direct communication with the package substrate. In some embodiments, each passive component of the plurality of passive components is packaged as a surface mount device. In some embodiments, the

packaged radio frequency module further comprises an overmold enclosing the first die, the stacked filter assembly, and the antenna. The wireless communication device can include the packaged radio frequency module. A system board assembly can include the packaged radio frequency module.

[0039] In certain embodiments, the present disclosure relates to a packaged radio frequency module for use in a wireless communication device that comprises a multi-layer substrate having a first side and a second side opposite to the first side, where the multi-layer substrate includes a ground plane, an antenna on the first side of the multi-layer substrate, a first die supported by the multi-layer substrate and including at least a radio frequency component, where the first die is disposed on the second side of the multi-layer substrate such that the ground plane is positioned between the antenna and the radio frequency component, a oscillator assembly supported by the multi-layer substrate and disposed on the second side of the multi-layer substrate such that the oscillator assembly is positioned between the first die and the second side of the multi-layer substrate, and conductive features disposed around the radio frequency component and electrically connected to the ground plane. In some embodiments, the first die further includes a microprocessor. In some embodiments, the conductive features and the ground plane are configured to provide shielding for the radio frequency component. In some embodiments, the packaged radio frequency module further comprises an overmold enclosing the first die and the oscillator assembly. The wireless communication device can include the packaged radio frequency module. A system board assembly can include the packaged radio frequency module.

[0040] In certain embodiments, the present disclosure relates to a radio frequency module that comprises a multi-layer substrate having a first side and a second side opposite to the first side, where the multi-layer substrate includes a ground plane, an antenna on the first side of the multi-layer substrate, a first die supported by the multi-layer substrate and including at least a radio frequency component disposed on the second side of the multi-layer substrate such that the ground plane is positioned between the antenna and the radio frequency component, conductive features disposed around the radio frequency component and electrically connected to the ground plane, and a oscillator assembly supported by the multi-layer substrate and disposed on the second side of the multi-layer substrate such that the oscillator assembly is positioned between the first die and the second side of the multi-layer substrate. The oscillator assembly includes a crystal, a conductive pillar, and an enclosure configured to enclose the crystal, where the conductive pillar is formed at least partially within a side of the enclosure and extending from a top surface to a bottom surface of the enclosure. In some embodiments, the conductive features and the ground plane are configured to provide shielding for the radio frequency component. In some embodiments, the oscillator assembly further includes an input terminal configured to receive a first signal, and an output terminal configured to output a second signal, where the conductive pillar is configured to conduct a third signal distinct from the first and second signals. In some embodiments, the packaged radio frequency module further comprises an overmold enclosing the first die and the oscillator assembly. A wireless communication device can include the radio frequency module. A system board assembly can include the radio frequency module.

[0041] In certain embodiments, the present disclosure relates to a radio frequency module that comprises a multi-layer substrate having a first side and a second side opposite to the first side, where the multi-layer substrate includes a ground plane, an antenna on the first side of the multi-layer substrate, a radio frequency component disposed on the second side of the multi-layer substrate such that the ground plane is positioned between the antenna and the radio frequency component, a first wireless device component supported by and spaced from the second side of the multi-layer substrate, where the radio frequency component is positioned between the first wireless device component and the second side of the multi-layer substrate, where at least a first overhanging portion of the first wireless device component extends beyond at least a portion of the periphery of the radio frequency component, and conductive features disposed around the radio frequency component and electrically connected to the ground plane. In some embodiments, the conductive features and the ground plane are configured to provide shielding for the radio frequency component. In some embodiments, the radio frequency module further comprises an overmold enclosing the radio frequency component and the first wireless device component. A wireless communication device can include the radio frequency module. A system board assembly can include the radio frequency module.

BRIEF DESCRIPTION OF THE DRAWING

[0042] Throughout the drawings, reference numbers are re-used to indicate correspondence between referenced elements. The drawings are provided to illustrate embodiments of the inventive subject matter described herein and not to limit the scope thereof.

[0043] FIG. **1** illustrates a schematic block diagram of one example of a packaged radio frequency module.

[0044] FIG. **2** is a cross section of a packaged module that includes an integrated circuit and an oscillator vertically integrated with the integrated circuit on a first side of the substrate and a second integrated circuit vertically integrated on a second side the substrate, according to an embodiment.

[0045] FIG. **3** is a cross section of a packaged module that includes a first integrated circuit, an oscillator assembly comprising a crystal, for example, vertically integrated with the first integrated circuit, and a radio frequency integrated circuit within a radio frequency shielding structure and an antenna external to the radio frequency shielding structure, according to an embodiment.

[0046] FIG. **3**A is a cross sectional view of the radio frequency module of FIG. **3** prior to forming a shielding layer over the radio frequency component, according to an embodiment.

[0047] FIG. **3**B is a cross sectional view of the radio frequency module of FIG. **3** with a shielding layer over the radio frequency component and not over the antenna, according to an embodiment.

[0048] FIG. **4** is a cross section of a packaged module that includes an oscillator assembly comprising a crystal, for example, a first integrated circuit vertically integrated with the crystal, and a radio frequency integrated circuit within a radio frequency shielding structure and an antenna external to the radio frequency shielding structure, according to an embodiment.

[0049] FIG. **5** is a cross section of a packaged module that includes a first integrated circuit, and an oscillator assembly comprising a crystal, for example, vertically integrated with the first integrated circuit on a first surface of the substrate and a radio frequency integrated circuit within a radio frequency shielding structure and an antenna external to the radio frequency shielding structure vertically integrated on a second surface of the substrate, according to an embodiment.

[0050] FIG. **6** is cross section of a packaged module that includes an oscillator assembly comprising a crystal, for example, a first integrated circuit vertically integrated with the oscillator assembly and extending beyond a periphery of the oscillator assembly, a radio frequency integrated circuit within a radio frequency shielding structure that is within an overhang formed by the first integrated circuit, and an antenna external to the radio frequency shielding structure, according to an embodiment.

[0051] FIG. **7** is cross section of a packaged module that includes an oscillator assembly comprising a crystal, for example, a first integrated circuit vertically integrated with the oscillator assembly, and a ground plane between an antenna and a radio frequency component, according to an embodiment.

[0052] FIG. **8** is a cross section of a packaged module that includes a stacked filter assembly and a ground plane between an antenna and a front end system, according to an embodiment.

[0053] FIG. **8A1** illustrates a first exemplary stacking configuration for surface mount devices, according to certain embodiments.

[0054] FIG. **8A2** illustrates an exemplary circuit diagram for the stacking configuration of FIG. **8A1**, according to certain embodiments.

[0055] FIG. **8B1** illustrates a second exemplary stacking configuration for surface mount devices, according to certain embodiments.

[0056] FIG. **8B2** illustrates an exemplary circuit diagram for the stacking configuration of FIG. **8B1**, according to certain embodiments.

[0057] FIG. **8C1** illustrates a third exemplary stacking configuration for surface mount devices, according to certain embodiments.

[0058] FIG. **8C2** illustrates a fourth exemplary stacking configuration for surface mount devices, according to certain embodiments.

[0059] FIG. **8C3** illustrates an exemplary circuit diagram for the stacking configuration of FIGS. **8C1** and **8C2**, according to certain embodiments.

[0060] FIG. **8D1** illustrates a fifth exemplary stacking configuration for surface mount devices, according to certain embodiments.

[0061] FIG. **8D2** illustrates an exemplary circuit diagram for the stacking configuration of FIG. **8D1**, according to certain embodiments.

[0062] FIG. **9** is a cross section of a packaged module that includes an oscillator assembly comprising a crystal, for example, a first integrated circuit vertically integrated with the oscillator assembly and ground plane between an antenna and a radio frequency component, according to an embodiment.

[0063] FIG. **10** is a cross section of a packaged module that includes an oscillator assembly having conductive pillars and an integrated circuit vertically integrated with the oscillator assembly, according to an embodiment.

[0064] FIG. **10A1** illustrates an exemplary crystal assembly with conductive pillars, according to certain embodiments.

[0065] FIG. **10A2** illustrates an exemplary crystal assembly with a conductive layer in communication with the conductive pillars on one or more sides, according to certain embodiments.

[0066] FIG. **10B1** illustrates a cross sectional view of an exemplary assembly including a crystal and a front end integrated circuit, according to certain embodiments.

[0067] FIG. **10B2** illustrates a cross sectional view of an exemplary assembly including a crystal and a surface acoustic wave (SAW) device, according to certain embodiments.

[0068] FIG. **10C** illustrates a bottom view of an exemplary crystal assembly, according the certain embodiments.

[0069] FIG. **11** is a cross section of a packaged module that includes an integrated circuit and an oscillator assembly having conductive pillars vertically integrated with the integrated circuit, according to an embodiment.

[0070] FIG. **12** is a cross section of a packaged module that includes an oscillator assembly having conductive pillars and stacked filter assemblies, according to an embodiment.

[0071] FIG. **13** is a cross section of a packaged module that includes an oscillator assembly having conductive pillars and a first integrated circuit vertically integrated with the oscillator assembly on a first side of the substrate, and a radio frequency integrated circuit vertically integrated on a second side of the substrate, according to an embodiment.

[0072] FIG. **14** is a cross section of a packaged module that includes an oscillator assembly having conductive pillars, a first integrated circuit vertically integrated with the oscillator assembly, and a radio frequency front end system vertically integrated with the first integrated circuit, according to an embodiment.

[0073] FIG. **15** is a cross section of a packaged module that includes an integrated circuit, an oscillator assembly comprising a crystal, for example, vertically integrated with the integrated circuit, and a stacked filter assembly, according to an embodiment.

[0074] FIG. **16** is a cross section of a packaged module that includes an oscillator assembly, an integrated circuit vertically integrated with the oscillator assembly, and a stacked filter assembly, according to an embodiment.

[0075] FIG. **17** is a cross section of a packaged module that includes an oscillator assembly, a first integrated circuit vertically integrated with the oscillator assembly on a first side of the substrate, a radio frequency front end system vertically integrated on a second side of the substrate, and a stacked filter assembly, according to an embodiment.

[0076] FIG. **18** is a cross section of a packaged module that includes an oscillator assembly, a first integrated circuit vertically integrated with the oscillator assembly, a radio frequency front end system vertically integrated with the first integrated circuit, and a stacked filter assembly, according to an embodiment.

[0077] FIG. **19** is a cross section of a packaged module that includes an oscillator assembly, a first integrated circuit vertically integrated with the oscillator assembly on a first side of the substrate, and a radio frequency front end system vertically integrated on a second side of the substrate, according to an embodiment.

[0078] FIG. **20** is a cross section of a packaged module that includes a first wireless device component and a second wireless device component vertically integrated with the first wireless device component and extending beyond a periphery of the first wireless device component, according to an embodiment.

[0079] FIG. **21** is a cross section of a packaged module that includes a first integrated circuit, a second integrated circuit vertically integrated with the first integrated circuit and extending beyond a periphery of the first integrated circuit, and an oscillator assembly vertically integrated with the second integrated circuit, according to an embodiment.

[0080] FIG. **22** is a cross section of a packaged module that includes a first integrated circuit, a second integrated circuit vertically integrated with the first integrated circuit and extending beyond a periphery of the first integrated circuit, and an oscillator assembly within the overhang formed by the second integrated circuit, according to an embodiment.

[0081] FIG. **23** is a cross section of a packaged module that an oscillator assembly having conductive pillars and a radio frequency integrated circuit within a radio frequency shielding structure and an antenna external to the radio frequency shielding structure that is vertically integrated with the oscillator assembly, according to an embodiment.

[0082] FIG. **24** is a cross section of a packaged module that includes a stacked filter assembly and a radio frequency integrated circuit within a radio frequency shielding structure and an antenna external to the radio frequency shielding structure, according to an embodiment.

[0083] FIG. **25** is a cross section of a packaged module that includes an oscillator assembly comprising a crystal, for example, and a ground plane between an antenna and a front end system that is vertically integrated with the oscillator assembly, according to an embodiment.

[0084] FIG. **26** is a cross section of a packaged module that includes an oscillator assembly having conductive pillars and a ground plane between an antenna and a front end system that is vertically integrated with the oscillator assembly, according to an embodiment.

[0085] FIG. **27** is a cross section of a packaged module that includes a ground plane between an antenna and a front end system and a first integrated circuit that is vertically integrated with the radio frequency front end system, according to an embodiment.

[0086] FIG. **28**A is a schematic diagram of one example of a wireless communication device, according to an embodiment.

[0087] FIG. **28**B is a schematic diagram of another example of a wireless communication device including a radio frequency module, according to an embodiment.

[0088] FIG. **29**A is a schematic diagram of another example of a wireless communication device including a radio frequency module, according to an embodiment.

[0089] FIG. **29**B illustrates a system board assembly with a radio frequency module and another component disposed on the system board, according to an embodiment.

[0090] FIG. **30** is an example block diagram illustrating a simplified wireless device including a system-in-a-package, according to certain embodiments.

[0091] FIG. **31** is a schematic diagram of one example of an Internet of things (IoT) network, according to an embodiment.

[0092] FIG. **32**A is a schematic diagram of one example of an IoT-enabled watch, according to an embodiment.

[0093] FIG. **32**B is a schematic diagram of one example of a front end system for an IoT-enabled object, according to an embodiment.

[0094] FIG. **33**A is a schematic diagram of one example of IoT-enabled vehicles, according to an embodiment.

[0095] FIG. **33**B is a schematic diagram of another example of a front end system for an IoT-enabled object, according to an embodiment.

[0096] FIG. **34**A is a schematic diagram of one example of IoT-enabled industrial equipment, according to an embodiment.

[0097] FIG. **34**B is a schematic diagram of another example of a front end system for an IoT-enabled object, according to an embodiment.

[0098] FIG. **35**A is a schematic diagram of one example of an IoT-enabled lock, according to an embodiment.

[0099] FIG. **35**B is a schematic diagram of one example of a circuit board for the IoT-enabled lock of FIG. **35**A, according to an embodiment.

[0100] FIG. **36**A is a schematic diagram of one example of an IoT-enabled thermostat, according to an embodiment.

[0101] FIG. **36**B is a schematic diagram of one example of a circuit board for the IoT-enabled thermostat of FIG. **36**A, according to an embodiment.

[0102] FIG. **37**A is a schematic diagram of one example of IoT-enabled light, according to an embodiment.

[0103] FIG. **37**B is a schematic diagram of one example of a circuit board for the IoT-enabled light of FIG. **37**A, according to an embodiment.

DETAILED DESCRIPTION

[0104] The following description of certain embodiments presents various descriptions of specific embodiments. However, the innovations described herein can be embodied in a multitude of different ways, for example, as defined and covered by the claims. In this description, reference is made to the drawings where like reference numerals can indicate identical or functionally similar elements. It will be understood that elements illustrated in the figures are not necessarily drawn to scale. Moreover, it will be understood that certain embodiments can include more elements than illustrated in a drawing and/or a subset of the elements illustrated in a drawing. Further, some embodiments can incorporate any suitable combination of features from two or more drawings.

[0105] A packaged radio frequency module can be used in a wireless device to provide space-saving implementation of radio frequency circuitry. In some embodiments, the packaged radio frequency module integrates radio frequency shielding and antennas to enhance the performance of the radio frequency circuitry.

[0106] Implementing one or more features described in the appendices submitted herewith in a packaged radio frequency module can achieve a number of advantages, including, but not limited to, more compact layout, lower cost, enhanced integration, reduced electromagnetic interference, reduced parasitic capacitance, and/or increased radio frequency shielding. Although some features are described herein in connection with packaging radio frequency systems and subsystems for wireless devices for illustrative

purposes, it will be understood that the principles and advantages described herein can be applied to a wide variety of other electronics.

[0107] FIG. **1** illustrates a schematic block diagram of one example of a packaged radio frequency module **100** for use in a wireless device. The packaged radio frequency module **100** includes one or more of a substrate **102**, an antenna **104**, radio frequency devices **106**, **108**, **112**, radio frequency shielding and or radio frequency isolation structures **124**, a crystal **118** and associated components **116**, which can be implemented as an oscillator assembly **114**, a filter assembly **120**, routing **126** representing signal paths, and an overmold **122** comprising molding material. The packaged radio frequency module **100** can incorporate one or more features described herewith.

[0108] The substrate **102** can be a single layer or a multi-layer laminate. The substrate **102** can include one or more ground planes. The substrate **102** can integrate the antenna **104**. For example, a front end system for a wireless device can be implemented on the packaged radio frequency module **100** along with one or more integrated antennas **104**. In an embodiment, a front end system can be implemented as an integrated circuit (IC) or semiconductor die, referred to as a front end integrated circuit (FEIC). In other embodiments, the front end system is implemented as a module, which is referred to as a front end module (FEM).

[0109] The packaged radio frequency module **100** is illustrated with three radio frequency devices **106**, **108**, and **112**. In other embodiments, the packaged module **100** can include more or less than three radio frequency devices. Radio frequency devices **106**, **108**, **112** can comprise, for example, an radio frequency integrated circuit (RFIC), a radio frequency front end module (FEM), an amplifier, a portion of a base-band processing system, a processor, a system-on-a-chip (SoC), which integrate multiple functions in a single integrated circuit die, and the like. The integrated circuit die can be manufactured using any suitable process technology. As one example, the integrated circuit die can be a semiconductor-on-insulator die, such as a silicon-on-insulator (SOI) die.

[0110] The oscillator assembly **114** is used for clocking purposes and has the crystal **118** associated components **116**, such as load capacitors. The oscillator assembly **114** can be placed discretely in the packaged radio frequency module or can be packaged within an enclosure. The oscillator assembly **114** illustrated in FIG. **1** comprises a crystal oscillator that includes the crystal **118**. In other embodiments, the oscillator assembly **114** can be a harmonic oscillator comprising an RC oscillator including a network of resistors and capacitors, an LC oscillator including at least an inductor and a capacitor, a linear oscillator including a transistor or operational amplifier connected in a feedback loop, surface acoustic wave (SAW) oscillators including a SAW device, and the like.

[0111] Filter assembly **120** comprises, for example, surface mount capacitors and inductors configured to filter radio frequency signals to and/or from the radio frequency devices **106**, **108**, **112**, and/or the antenna **104**.

[0112] The routing **126** represents electrical communication between the various components of the packaged radio frequency module **100**. The routing **126** can comprise traces on the substrate **102**, conductive vias, conductive pillars, routing substrates, which provide electrical communication between components of the packaged radio frequency module **100** and input/output signal communication for the packaged radio frequency module **100** according to the circuit design.

[0113] The overmold **122** comprises a molding material or molding compound that is pliable and moldable in process and hardens when cured. The overmold **122** at least partially covers or houses one or more of the active and passive components **104**, **106**, **108**, **112**, **114**, **116**, **118**, **120**, **124** on the substrate **102**. In an embodiment, the molding material provides the overmold **122** for the packaged radio frequency module **100**.

[0114] In an embodiment, the packaged radio frequency module **100** comprises a system-in-a-package, which includes multiple ICs including SoCs and discrete components using vertical integration technologies of at least some of the components. Some packaged radio frequency modules can be multi-chip modules (MCMs).

[0115] In an embodiment, the packaged radio frequency module **100** comprises a packaged radio frequency device. Although one example of packaged radio frequency module is shown in FIG. **1**, a packaged radio frequency module can be adapted in a wide variety of ways. For example, a packaged radio frequency module can include more, fewer, or different components and/or more, fewer or different signals paths. Accordingly, the teachings herein are applicable to packaged radio frequency modules implemented in a wide variety of ways.

[0116] In certain embodiments, the packaged radio frequency module **100** of FIG. **1** can include radio frequency shielding and/or radio frequency isolation structures **124**. For example, the packaged radio frequency module **100** can be implemented with partial shielding. In one embodiment, a shielded layer is included over a first portion of the packaged radio frequency module and a second portion of the packaged radio frequency module is unshielded. The shielding layer can shield certain components, such as, the radio frequency devices **106**, **108**, **112**, for example, and leave other components, such as, the antenna **104**, for example, unshielded.

[0117] In certain embodiments, the packaged radio frequency module **100** of FIG. **1** can include a laminated substrate **102** including an antenna **104** that is printed on a top layer and a ground plane for shielding on a layer underneath the top layer. Additionally, at least one electronic component, such as radio frequency devices **106**, **108**, **112**, and/or one or more surface mount components forming one or more filter assemblies **120**, for example can be disposed along a bottom layer of the laminate substrate **102**. Solder bumps are disposed around the electronic component and electrically connected to the ground plane. The solder bumps can attach the packaged radio frequency module to a carrier or directly to a system board. The electronic component can be surrounded by solder bumps, and the outside edges of the electronic component can have ground solder bumps that are connected to the ground plane by way of vias. Accordingly, a shielding structure with can be completed when the packaged radio frequency module is placed onto a carrier or system board, and the shielding structure can serve as a Faraday cage around the electronic component.

[0118] In certain embodiments, the packaged radio frequency module **100** of FIG. **1** can vertically stack an oscillator assembly **114** comprising the crystal **118** and discrete components **116** associated with the crystal **118**, for example, over a system-on-a-chip **106**, **108**, and/or **112** on

the substrate **102** with a front end system. By implementing such a packaged module, a smaller footprint and/or a more compact substrate area can be achieved. Other advantages include decreased crystal trace parasitic capacitance associated with the oscillator assembly **114**.

[0119] In certain embodiments, the packaged radio frequency module **100** of FIG. **1** can vertically stack a system-on-a-chip **106**, **108**, and/or **112** over the oscillator assembly **114** including the crystal **118** and discrete components **116** associated with the crystal **118**, for example, over the substrate **102** with a front end system. Since the system-on-a-chip tends to be larger than the oscillator assembly **114**, additional discrete components or additional radio frequency integrated circuits can be located in the overhang created by the system-on-a-chip above the oscillator assembly **114**. By implementing such a packaged module, a smaller footprint and/or a more compact substrate area can be achieved.

[0120] In certain embodiments, vertically stacked radio frequency module **100** of FIG. **1** can include radio frequency devices **106**, **108**, or **112** implementing at least a portion of a baseband subsystem above the substrate **102** and radio frequency devices **106**, **108**, **112** implementing at least a portion of a radio frequency front end system below the substrate.

[0121] In certain embodiments, the vertically stacked radio frequency devices **106**, **108**, **112** of different sized footprints can provide a space under a first larger device and beside a second smaller device. For manufacturing purposes, a spacer is placed in the space to support the first larger device on the substrate. Discrete components, such as resistors, capacitors, and inductors, can be placed in such spaces, but can leave gaps between the discrete component and the first larger device. Gap filling spacers are provided to reduce the occurrence of tilted or crooked assemblies. By implementing such a packaged module, manufacturing yields are increased.

[0122] In certain embodiments, the packaged module **100** of FIG. **1** includes the oscillator assembly **114** and a system-on-a-chip, such as a transceiver die. For example, the system-on-a-chip can be stacked over the oscillator assembly **114** to save space and provide shorter crystal traces. The oscillator assembly **114** may be a crystal oscillator housed in a housing that includes one or more conductive pillars for routing signals from the system-on-a-chip to a substrate and/or to provide thermal conductivity.

[0123] In certain embodiments, the packaged radio frequency module **100** of FIG. **1** includes at least a portion of a front end system, a filter assembly **120**, and a system-on-a-chip. For example, the filter assembly **120** can be stacked with other dies and components of the packaged module to reduce a footprint of the packaged module. Furthermore, stacking the filter assembly **120** in this manner can reduce lengths of signal carrying conductors, thereby reducing parasitic capacitance and enhancing signaling performance.

Radio Frequency Modules

[0124] FIG. **2** comprises an embodiment of a radio frequency packaged module **200** that can be implemented in a wireless device. FIG. **2** illustrates a cross section of the packaged module **200** that includes an integrated circuit **2** and an oscillator assembly **3** vertically integrated with the integrated circuit **2** on a first side of a package substrate **4** and a second integrated circuit **5** vertically integrated with the first integrated circuit **2** and the oscillator assembly **3** on a second side the package substrate **4** according to an embodiment. The package substrate **4** supports the first integrated circuit **2** and the oscillator assembly **3** on the first side and supports the second integrated circuit **5** on the second side. The first integrated circuit **2** is interposed between the package substrate **4** and the oscillator assembly **3**.

[0125] As illustrated in FIG. **2**, the packaged module **200** further includes a routing substrate or interposer **7**, one or more load capacitors **8** and one or more wire bonds **6**. In an embodiment, the first integrated circuit **2** is a system on a chip (SoC) and includes at least a portion of a baseband subsystem and the second integrated circuit **5** is a radio frequency front end system, such as an FEIC. FIG. **2** is not necessarily drawn to scale.

[0126] FIG. **2** shows the one or more load capacitors **8** as being external to the SoC **2**. In other embodiments, the SoC **2** comprises the one or more load capacitors **8**.

[0127] The SoC **2** can be epoxied to the substrate **4** and can be wire bonded to the substrate **4** in a manner as is known to one of skill in the art of semiconductor fabrication from the disclosure herein. The routing substrate **7** is stacked on top of the SoC **2**. The oscillator assembly **3** and its load capacitors **8** can then be soldered on the top of the routing substrate **7**.

[0128] The routing substrate **7** holds the oscillator assembly **3** and the capacitors **8** and routes signals to the oscillator assembly **3**. In an embodiment, the routing substrate **7** comprises a single layer or a multi-layer laminate.

[0129] In an embodiment, the one or more ground bond wires **6** are in communication with a ground signal, such as a ground plane, a grounded via or the like, on the substrate **4** and the routing substrate **7**, which in turn routes the ground signal to the oscillator assembly **3**. In an embodiment, the one or more wire bonds **6** are in communication with devices, such as an oscillator assembly or the like, on the SoC **2** and the routing substrate **7**, which in turn, routes the signals to the oscillator assembly **3**.

[0130] Stacking the oscillator assembly **3** and the capacitors **8** permits the substrate **4** be smaller (have a smaller footprint) and provides the same or similar functionality. The advantage of stacking the oscillator assembly **3** and the capacitors **8** is not only space savings, but also the length of at least one trace between the oscillator assembly **3** and the SoC **2** has been greatly reduced. It is desirable to have as short a trace as possible between an oscillator and a SoC to reduce parasitic capacitance of the trace. By stacking the oscillator assembly **3** over the SoC **2**, the trace is all but eliminated and the opportunity for parasitic capacitance to develop is greatly reduced. In an embodiment, the signals to/from the oscillator assembly **3** are routed from the SoC **2** directly to the routing substrate **7** via the one or more wire bonds **6**. Another benefit of reducing the traces in communication with the oscillator assembly **3** is a reduced opportunity of coupling between the crystal path and other sensitive paths on the substrate **4**, such as RF traces that are in communication with the radio frequency front end system **5**, for example.

[0131] FIG. **3** comprises another embodiment of a radio frequency packaged module **300** that can be implemented in a wireless device. FIG. **3** illustrates a cross section of the packaged module **300** that includes a first integrated circuit **2**, an oscillator assembly **3** vertically integrated with the first

integrated circuit **2**, and a radio frequency component **11** within a radio frequency shielding structure **9** and an antenna **10** external to the radio frequency shielding structure **9** according to an embodiment. The packaged module **300** includes a package substrate **4** that supports the first integrated circuit **2**, the oscillator assembly **3**, the radio frequency component **11**, and the antenna **10**. The first integrated circuit **2** is interposed between the oscillator assembly **3** and the package substrate **4**. FIG. **3** is not necessarily drawn to scale.

[0132] As illustrated in FIG. **3**, the packaged module **300** further includes a routing substrate or interposer **7**, one or more load capacitors **8** and one or more wire bonds **6**. In an embodiment, the first integrated circuit **2** is a system on a chip (SoC) and includes at least a portion of a baseband subsystem and the radio frequency component **11** is at least a portion of a radio frequency front end system, a radio frequency front end module (FEM), or front end integrated circuit (FEIC). The shielding structure **9** can include a shielding layer formed over the radio frequency component **11** such that the antenna **10** is unshielded opposite the common package substrate **4**.

[0133] FIG. **3** shows the one or more load capacitors **8** as being external to the SoC **2**. In other embodiments, the SoC **2** comprises the one or more load capacitors **8**. As described above with respect to FIG. **2**, the SoC **2** can be epoxied to the substrate **4** and can be wire bonded to the substrate **4** in a manner as is known to one of skill in the art of semiconductor fabrication from the disclosure herein. The routing substrate **7** is stacked on top of the SoC **2**. The oscillator assembly **3** and its load capacitors **8** can then be soldered on the top of the routing substrate **7**.

[0134] The routing substrate **7** holds the oscillator assembly **3** and the capacitors **8** and routes signals to the oscillator assembly **3**. In an embodiment, the routing substrate **7** comprises a single layer or a multi-layer laminate.

[0135] In an embodiment, the one or more ground bond wires **6** are in communication with a ground signal, such as a ground plane, a grounded via or the like, on the substrate **4** and the routing substrate **7**, which in turn routes the ground signal to the oscillator assembly **3**. In an embodiment, the one or more wire bonds **6** are in communication with devices, such as an oscillator assembly or the like, on the SoC **2** and the routing substrate **7**, which in turn, routes the signals to the oscillator assembly **3**.

[0136] Stacking the oscillator assembly **3** and the capacitors **8** permits the substrate **4** be smaller (have a smaller footprint) and provides the same or similar functionality. Advantageously, stacking the oscillator assembly **3** and the capacitors **8** permits the substrate **4** to accommodate the radio frequency front end system **11**. Another advantage of stacking the oscillator assembly **3** and the capacitors **8** is not only space savings, but also the length of at least one trace between the oscillator assembly **3** and the SoC **2** has been greatly reduced. It is desirable to have as short a trace as possible between an oscillator and a SoC to reduce parasitic capacitance of the trace. By stacking the oscillator assembly **3** over the SoC **2**, the trace is all but eliminated and the opportunity for parasitic capacitance to develop is greatly reduced. In an embodiment, the signals to/from the oscillator assembly **3** are routed from the SoC **2** directly to the routing substrate **7** via the one or more wire bonds **6**. Another benefit of reducing the traces in communication with the oscillator assembly **3** is a reduced opportunity of coupling between the crystal path and other sensitive paths on the substrate **4**, such as RF traces that are in communication with the radio frequency component **11**, for example.

[0137] FIG. **3** also illustrates the radio frequency component **11**, shielding structure **9** and antenna **10** without a top shielding layer in plan view. The radio frequency shielding structure **9** can shield the radio frequency component **11** from electromagnetic interference from the integrated antenna **10** and/or from other components outside of the radio frequency shielding structure **9**. Alternatively or additionally, the radio frequency shielding structure **9** can shield the antenna **10** and/or other components from electromagnetic interference from the radio frequency component **11**. Accordingly, the antenna **10** can be integrated in the packaged module **300** and the radio frequency shielding structure **9** can reduce electromagnetic interference between components of the packaged module **300**. The antenna **10** is outside of an RF shielding structure **9** around the RF component **11**. Accordingly, the antenna **10** can wirelessly receive and/or transmit RF signals without being shielded by the shielding structure around the RF component **11**. At the same time, the shielding structure **9** can provide RF isolation between the RF component **11** and the antenna **10** and the other electronic components of the radio frequency module **300**.

[0138] The RF component **11** can include any suitable circuitry configured to receive, process, and/or provide an RF signal. For instance, the RF component **11** can include an RF front end, a crystal, a system on a chip, or any combination thereof. In certain implementations, the RF component **11** can include a power amplifier, a low-noise amplifier, an RF switch, a filter, a matching network, a crystal, or any combination thereof. An RF signal can have a frequency in the range from about 30 kHz to 300 GHz. In accordance with certain communications standards, an RF signal can be in a range from about 450 MHz to about 6 GHz, in a range from about 700 MHz to about 2.5 GHz, or in a range from about 2.4 GHz to about 2.5 GHz. In certain implementations, the RF component **11** can receive and/or provide signals in accordance with a wireless personal area network (WPAN) standard, such as Bluetooth, ZigBee, Z-Wave, Wireless USB, INSTEON, IrDA, or Body Area Network. In some other implementations, the RF component and receive and/or provide signals in accordance with a wireless local area network (WLAN) standard, such as Wi-Fi.

[0139] The antenna **10** can be any suitable antenna configured to receive and/or transmit RF signals. The antenna **10** can be a folded monopole antenna in certain applications. The antenna **10** can be any suitable shape. For instance, the antenna **10** can have a meandering shape as shown in FIG. **3**. In other embodiments, the antenna can be U-shaped, coil shaped, or any other suitable shape for a particular application. The antenna **10** can transmit and/or receive RF signals associated with the RF component **11**. The antenna **10** can occupy any suitable amount of area of the packaging substrate. For instance, the antenna **10** can occupy from about 10% to 75% of the area of the package substrate in certain implementations.

[0140] The antenna **10** can be printed on the packaging substrate. A printed antenna can be formed from one or more conductive traces on the packaging substrate. The one or more conductive traces can be formed by etching a metal pattern on the packaging substrate. A printed antenna can be a microstrip antenna. Printed antennas can be manufactured relatively inexpensively and compactly due to, for example,

their 2-dimensional physical geometries. Printed antennas can have a relatively high mechanical durability.

[0141] The package substrate that includes the antenna **10** and the radio frequency component **11** can be a laminate substrate. The package substrate can include one or more routing layers, one or more insulating layers, a ground plane, or any combination thereof. In certain applications, the package substrate can include four layers. The RF component **11** can be electrically connected to the antenna **10** by way of metal routing in a routing layer of the packaging substrate **16** in certain applications.

[0142] The wire bonds are part of the RF shielding structure **9** around the RF component **11**. An RF shielding structure can be any shielding structure configured to provide suitable shielding associated with RF signals. The wire bonds can provide RF isolation between the antenna **10** and the RF component **11** so as to prevent electromagnetic interference between these components from significantly impacting performance of the antenna **10** or the RF component **11**. The wire bonds can surround the RF component **11** as illustrated. The wire bonds can be arranged around the RF component **11** in any suitable arrangement, which can be rectangular as illustrated or non-rectangular in some other implementations. In the radio frequency module **300** illustrated in FIG. **3**, the wire bonds form four walls around the RF component **11**. The wire bonds can be arranged such that adjacent wire bonds are spaced apart from each other by a distance to provide sufficient RF isolation between the RF component **11** and other electronic components.

[0143] FIG. **3**A is a cross sectional view of the portion of the radio frequency module **300** that comprises the radio frequency shielding structure **9**, the radio frequency component **11** and the antenna **10** prior to forming a shielding layer over the radio frequency component **11** according to an embodiment. Molding material **42** can be disposed over the RF component **11**, the wire bonds, and the antenna **10**. In FIG. **3**A, the RF component **11** includes two die **11**A and **11**B on a package substrate **46**. Upper portions **43** of wire bonds **58** can extend above upper surface **44** of an overmold structure of the molding material **42** that is over the wire bonds **58**. The wire bonds **58** can extend above the upper surface **44** to a top point **45** of the wire bonds **58**. The upper portions **43** of the wire bonds **58** can be exposed by removing molding material after forming an overmold structure of the molding material **42**. Having the upper portions **43** of the wire bonds **58** exposed as shown in FIG. **3**A can allow a conductive layer over the molding material **42** to be in contact with the wire bonds **58** to thereby provide an electrical connection. FIG. **3**A also illustrates vias **46** in the package substrate **56**. The wire bonds **58** can be electrically connected to a ground plane **47** of the package substrate **56** by way of the vias **46**. The wire bonds **58** can be electrically connected to a ground contact of a substrate **4** on which the module **50** is disposed by way of the vias **46**.

[0144] FIG. **3**B is a cross sectional view of the radio frequency module of FIG. **3**A with a shielding layer over the radio frequency component and not over the antenna according to an embodiment. The RF module **50'** illustrated in FIG. **3**B includes a shielding layer **52** formed over the upper surface **44** of the overmold structure over the RF component **11**. The shielding layer **52** is formed over a shielded portion of the RF module **50'** and an unshielded portion of the RF module **50'** is left unshielded opposite the package substrate **56**. As illustrated, the antenna **10** is included in the unshielded portion of the RF module **50'**. The shielding layer **52** is formed of electrically conductive material. As shown in FIG. **3**B, the shielding layer **52** is in contact with wire bonds **88**.

[0145] A shielding structure around the RF component **12** includes the shielding layer **32** and the wire bonds **18**. The shielding structure can also include vias **26** in the package substrate **16**, a ground plane **27** in the package substrate **16**, ground pads and/or a ground plane of a system board on which the RF module **10** is disposed, or any combination thereof. RF The shielding structure can function as a Faraday cage around the RF component **12**. The RF shielding structure can be configured at a ground potential. The RF shielding structure around the RF component **12** can shield the RF component **12** from signals external to the shielding structure and/or shield circuits outside of the shielding structure from the RF component **12**. The antenna **14** is external to the shielding structure in FIG. **3**.

[0146] A shielding layer, such as the shielding layer **52** of FIG. **3**B, can be formed over a portion of an RF module and a different portion of the RF module can be unshielded opposite a package substrate. Prior to forming the shielding layer over an RF module in any of the methods of forming the shielding layer discussed herein, the RF module can have molding material over an antenna and wire bonds with exposed upper portions that extend beyond of surface of an overmold structure of the molding material (e.g., as shown in FIG. **3**A. RF modules discussed herein can include a shielding layer formed by any of these methods as appropriate and/or by any suitable operations discussed with reference to any of these methods. The shielding layer can be formed over a selected portion of an RF module by an additive process or a subtractive process. The methods of forming shielding layers discussed herein can be implemented in high volume manufacturing. Such methods can be automated in an accurate and repeatable manner.

[0147] FIG. **4** comprises another embodiment of a radio frequency packaged module **400** that can be implemented in a wireless device. FIG. **4** illustrates a cross section of the radio frequency packaged module **400** that can be used in a wireless device. Radio frequency packaged module **400** includes an oscillator assembly **3**, a first integrated circuit **2** vertically integrated with the oscillator assembly **3**, and a radio frequency component **11** within a radio frequency shielding structure **9** and an antenna external **10** to the radio frequency shielding structure **9** according to an embodiment. The packaged module **400** includes a package substrate **4** that supports the first integrated circuit **2**, the oscillator assembly **3**, the radio frequency component **11**, and the antenna **10**. The oscillator assembly **3** is interposed between the first integrated circuit **2** and the package substrate **4**. FIG. **4** is not necessarily drawn to scale.

[0148] As illustrated in FIG. **4**, the packaged module **400** further includes one or more discrete components **12**, such as load capacitors, and one or more wire bonds **6**. In an embodiment, the first integrated circuit **2** is a system on a chip (SoC) and includes at least a portion of a baseband subsystem and the radio frequency component **11** is a radio frequency front end module (FEM) or front end integrated circuit (FEIC). The oscillator assembly **3** can be used to provide a clock signal for one or more of the first integrated circuit **2** and the radio frequency component **11**. The shielding structure **9** can include a shielding layer formed over the

radio frequency component **11** such that the antenna **10** is unshielded opposite the common package substrate **4**.

[0149] In the radio frequency packaged module **400**, the oscillator assembly **3** is over the substrate **4** and the SoC is stacked directly over the oscillator assembly **3**, without a routing substrate between the SoC **2** and the oscillator assembly **3**. In an embodiment, the oscillator assembly **3** is immediately adjacent to the SoC **2** and the substrate **4**. In an embodiment, the footprint of the SoC **2** is larger than the footprint of the oscillator assembly **3**, which creates an overhang volume that is bounded by the sides of the oscillator assembly **3**, the portion of the SoC **2** that extends beyond oscillator assembly **3**, and the portion of the substrate **4** that is within the footprint of the SoC **2** and not covered by the oscillator assembly **3**.

[0150] In an embodiment, the discrete components **12** and/or the front end system **11** are placed outside of the SoC footprint. In another embodiment, the discrete components **12** and/or the front end system **11** are placed between the SoC **2** and the oscillator assembly **3** within the SoC footprint. In another embodiment, the discrete components **12** and/or the front end system **11** are placed within the overhang volume.

[0151] There are several factors to consider when utilizing the overhang volume. Factors to consider include, but are not limited to the thickness of the SoC, bond wire types, an amount of pressure used to bond the bond wire to the SoC without cracking the SoC, an amount of overhang that can be supported, and the like.

[0152] FIG. **4** also illustrates the radio frequency component **11**, shielding structure **9** and antenna **10** without a top shielding layer in plan view. The radio frequency shielding structure **9** can shield the radio frequency component **11** from electromagnetic interference from the integrated antenna **10** and/or from other components outside of the radio frequency shielding structure **9**. Alternatively or additionally, the radio frequency shielding structure **9** can shield the antenna **10** and/or other components from electromagnetic interference from the radio frequency component **11**. Accordingly, the antenna **10** can be integrated in the packaged module **400** and the radio frequency shielding structure **9** can reduce electromagnetic interference between components of the packaged module **400**. The radio frequency component **11**, shielding structure **9** and antenna **10** may be implemented as described above with respect to FIGS. **3**, **3**A, and **3**B.

[0153] FIG. **5** comprises another embodiment of a radio frequency packaged module **500** that can be implemented in a wireless device. FIG. **5** illustrates a cross section of the packaged module **500** that includes a first integrated circuit **2**, and an oscillator assembly **3** vertically integrated with the first integrated circuit **2** and a radio frequency component **11** within a radio frequency shielding structure **9** and an antenna **10** external to the radio frequency shielding structure **9** according to an embodiment. FIG. **5** is not necessarily drawn to scale. The package substrate **4** supports the first integrated circuit **2** and the oscillator assembly **3** on the first side and supports the radio frequency component **11** on the second side. The oscillator assembly **3** is interposed between the package substrate **4** and the first integrated circuit **2**. The radio frequency component **11** within the radio frequency shielding structure **9** is vertically integrated with the first integrated circuit **2** and the oscillator assembly **3**.

[0154] As illustrated in FIG. **5**, the packaged module **500** further includes one or more discrete components **12**, such as load capacitors, and one or more supports **15**. In an embodiment, the first integrated circuit **2** is a system on a chip (SoC) and includes at least a portion of a baseband subsystem and the radio frequency component **11** is a radio frequency front end module (FEM) or front end integrated circuit (FEIC). The oscillator assembly **3** can be used to provide a clock signal to one or more of the first integrated circuit **2** and the radio frequency component **11**. The shielding structure **9** can include a shielding layer formed over the radio frequency component **11** such that the antenna **10** is unshielded opposite the common package substrate **4**.

[0155] In an embodiment, the footprint of the SoC **2** is larger than the footprint of the oscillator assembly **3**, which creates an overhang volume that is bounded by the sides of the oscillator assembly **3**, the portion of the SoC **2** that extends beyond oscillator assembly **3**, and the portion of the substrate **4** that is within the footprint of the SoC **2** and not covered by the oscillator assembly **3**. In an embodiment, the discrete components **12** are placed between the substrate **4** and the SoC **2** in the footprint of the SoC **2** to save space. In an embodiment, the discrete components **12** are placed in the overhang volume.

[0156] FIG. **5** also illustrates the radio frequency component **11**, shielding structure **9** and antenna **10** without a top shielding layer in plan view. The radio frequency shielding structure **9** can shield the radio frequency component **11** from electromagnetic interference from the integrated antenna **10** and/or from other components outside of the radio frequency shielding structure **9**. Alternatively or additionally, the radio frequency shielding structure **9** can shield the antenna **10** and/or other components from electromagnetic interference from the radio frequency component **11**. Accordingly, the antenna **10** can be integrated in the packaged module **500** and the radio frequency shielding structure **9** can reduce electromagnetic interference between components of the packaged module **500**. The radio frequency component **11**, shielding structure **9** and antenna **10** may be implemented as described above with respect to FIGS. **3**, **3**A, and **3**B.

[0157] FIG. **6** comprises another embodiment of a radio frequency packaged module **600** that can be implemented in a wireless device. FIG. **6** illustrates a cross section of the packaged module **600** that includes an oscillator assembly **3**, a first integrated circuit **2** vertically integrated with the oscillator assembly **3** and extending beyond a periphery of the oscillator assembly **3**, a second integrated circuit **14** vertically integrated with the oscillator assembly **3**, a radio frequency component **11** within a radio frequency shielding structure **9** that is within an overhang formed by the first integrated circuit **2**, and an antenna **10** external to the radio frequency shielding structure **9** according to an embodiment. FIG. **6** is not necessarily drawn to scale.

[0158] The package substrate **4** supports the first integrated circuit **2**, the second integrated circuit **14**, the oscillator assembly **3**, the radio frequency component **11**, and the antenna **10**. The oscillator assembly **3** is interposed between the first integrated circuit **2** and the package substrate **4** and the first integrated circuit **2** is interposed between the second integrated circuit **14** and the oscillator assembly **3**. The radio frequency component **11** within the radio frequency shielding structure **9** is supported by the package substrate **4** and is within the overhang formed by the first integrated circuit

2. In an embodiment, the antenna **10** is supported by the package substrate **4** and is outside of the overhang formed by the first integrated circuit **2**.

[0159] As illustrated in FIG. **6**, the packaged module **600** further includes one or more discrete components **13**, such as load capacitors, and one or more supports **15**. In an embodiment, the one or more discrete components **13** and the one or more supports **15** are within the overhang formed by the first integrated circuit **2** and provide support for the first integrated circuit **2**. In an embodiment, the first integrated circuit **2** is a system on a chip (SoC) and includes at least a portion of a baseband subsystem and the radio frequency component **11** is a radio frequency front end module (FEM) or front end integrated circuit (FEIC). The oscillator assembly **3** can be used to provide a clock signal to one or more of the first integrated circuit **2**, the second integrated circuit **14**, and the radio frequency component **11**. The shielding structure **9** can include a shielding layer formed over the radio frequency component **11** such that the antenna **10** is unshielded opposite the common package substrate **4**.

[0160] In an embodiment, the footprint of the SoC **2** is larger than the footprint of the oscillator assembly **3**, which creates an overhang volume that is bounded by the sides of the oscillator assembly **3**, the portion of the SoC **2** that extends beyond oscillator assembly **3**, and the portion of the substrate **4** that is within the footprint of the SoC **2** and not covered by the oscillator assembly **3**. In an embodiment, the supports **15** are placed between the substrate **4** and the SoC **2** in the footprint of the SoC **2**. In an embodiment, the radio frequency component **11** and at least a portion of the shielding structure **9** can be placed within the overhang volume.

[0161] FIG. **6** also illustrates the radio frequency component **11**, shielding structure **9**, and antenna **10** without a top shielding layer in plan view. The radio frequency shielding structure **9** can shield the radio frequency component **11** from electromagnetic interference from the integrated antenna **10** and/or from other components outside of the radio frequency shielding structure **9**. Alternatively or additionally, the radio frequency shielding structure **9** can shield the antenna **10** and/or other components from electromagnetic interference from the radio frequency component **11**. Accordingly, the antenna **10** can be integrated in the packaged module **600** and the radio frequency shielding structure **9** can reduce electromagnetic interference between components of the packaged module **600**. The radio frequency component **11**, shielding structure **9** and antenna **10** may be implemented as described above with respect to FIGS. **3**, **3**A, and **3**B.

[0162] FIG. **7** comprises another embodiment of a radio frequency packaged module **700** that can be implemented in a wireless device. FIG. **7** illustrates a cross section of the packaged module **700** that includes an oscillator assembly **3**, a first integrated circuit **2** vertically integrated with the oscillator assembly **3**, and a ground plane **21** between an antenna **18** and a radio frequency component **16** according to an embodiment. FIG. **7** is not necessarily drawn to scale.

[0163] As illustrated in FIG. **7**, the packaged module **700** further includes one or more discrete components **12**, such as load capacitors, and one or more wire bonds **6**. In an embodiment, the first integrated circuit **2** is a system on a chip (SoC) and includes at least a portion of a baseband subsystem and the radio frequency component **16** is a radio frequency front end module (FEM) or front end integrated circuit (FEIC). The oscillator assembly **3** can be used to provide a clock signal to one or more of the first integrated circuit **2** and the radio frequency component **16**. A multi-layer substrate **17** supports the first integrated circuit **2** and the oscillator assembly **3** on a first side. The oscillator assembly **3** is interposed between the first integrated circuit **2** and the multi-layer substrate **17**.

[0164] In the radio frequency packaged module **700**, the oscillator assembly **3** is over the substrate **17** and the SoC **2** is stacked directly over the oscillator assembly **3**, without a routing substrate between the SoC **2** and the oscillator assembly **3**. In an embodiment, the oscillator assembly **3** is immediately adjacent to the SoC **2** and the substrate **17**. In an embodiment, the footprint of the SoC **2** is larger than the footprint of the oscillator assembly **3**, which creates an overhang volume that is bounded by the sides of the oscillator assembly **3**, the portion of the SoC **2** that extends beyond oscillator assembly **3**, and the portion of the substrate **17** that is within the footprint of the SoC **2** and not covered by the oscillator assembly **3**.

[0165] In an embodiment, the discrete components **12** and/or the front end system **11** are placed outside of the SoC footprint. In another embodiment, the discrete components **12** are placed between the SoC **2** and the oscillator assembly **3** within the SoC footprint. In another embodiment, the discrete components **12** are placed within the overhang volume.

[0166] There are several factors to consider when utilizing the overhang volume. Factors to consider include, but are not limited to the thickness of the SoC, bond wire types, an amount of pressure used to bond the bond wire to the SoC without cracking the SoC, an amount of overhang that can be supported, and the like.

[0167] The multi-layer substrate **17** includes the ground plane **21**. The multi-layer substrate **17** supports the antenna **18** on a second side and the radio frequency component **16** on the first side. The ground plane **21** is positioned between the antenna **18** and the radio frequency component **16**. The ground plane **21** can shield the radio frequency component **16** and other components of the packaged module **700** from electromagnetic interference from the antenna **18**. Alternatively or additionally, the ground plane **21** can shield the antenna **18** from electromagnetic interference from the radio frequency component **16** and the other components of the packaged module **700**. Accordingly, the antenna **18** can be integrated in the packaged module **700** and the ground plane **21** can reduce electromagnetic interference between components of the packaged module **700**.

[0168] The packaged module **700** further includes an insulating layer **22** disposed between the antenna layer **18** and the ground plane **21**, other layers **23** (e.g., including signal routing and/or passive components), vias **20** extending from the ground plane **21** to the first side of the multi-layer substrate **17**, and solder bumps **19**. Molding material, not shown, can encapsulate the packaged module **700** and through mold vias can extend through the molding material.

[0169] The antenna **18** in FIG. **7** may comprise part of an antenna in a packaging system. The antenna in a package system includes the antenna **18** integrated with and shielded from the RF component **16**. The antenna **18** is unshielded from transmitting RF signals to and receiving RF signals from remote to the system **700**. Accordingly, the antenna **18**

can transmit and/or receive any suitable RF signal. The antenna **18** can transmit and/or receive RF signals for the system of the radio frequency packaged module **700**. In certain embodiments, the antenna **18** of the antenna in a package system can be arranged to transmit and/or receive Bluetooth and/or ZigBee signals.

[0170] The antenna in a package system includes a multi-layer substrate **17** that includes an antenna layer **18**, a ground plane **21**, an insulating layer **22**, and an other layer **23**. An RF component **16** is attached to the multi-layer substrate **17** on a side opposite the antenna layer **18**. The ground plane **21** is disposed between the antenna layer **18** and the RF component **16** such that the ground plane **21** provides shielding between the RF component **16** and the antenna layer **18**. The antenna **18** can be in communication with the RF component **16** by way of one or more wire bonds, by way of one or more vias extending through the substrate **17** outside of the shielding structure, by way of magnetic coupling, or any suitable combination thereof.

[0171] The multi-layer substrate **17** can be a laminate substrate. The insulating layer **22** can be disposed between the antenna layer **18** and the ground plane **21**. The insulating layer **22** can include any suitable dielectric material. The multi-layer substrate **17** can include one or more other layers **23**, which can implement signal routing and/or passive components. Vias **20** extending from the ground plane **21** to the bottom side of the multi-layer substrate **17** shown in FIG. **7** can provide ground connections at the bottom side of the multi-layer substrate **17**. In some implementations, each of the vias **20** can be implemented by several vias through different insulating layers connected to each other by metal in component layers disposed between insulating layers.

[0172] The RF component **16** can include any suitable circuitry configured to receive and/or provide an RF signal. For instance, the RF component **16** can include a power amplifier, a low-noise amplifier, an RF switch, a filter, a matching network, or any combination thereof. An RF signal can have a frequency in the range from about 30 kHz to 300 GHz. In accordance with certain communications standards, RF signal can be in a range from about 450 MHz to about 6 GHz, in a range from about 700 MHz to about 2.5 GHz, or in a range from about 2.4 GHz to about 2.5 GHz. In certain implementations, the RF component **16** can receive and/or provide signals in accordance with a wireless personal area network (WPAN) standard, such as Bluetooth, ZigBee, Z-Wave, Wireless USB, INSTEON, IrDA, or Body Area Network. In some other implementations, the RF component and receive and/or provide signals in accordance with a wireless local area network (WLAN) standard, such as Wi-Fi.

[0173] The antenna in a package system in FIG. **7** is illustrated without being encapsulated in molding material. In an embodiment, the RF component **16** can be encapsulated in molding material and further comprise mold vias. Through mold vias can extend through the molding material to bumps **19**. The bumps **19** can be any suitable conductive bumps, such as solder bumps, solder balls, copper pillars, or the like. The bumps **19** can facilitate mounting of the antenna in a package system onto a system board. Bumps **19** can be in physical contact with through mold vias. Accordingly, the bumps **19** can be electrically connected to the ground plane **21** by way of through mold vias and vias **20** in the multi-layer substrate **17**. While two bumps **19**, two vias **24** are illustrated in the cross section of FIG. **7**, any suitable number of such elements can be included in the antenna in a package system to provide a suitable ground connection and/or to provide suitable shielding around the RF component **16**. For instance, the bumps **19** can extend along outer edges of the antenna in a package system to surround the RF component **16** in plan view. Corresponding mold vias and vias **20** can be implemented with such bumps **19**.

[0174] FIG. **8** comprises another embodiment of a radio frequency packaged module **800** that can be implemented in a wireless device. FIG. **8** illustrates a cross section of the packaged module **800** that includes a stacked filter assembly **24** and a ground plane **21** between an antenna **18** and a radio frequency component **16** according to an embodiment. FIG. **8** is not necessarily drawn to scale.

[0175] A multi-layer substrate **17** supports the stacked filter assembly **24** and the radio frequency component **16** on a first side and the antenna **18** on a second side. The multi-layer substrate **17** includes the ground plane **21** which is positioned between the antenna **18** and the radio frequency component **16**. The ground plane **21** can shield the radio frequency component **16** and other components of the packaged module **800** from electromagnetic interference from the antenna **18**. Alternatively or additionally, the ground plane **21** can shield the antenna **18** from electromagnetic interference from the radio frequency component **16** and the other components of the packaged module **800**. Accordingly, the antenna **18** can be integrated in the packaged module **800** and the ground plane **21** can reduce electromagnetic interference between components of the packaged module **800**. The stacked filter assembly **24** can filter a signal associated with the radio frequency component **16**. In an embodiment, the stacked filter assembly **24** comprises surface mount discrete components, such as resistor, capacitors, and inductors.

[0176] In an embodiment, the radio frequency component **16** is a radio frequency front end module (FEM) or front end integrated circuit (FEIC). In an embodiment, the packaged module **800** further includes an integrated circuit that comprises at least a portion of a baseband subsystem. The packaged module **800** further includes an antenna in a package system. The antenna in a package system includes an insulating layer **22** disposed between the antenna layer **18** and the ground plane **21**, other layers **23** (e.g., including signal routing and/or passive components), vias **20** extending from the ground plane **18** to the first side of the multi-layer substrate **17**, and solder bumps **19**. Molding material, not shown, can encapsulate the packaged module **800** and through mold vias can extend through the molding material. The antenna in a package system may be implemented as described above with respect to FIG. **7**.

[0177] FIGS. **8A1**-**8D2** illustrate exemplary space saving stacking configurations and corresponding exemplary circuit diagrams for surface mount parts, components, or devices that may form at least a part of the stacked filter assembly **24**. Stacking the surface mount components to form circuits or portions of circuits saves layout space on substrates or laminates as compared to mounting each surface mount component directly onto the substrate or laminate. Further, traces are used to interconnect the surface mount components on the substrate or laminate to form at least portions of electrical circuits. The direct connection between two stacked surface mount parts eliminates at least one trace from the substrate or laminate and saves additional space. In an embodiment, the stacked surface mount components

form at least portions of filter circuits used to filter radio frequency signals. In an embodiment, the surface mount devices comprise inductors, capacitors, and resistors. In other embodiments, the surface mount components comprise active or passive surface mount devices.

[0178] FIG. **8**A**1** illustrates a surface mount stacking assembly **1210** comprising a first horizontally positioned surface mount device **1212** stacked over and immediately adjacent to a second horizontally positioned surface mount device **1214**, where the second surface mount device **1214** is over and immediately adjacent to a bottom surface **1216**. In an embodiment, the contacts of the first surface mount device **1212** are in electrical communication with respective contacts of the second surface mount device **1214**.

[0179] FIG. **8**A**2** illustrates an exemplary filter circuit **1215**. In an embodiment, the stacking configuration **1210** comprises the filter circuit **1215**. In other embodiments, other filter circuits or other circuits can be formed using the surface mount stacking assembly **1210**.

[0180] FIG. **8**B**1** illustrates a surface mount stacking assemblyl**220** comprising a first vertically oriented surface mount device **1222** stacked on end over and immediately adjacent to a second vertically oriented surface mount device **1224**. A first end of the surface mount device **1222** is in electrical communication with a first end of the second surface mount device **1224**, and a second end of the second surface mount device **1224** is over and immediately adjacent to a bottom surface **1226**. In an embodiment, the second end of the second surface mount device **1224** is in electrical communication with pads or traces on the bottom surface **1226**.

[0181] FIG. **8**B**2** illustrates an exemplary filter circuit **1225**. In an embodiment, the stacking configuration **1220** comprises the filter circuit **1225**. In other embodiments, other filter circuits or other circuits can be formed using the surface mount stacking assembly **1220**.

[0182] FIG. **8**C**1** illustrates a surface mount stacking assemblyl**230** comprising a horizontally oriented first surface mount device **1232**, a horizontally oriented second surface mount device **1234**, and a horizontally oriented third surface mount device **1238**. In an embodiment, the first surface mount device **1232** and the second surface mount device **1234** are over and immediately adjacent to a bottom surface **1236** and spaced apart such that a first end of the third surface mount device **1238** is stacked over a first end of the first surface mount device **1232** and a second end of the third surface mount device **1234** is stacked over a first end of the second surface mounted device **1234**. In an embodiment, the surface mount devices **1232**, **1234**, **1238** are electrically connected in series. In an embodiment, the stacking configuration **1230** has a smaller footprint than the footprint formed by mounting three surface mount devices on the bottom layer **1236** to form a series connection.

[0183] FIG. **8**C**2** illustrates a surface mount stacking assemblyl**240** comprising a first vertically oriented surface mount device **1242**, a second vertically oriented surface mount device **1244**, and a third horizontally oriented surface mount device **1248**. The first surface mount device **1242** is over and immediately adjacent to a bottom layer **1206** such that a first end of the first surface mount device **1242** is in electrical communication with pads or traces on the bottom layer **1246**. The second surface mount device **1244** is over and immediately adjacent to the bottom layer **1206** that a first end of the second surface mount device **1242** is in electrical communication with pads or traces on the bottom layer **1246**.

[0184] Further, the first and second surface mount devices **1242**, **1244** are spaced apart such that a first end of the third surface mount device **1248** is over and in electrical communication with a second end of the first surface mount device **1242** and a second end of the third surface mount device **1248** is over and in electrical communication with a second end of the second surface mount device **1244**.

[0185] In an embodiment, the surface mount stacking assemblies**1230**, **1240** comprises a pi (Tr) filter topology. An exemplary pi filter **1245** is illustrated in FIG. **12**C**3**. In an embodiment, the stacking configuration **1240** has a smaller footprint than the footprint formed by mounting three surface mount devices on the bottom layer **1236**, **1246** to form the pi filter.

[0186] In another embodiment, the stacking configuration **1240** can be flipped over such that surface mount device **1248** is over the bottom layer **1246**, and surface mount devices **1242** and **1244** are over surface mount device **1248**.

[0187] FIG. **8**D**1** illustrates a surface mount stacking assembly **1250** comprising a first surface mount device **1252**, a second surface mount device **1254**, a third surface mount device **1258**, and a fourth surface mount device **1260**. In a first embodiment, as illustrated in FIG. **12**E, the first, second, and third surface mount devices **1252**, **1254**, **1258** form the surface mount stacking assembly **1240** over and immediately adjacent to a bottom layer **1256**, and the fourth surface mount device **1260** is stacked over and immediately adjacent to the third surface mount device **1258**. In an embodiment, pads of the fourth surface mount device **1260** are in electrical communication with corresponding pads of the third surface mount device **1258**.

[0188] In a second embodiment, not illustrated, the first, second, and third surface mount devices **1252**, **1254**, **1258** form the surface mount stacking assembly **1240** over and immediately adjacent to the bottom layer **1256**, and the fourth surface mount device **1260** is stacked beside and immediately adjacent to the third surface mount device **1258** and also over and immediately adjacent to the first and second surface mount devices **1252**, **1254**. In an embodiment, pads of the fourth surface mount device **1260** are in electrical communication with corresponding pads of the third surface mount device **1258** and the corresponding pads of the first and second surface mount devices **1252**, **1254**.

[0189] In a third embodiment, not illustrated, the first, second, and third surface mount devices **1252**, **1254**, **1258** form the stacking configuration **1230** over and immediately adjacent to the bottom layer **1256**, and the fourth surface mount device **1260** is stacked over and immediately adjacent to the third surface mount device **1258**. In an embodiment, pads of the fourth surface mount device **1260** are in electrical communication with corresponding pads of the third surface mount device **1258**.

[0190] In a fourth embodiment, not illustrated, the first, second, and third surface mount devices **1252**, **1254**, **1258** form the surface mount stacking assembly **1230** over and immediately adjacent to the bottom layer **1256**, and the fourth surface mount device **1260** is stacked beside and immediately adjacent to the third surface mount device **1258** and also over and immediately adjacent to the first and second surface mount devices **1252**, **1254**. In an embodiment, pads of the fourth surface mount device **1260** are in

electrical communication with corresponding pads of the third surface mount device **1258** and the corresponding pads of the first and second surface mount devices **1252**, **1254**.

[0191] In a fifth embodiment, not illustrated, the surface mount stacking assembly **1250** can be flipped over such that surface mount device **1260** is over the bottom layer **1256**, surface mount device **1258** is over surface mount device **1260**, and surface mount devices **1252** and **1254** are each over a different end of surface mount device **1258**.

[0192] In an embodiment, the surface mount stacking assembly **1250** comprises a band-reject or notch filter topology that can be configured to form a notch or reject at specific frequencies. An exemplary band-reject filter circuit **1255** is illustrated in FIG. **12**D**2**. In an embodiment, a surface mount stacking assembly that comprises a first surface mount stacking assembly **1250** beside a second surface mount stacking assembly **1250** such that both the first and second surface mount stacking assemblies **1250** share surface mount device **1254** comprises a band-reject filter with a notch at two specified frequencies.

[0193] In an embodiment, the stacking configuration **1250** has a smaller footprint than the footprint formed by mounting four surface mount devices on the bottom layer **1256** to form the band-reject or notch filter topology. Since any node or pad of any of the surface mount devices **1212**, **1214**, **1222**, **1224**, **1232**, **1234**, **1238**, **1242**, **1244**, **1248**, **1252**, **1254**, **1258**, **1260** is configured for bonding, additional surface mount devices and/or various combinations of the stacking structures **1210**, **1220**, **1230**, **1240**, **1250**, for example, can be combined to create structures with more complex topology.

[0194] Surface mount devices **1212**, **1214**, **1222**, **1224**, **1232**, **1234**, **1238**, **1242**, **1244**, **1248**, **1252**, **1254**, **1258**, **1260** can be, for example, passive components, such as capacitors, resistor, and inductors, discrete semiconductors, such as transistors, diodes, and FETs, integrated circuits, and the like, and can have short pins or leads of various styles, flat contacts, a matrix of solder balls (BGAs), or terminations on the body of the component.

[0195] FIG. **9** comprises another embodiment of a radio frequency packaged module **900** that can be implemented in a wireless device. FIG. **9** illustrates a cross section of the packaged module **900** that includes an oscillator assembly **3**, a first integrated circuit **2** vertically integrated with the oscillator assembly **3** and ground plane **21** between an antenna **18** and a radio frequency component **16** according to an embodiment. FIG. **9** is not necessarily drawn to scale.

[0196] The multi-layer substrate **17** supports the first integrated circuit **2**, the oscillator assembly **3**, and the antenna **18** on a first side and supports the radio frequency component **16** on a second side. The oscillator assembly **3** is interposed between the multi-layer substrate **17** and the first integrated circuit **2**. The multi-layer substrate **17** includes the ground plane **21**, which is positioned between the antenna **18** and the radio frequency component **16**. The ground plane **21** can shield the radio frequency component **16** and other components of the packaged module **900** from electromagnetic interference from the antenna **18**. Alternatively or additionally, the ground plane **21** can shield the antenna **18** from electromagnetic interference from the radio frequency component **16** and the other components of the packaged module **900**. Accordingly, the antenna **18** can be integrated in the packaged module **900** and the ground plane **21** can reduce electromagnetic interference between components of the packaged module **900**.

[0197] As illustrated in FIG. **9**, the packaged module **900** further includes one or more discrete components **12**, such as load capacitors and one or more supports **15**. In an embodiment, the first integrated circuit **2** is a system on a chip (SoC) and includes at least a portion of a baseband subsystem and the radio frequency component **16** is a radio frequency front end module (FEM) or front end integrated circuit (FEIC). The oscillator assembly **3** can be used to provide a clock signal to one or more of the first integrated circuit **2** and the radio frequency component **16**. The stacked SoC **2**, oscillator assembly **3**, and substrate **17** including the discrete components **12** within the overhang volume may be implemented as described above with respect to FIG. **5**.

[0198] The packaged module **900** further includes an antenna in a package system. The antenna in a package system includes an insulating layer **22** disposed between the antenna layer **18** and the ground plane **21**, other layers **23** (e.g., including signal routing and/or passive components), vias **20** extending from the ground plane **18** to the first side of the multi-layer substrate **17**, and solder bumps **19**. Molding material, not shown, can encapsulate the packaged module **900** and through mold vias can extend through the molding material. The antenna in a package system may be implemented as described above with respect to FIG. **7**.

[0199] FIG. **10** comprises another embodiment of a radio frequency packaged module **1000** that can be implemented in a wireless device. FIG. **10** illustrates a cross section of the packaged module **1000** that includes an oscillator assembly **25** having conductive pillars **31** and an integrated circuit **2** vertically integrated with the oscillator assembly **25**, and a front end system **26** according to an embodiment. FIG. **10** is not necessarily drawn to scale. A package substrate **4** supports the oscillator assembly **25**, the integrated circuit **2**, and the front end system **26**. The oscillator assembly **25** is disposed between the integrated circuit **2** and the package substrate **4**.

[0200] As illustrated in FIG. **10**, the oscillator assembly **25** further includes one or more pillars **31**, a lid **32**, load capacitors **27**, a crystal **28**, oscillator circuitry **29**, and one or more filters, such as surface acoustic wave (SAW) filter **32**, disposed within a cavity formed within the oscillator assembly **25**. In an embodiment, the integrated circuit **2** is a system on a chip (SoC) and includes at least a portion of a baseband subsystem. In an embodiment, the one or more pillars **31** that are formed within and along the side of the oscillator assembly **25** are conductive and conduct one or more signals from the oscillator assembly **25** to the integrated circuit **2**. In an embodiment, the oscillator assembly **25** generates clock signals used in the front end system **26** and/or the integrated circuit **2**.

[0201] FIG. **10A1** illustrates an exemplary oscillator assembly **908** comprising an enclosure, housing or case **932** and one or more pillars **934** along one or more sides of the housing **932**. In an embodiment, the pillars or vias **934** comprise a conductive material, such as solder, metal, copper, gold, nickel gold-plated metal, and the like, and the housing **932** comprises a non-conductive material. In an embodiment, the housing **932** further comprises a lid **930**. In an embodiment, the lid **930** comprises a non-conductive material, such as ceramic, glass and epoxy, woven glass and polyester, alumina, polyimide, and the like.

[0202] The pillars or vias **934** are formed from a top surface of the housing **932** to a bottom surface of the housing **932** and provide electrical and/or thermal conduction. In an embodiment, the pillars **934** are formed at least partially within the sides of the housing **932**. In another embodiment, the housing **932** is formed with one or more tubes along one or more sides of the housing **932**, such that filling the tubes with solder forms the pillars **934**. In another embodiment, the pillars **934** are formed as cylindrical, rectangular, or the like, tubes or columns outside, partially with, or within the housing **932**.

[0203] In an embodiment, the tops and the bottoms of the pillars **934** form pads **936** around the perimeter of the housing **932**. In another embodiment, the pillars **934** are in electrical communication with the pads **936** formed along the top and bottom surfaces of the pillars **934**. In an embodiment, the pads **936** are configured as surface mount pads. In another embodiment, the pads **936** are wirebondable. In another embodiment, the pads **936** are configured to be soldered to solder balls of ball-grid array packaged integrated circuit.

[0204] In an embodiment, the lid **930** comprises a ceramic substrate material or other non-conductive material and can be configured as a routing substrate, interposer, or circuit board. As illustrated in FIG. 9**A1**, the lid **930** further comprises routing **933** and pads **935**, where the routing **933** is configured to carry a signal between the pads **935**. In an embodiment, the routing and pads are formed on the lid **930** according to routing substrate, interposer, or circuit board fabrication techniques. In an embodiment, a first wire bond **931** is bonded to a first pillar **934** and a second wire bond **931** is bonded to a second pillar **934**. Wire bonds **931** communicate a signal from one of the wire bond-connected pillars **934** through the pads **935** and trace **933** on the lid **930** to the other of the wire bond-connected pillar **934**.

[0205] FIG. **10**A**2** illustrates the oscillator assembly **908** further comprising a conductive layer **937** wrapped around four sides of the oscillator assembly **908**. The conductive layer **937** is in electrical communication with each of the pillars **934**. In an embodiment, the wrapped conductive layer **937** comprises copper, plated copper, where the plating material can be solder, tin, gold over nickel, and the like, or any other conductive material. In another embodiment, the wrapped conductive layer can be plated onto the one, two, three, or four sides of the oscillator assembly **908**, where the plating material can be solder, tin, gold over nickel, and the like.

[0206] In other embodiments, the wrapped conductive layer **937** wraps around one, two, three, or four of the sides of the oscillator assembly **908** and is in electrical communication with the pillars **934** of the one, two, three, or four of the sides, respectively. In an embodiment, the pillars **934** in electrical communication with the wrapped conductive layer **937** are connected to ground. The combination of the grounded pillars **934** and the wrapped conductive layer **937** forms a "super ground". The super ground **934**, **937** reduces inductance coupling onto the ground and provides better signal isolation.

[0207] In another embodiment, the pillars **934** in electrical communication with the wrapped conductive layer **937** form a radio frequency (RF) shield to shield the devices within the cavity of the enclosure **932** from RF interference.

[0208] In another embodiment, the pillars **934** in electrical communication with the wrapped conductive layer **937** form a heat sink to dissipate heat. For example, the pillars **934** and wrapped conductive layer **937** can dissipate heat generated by a power amplifier placed above or below the crystal assembly **908** and in thermal contact with the heat sink formed by the pillars **934** and the wrapped conductive layer **937**.

[0209] FIG. **10B1** illustrates a cross-sectional view of the exemplary oscillator assembly **908** comprising the lid **930**, the housing **932**, and one or more pillars **934**. The oscillator assembly **908** further comprises a crystal **938** housed within the housing **932**. In another embodiment, the oscillator assembly **908** further comprises one or more load capacitors **940**, oscillator circuitry **942**, and an FEIC **944** housed within the housing **932** of the oscillator assembly **908**. In a further embodiment, one or more integrated circuit die are housed within the housing **932**.

[0210] FIG. **10**B**2** illustrates a cross-sectional view of the exemplary oscillator assembly **908** comprising the lid **930**, the housing **932**, and one or more pillars **934**. The oscillator assembly **908** further comprises the crystal **938** housed within the housing **932**. In another embodiment, the oscillator assembly **908** further comprises the one or more load capacitors **940**, the oscillator circuitry **942**, and a surface acoustic wave (SAW) device **945** housed within the housing **932** of the oscillator assembly **908**. Examples of SAW devices **945** include filters, delay lines, correlators and DC to DC converters. In a further embodiment, one or more integrated circuit die are housed within the housing **932**.

[0211] The embodiment of FIG. **10**B**2** illustrates the SAW device **945**, such as a SAW filter, and the crystal **938** in the same physical cavity formed within the oscillator assembly **908**. In an embodiment, the oscillator assembly **908** is hermetically sealed. In another embodiment, the cavity is gas-filled, and the oscillator assembly is hermetically sealed. Placing the SAW device and the crystal in the same physical cavity advantageously saves space on the module.

[0212] FIG. **10**C illustrates a bottom view of the exemplary oscillator assembly **908**. In an embodiment, the oscillator assembly **908** further comprises one or more pads **952** in communication with one or more of the components **938**, **940**, **942**, **944** housed within the housing **932**.

[0213] FIG. **11** comprises another embodiment of a radio frequency packaged module **1100** that can be implemented in a wireless device. FIG. **11** illustrates a cross section of the packaged module **1100** that includes an oscillator assembly **25** having conductive pillars **31** and an integrated circuit **2** vertically integrated with the oscillator assembly **25**, a front end module or integrated circuit (FEM/FEIC) **26** according to an embodiment. FIG. **11** is not necessarily drawn to scale. A package substrate **4** supports the oscillator assembly **25**, the integrated circuit **2**, and the front end **26**. The integrated circuit **2** is disposed between the oscillator assembly **25** and the package substrate **4**.

[0214] As illustrated in FIG. **11**, the oscillator assembly **25** further includes the one or more pillars **31**, a lid **32**, load capacitors **27**, a crystal **28**, oscillator circuitry **29**, and one or more filters, such as surface acoustic wave (SAW) filter **32**, disposed within a cavity formed within the oscillator assembly **25**. In an embodiment, the integrated circuit **2** is a system on a chip (SoC) and includes at least a portion of a baseband subsystem. In an embodiment, the one or more pillars **31** are formed within and along the side of the oscillator assembly **25** and conduct one or more signals from the oscillator assembly **25** to the integrated circuit **2**. In an embodiment,

the oscillator assembly **25** generates clock signals used in the front end **26** and/or the integrated circuit **2**. Additional details of the oscillator assembly **25** are illustrated in FIGS. **10**A**1**, **10**A**2**, **10**B**1**, **10**B**2**, and **10**C.

[0215] FIG. **12** comprises another embodiment of a radio frequency packaged module **1200** that can be implemented in a wireless device. FIG. **12** illustrates a cross section of the packaged module **1200** that includes an oscillator assembly **25** having conductive pillars **31** and one or more stacked filter assemblies **24** according to an embodiment. A package substrate **4** supports the oscillator assembly **25** and the one or more stacked filter assemblies **24**. FIG. **12** is not necessarily drawn to scale.

[0216] As illustrated in FIG. **12**, the oscillator assembly **25** further includes one or more pillars **31**, a lid **32**, load capacitors **27**, a crystal **28**, oscillator circuitry **29**, and one or more filters, such as surface acoustic wave (SAW) filter **32**, disposed within a cavity formed within the oscillator assembly **25**. In an embodiment, the one or more pillars **31** formed within and along the side of the oscillator assembly **25** are conductive and conduct one or more signals from the oscillator assembly **25** to the package substrate **4**. In an embodiment, the oscillator assembly **25** generates clock signals used in the packaged module **1200**. The stacked filter assembly **24** can filter a signal associated with crystal assembly **25**. In an embodiment, the stacked filter assembly **24** comprises surface mount discrete components, such as resistor, capacitors, and inductors. In an embodiment, the stacked filter assembly **24** is described above and illustrated in FIGS. **8**A**1**, **8**A**2**, **8**B**1**, **8**B**2**, **8**C**1**, **8**C**2**, **8**D**1**, and **8**D**2**.

[0217] FIG. **13** comprises another embodiment of a radio frequency packaged module **1300** that can be implemented in a wireless device. FIG. **13** illustrates a cross section of the packaged module **1300** that includes an oscillator assembly **25** having conductive pillars **31** and a first integrated circuit **2** vertically integrated with the oscillator assembly **25** on a first side of a package substrate **4**, and a radio frequency front end integrated circuit or radio frequency front end module (FEM/FEIC) **26** vertically integrated on a second side of the package substrate **4** according to an embodiment. FIG. **13** is not necessarily drawn to scale.

[0218] The oscillator assembly **25** is interposed between the first integrated circuit **2** and the package substrate **4**. In an embodiment, the first integrated circuit **2** has a larger footprint than the oscillator assembly **25** and forms an overhang above the package substrate **4**. A support **15** is positioned within the overhang and provides support for the first integrated circuit **2** above the package substrate **4**.

[0219] As illustrated in FIG. **13**, the oscillator assembly **25** further includes one or more pillars **31**, a lid **32**, load capacitors **27**, a crystal **28**, oscillator circuitry **29**, and one or more filters, such as surface acoustic wave (SAW) filter **32**, disposed within a cavity formed within the oscillator assembly **25**. In an embodiment, the one or more pillars **31** formed within and along the sides of the oscillator assembly **25** are conductive and conduct one or more signals from the first integrated circuit **2** and/or circuitry formed on the lid **32** to the package substrate **4**. In an embodiment, the stacked filter assembly **24** is described above and illustrated in FIGS. **8**A**1**, **8**A**2**, **8**B**1**, **8**B**2**, **8**C**1**, **8**C**2**, **8**D**1**, and **8**D**2**.

[0220] In an embodiment, the integrated circuit **2** is a system on a chip (SoC) and includes at least a portion of a baseband subsystem. In an embodiment, the oscillator assembly **25** generates clock signals used in the front end **26** and/or the first integrated circuit **2**.

[0221] FIG. **14** comprises another embodiment of a radio frequency packaged module **1400** that can be implemented in a wireless device. FIG. **14** illustrates a cross section of the packaged module **1400** that includes an oscillator assembly **25** having conductive pillars **31**, a first integrated circuit **2** vertically integrated with the oscillator assembly **25**, and a radio frequency front end integrated circuit or radio frequency front end module (FEIC/FEM) **26** vertically integrated with the first integrated circuit **2** and the oscillator assembly **25** according to an embodiment. FIG. **14** is not necessarily drawn to scale.

[0222] The oscillator assembly **25** is interposed between the first integrated circuit **2** and the package substrate **4**. The first integrated circuit **2** is interposed between the front end **26** and the oscillator assembly **25**.

[0223] As illustrated in FIG. **14**, the oscillator assembly **25** further includes one or more pillars **31**, a lid **32**, load capacitors **27**, a crystal **28**, oscillator circuitry **29**, and one or more filters, such as surface acoustic wave (SAW) filter **30**, disposed within a cavity formed within the oscillator assembly **25**. In an embodiment, the one or more pillars **31** formed within and along the side of the oscillator assembly **25** are conductive and conduct one or more signals from the first integrated circuit **2** and/or circuitry formed on the lid **32** to the package substrate **4**. In an embodiment, the radio frequency package module **1400** further includes the stacked filter assembly **24** that is described above and illustrated in FIGS. **8**A**1**, **8**A**2**, **8**B**1**, **8**B**2**, **8**C**1**, **8**C**2**, **8**D**1**, and **8**D**2**.

[0224] In an embodiment, the first integrated circuit **2** is a system on a chip (SoC) and includes at least a portion of a baseband subsystem. In an embodiment, the oscillator assembly **25** generates clock signals used in the radio frequency front end **26** and/or the first integrated circuit **2**. In an embodiment, the footprint of the first integrated circuit **2** is larger than the footprint of the oscillator assembly **25** such that the first integrated circuit **2** overhangs the oscillator assembly **25**. Additional integrated circuits or discrete components or the stacked filter assembly **24** can be placed beside the oscillator assembly **25** within the overhang formed by the first integrated circuit **2**.

[0225] FIG. **15** comprises another embodiment of a radio frequency packaged module **1500** that can be implemented in a wireless device. FIG. **15** illustrates a cross section of the packaged module **1500** that includes a first integrated circuit **2**, an oscillator assembly **3** vertically integrated with the first integrated circuit **2**, a radio frequency front end integrated circuit or radio frequency front end module (FEIC/FEM) **26**, and a stacked filter assembly **24** according to an embodiment. FIG. **15** is not necessarily drawn to scale. A package substrate **4** supports the first integrated circuit **2**, the oscillator assembly **3**, the radio frequency front end **26**, and the stacked filter assembly **24**. The first integrated circuit **2** is interposed between the oscillator assembly **3** and the package substrate **4**.

[0226] As illustrated in FIG. **15**, the packaged module **1500** further includes a routing substrate or interposer **7**, one or more load capacitors **8**, and one or more wire bonds **6**. In an embodiment, the first integrated circuit **2** is a system on a chip (SoC) and includes at least a portion of a baseband subsystem. In an embodiment, the oscillator assembly **3** is use to provide clock signals to at least one of the first integrated circuit and the radio frequency front end **26**. The

stacked filter assembly **24** can filter a signal associated with the first integrated circuit **2** or the radio frequency front end **26**. In an embodiment, the stacked filter assembly **24** comprises surface mount discrete components, such as resistor, capacitors, and inductors. In an embodiment, the stacked filter assembly **24** is described above and illustrated in FIGS. **8A1**, **8A2**, **8B1**, **8B2**, **8C1**, **8C2**, **8D1**, and **8D2**.

[0227] FIG. **16** comprises another embodiment of a radio frequency packaged module **1600** that can be implemented in a wireless device. FIG. **16** illustrates a cross section of the packaged module **1600** that includes an oscillator assembly **3**, a first integrated circuit **2** vertically integrated with the oscillator assembly **3**, a radio frequency circuit **26**, and a stacked filter assembly **24** according to an embodiment. FIG. **16** is not necessarily drawn to scale. The packaged module **1600** includes a package substrate **4** that supports the first integrated circuit **2**, the oscillator assembly **3**, the radio frequency circuit **26**, and the stacked filter assembly **24**. The oscillator assembly **3** is interposed between the first integrated circuit **2** and the package substrate **4**.

[0228] As illustrated in FIG. **16**, the packaged module **1600** further includes one or more discrete components **12**, such as load capacitors, and one or more wire bonds **6**. In an embodiment, the first integrated circuit **2** is a system on a chip (SoC) and includes at least a portion of a baseband subsystem and the radio frequency circuit **26** is a radio frequency front end module (FEM) or front end integrated circuit (FEIC). The stacked filter assembly **24** can filter a signal associated with the first integrated circuit **2** or the radio frequency circuit **26**. In an embodiment, the stacked filter assembly **24** comprises surface mount discrete components, such as resistor, capacitors, and inductors. In an embodiment, the stacked filter assembly **24** is described above and illustrated in FIGS. **8A1**, **8A2**, **8B1**, **8B2**, **8C1**, **8C2**, **8D1**, and **8D2**.

[0229] FIG. **17** comprises another embodiment of a radio frequency packaged module **1700** that can be implemented in a wireless device. FIG. **17** illustrates a cross section of the packaged module **1700** that includes an oscillator assembly **3**, a first integrated circuit **2** vertically integrated with the oscillator assembly **3**, a radio frequency circuit **26** vertically integrated with the oscillator assembly **3** and the first integrated circuit **2**, and a stacked filter assembly **24**. FIG. **17** is not necessarily drawn to scale.

[0230] A package substrate **4** supports the oscillator assembly **3**, the first integrated circuit **2**, and the stacked filter assembly **24** on a first side and the radio frequency circuit **26** on a second side. The oscillator assembly **3** is interposed between the first integrated circuit **2** and the package substrate **4**.

[0231] As illustrated in FIG. **17**, the packaged module **1700** further includes one or more discrete components **12**, such as load capacitors, and one or more supports **15**. In an embodiment, the first integrated circuit **2** is a system on a chip (SoC) and includes at least a portion of a baseband subsystem and the radio frequency circuit **26** is a radio frequency front end module (FEM) or front end integrated circuit (FEIC). The oscillator assembly **3** can be used to provide a clock signal for one or more of the first integrated circuit **2** and the radio frequency circuit **26**. The stacked filter assembly **24** can filter a signal associated with the first integrated circuit **2** or the radio frequency circuit **26**. In an embodiment, the stacked filter assembly **24** comprises surface mount discrete components, such as resistor, capacitors, and inductors. In an embodiment, the stacked filter assembly **24** is described above and illustrated in FIGS. **8A1**, **8A2**, **8B1**, **8B2**, **8C1**, **8C2**, **8D1**, and **8D2**.

[0232] In an embodiment, the footprint of the first integrated circuit **2** is larger than the footprint of the oscillator assembly **3** such that at least a portion of the perimeter of the first integrated circuit **2** overhangs the oscillator assembly **3**. The support **15** provides support to the first integrated circuit **2** under the overhang and between the first integrated circuit **2** and the package substrate **4**. The one or more discrete components **12** can be placed under the overhang of the first integrated circuit **2**.

[0233] FIG. **18** comprises another embodiment of a radio frequency packaged module **1800** that can be implemented in a wireless device. FIG. **18** illustrates a cross section of the packaged module **1800** that includes an oscillator assembly **3**, a first integrated circuit **2** vertically integrated with the oscillator assembly **3**, a radio frequency circuit **26** vertically integrated with the first integrated circuit **2**, and a stacked filter assembly **24** according to an embodiment. FIG. **18** is not necessarily drawn to scale.

[0234] The oscillator assembly **3** is interposed between the first integrated circuit **2** and a package substrate **4**. The first integrated circuit **2** is interposed between the radio frequency circuit **26** and the oscillator assembly **3**. A package substrate **4** supports the oscillator assembly **3**, the first integrated circuit **2**, the radio frequency circuit **26**, and the stacked filter assembly **24**.

[0235] As illustrated in FIG. **18**, the packaged module **1800** further includes one or more one or more supports **15**. In an embodiment, the one or more supports **15** can be inactive mechanical supports or discrete components that form a portion of the circuitry in the packaged module **1800**. In an embodiment, the first integrated circuit **2** is a system on a chip (SoC) and includes at least a portion of a baseband subsystem and the radio frequency circuit **26** is a radio frequency front end module (FEM) or front end integrated circuit (FEIC). The oscillator assembly **3** can be used to provide a clock signal for one or more of the first integrated circuit **2** and the radio frequency circuit **26**. The stacked filter assembly **24** can filter a signal associated with the first integrated circuit **2** or the radio frequency circuit **26**. In an embodiment, the stacked filter assembly **24** comprises surface mount discrete components, such as resistor, capacitors, and inductors. In an embodiment, the stacked filter assembly **24** is described above and illustrated in FIGS. **8A1**, **8A2**, **8B1**, **8B2**, **8C1**, **8C2**, **8D1**, and **8D2**.

[0236] In an embodiment, the footprint of the first integrated circuit **2** is larger than the footprint of the oscillator assembly **3** such that at least a portion of the perimeter of the first integrated circuit **2** overhangs the oscillator assembly **3**. The one or more supports **15** provide support to the first integrated circuit **2** under the overhang and between the first integrated circuit **2** and the package substrate **4**.

[0237] FIG. **19** comprises another embodiment of a radio frequency packaged module **1900** for use in a wireless device. FIG. **19** illustrates a cross section of the packaged module **1900** that includes an oscillator assembly **3**, a first integrated circuit **2** vertically integrated with the oscillator assembly **3**, and a radio frequency circuit **26** vertically integrated with the oscillator assembly **3**. A package substrate **4** supports the oscillator assembly **3** and the first integrated circuit **2** on a first side and the radio frequency circuit **26** on a second side. The oscillator assembly **3** is

interposed between the first integrated circuit **2** and the package substrate **4**. FIG. **19** is not necessarily drawn to scale.

[0238] As illustrated in FIG. **19**, the packaged module **1900** further includes one or more discrete components **12**, such as load capacitors, and one or more supports **15**. In an embodiment, the first integrated circuit **2** is a system on a chip (SoC) and includes at least a portion of a baseband subsystem and the radio frequency circuit **26** is a radio frequency front end module (FEM) or front end integrated circuit (FEIC). The oscillator assembly **3** is used to provide a clock signal for one or more of the first integrated circuit **2** and the radio frequency circuit **26**. In an embodiment, the footprint of the first integrated circuit **2** is larger than the footprint of the oscillator assembly **3** such that at least a portion of the perimeter of the first integrated circuit **2** overhangs the oscillator assembly **3**. The support **15** provides support to the first integrated circuit **2** under the overhang and between the first integrated circuit **2** and the package substrate **4**. The one or more discrete components **12** can be placed under the overhang of the first integrated circuit **2**.

[0239] FIG. **20** comprises another embodiment of a radio frequency packaged module **2000** for use in a wireless device. FIG. **20** illustrates a cross section of the cross section of a packaged module **2000** that includes a first wireless device component **33**, a second wireless device component **34**, and a radio frequency circuit **26** according to an embodiment. FIG. **20** is not necessarily drawn to scale.

[0240] A package substrate **4** supports the first wireless device component **33** and the second wireless device component **34** on a first side and the radio frequency circuit **26** on a second side. The second wireless device component **34** is vertically integrated with the first wireless device component **33** and extends beyond a periphery of the first wireless device component **33**. The first wireless device component **33** is interposed between the second wireless device component **34** and the package substrate **4**. The radio frequency circuit **26** is vertically integrated with the first wireless device component **33** and the second wireless device component **34**.

[0241] As illustrated in FIG. **20**, the packaged module **2000** further includes one or more discrete components **12** and one or more supports **15**. In an embodiment, the radio frequency circuit **26** is a radio frequency front end module (FEM) or front end integrated circuit (FEIC). In an embodiment, the footprint of the second wireless device component **34** is larger than the footprint of the first wireless device component **33** such that at least a portion of the perimeter of the second wireless device component **34** overhangs the first wireless device component **33**. The one or more supports **15** provide support to the second wireless device component **34** under the overhang and between the second wireless device component **34** and the package substrate **4**. The one or more discrete components **12** can be placed under the overhang of the second wireless device component **34**.

[0242] FIG. **21** comprises another embodiment of a radio frequency packaged module **2100** for use in a wireless device. FIG. **21** illustrates a cross section of the packaged module **2100** that includes a first integrated circuit **2**, a second integrated circuit **35** vertically integrated with the first integrated circuit **2** and extending beyond a periphery of the first integrated circuit **2**, and an oscillator assembly **3** vertically integrated with the second integrated circuit **35** according to an embodiment. FIG. **21** is not necessarily drawn to scale.

[0243] A package substrate **4** supports the first integrated circuit **2**, the second integrated circuit **35**, and the oscillator assembly **3**. The second integrated circuit **35** is interposed between the first integrated circuit **2** and the oscillator assembly **3**. The first integrated circuit **2** is interposed between the second integrated circuit **35** and the package substrate **4**.

[0244] As illustrated in FIG. **21**, the packaged module **2100** further includes a routing substrate or interposer **7**, one or more load capacitors **8**, one or more wire bonds **6**, and one or more supports **15**. In an embodiment, the first integrated circuit **2** is a first system on a chip (SoC) and includes at least a portion of a baseband subsystem and the second integrated circuit **35** is second system on a chip (SoC). In an embodiment, the footprint of the second integrated circuit **35** is larger than the footprint of the first integrated circuit **2** such that at least a portion of the perimeter of the second integrated circuit **35** overhangs the first integrated circuit **2**. The support **15** provides support to the second integrated circuit **35** under the overhang and between the second integrated circuit **35** and the package substrate **4**.

[0245] FIG. **22** comprises another embodiment of a radio frequency packaged module **2200** for use in a wireless device. FIG. **22** illustrates a cross section of the packaged module **2200** that includes a first integrated circuit **2**, a second integrated circuit **35** vertically integrated with the first integrated circuit **2** and extending beyond a periphery of the first integrated circuit **2**, and an oscillator assembly **3** within the overhang formed by the second integrated circuit **35** according to an embodiment. FIG. **22** is not necessarily drawn to scale.

[0246] A package substrate **4** supports the first integrated circuit **2**, the second integrated circuit **35**, and the oscillator assembly **3**. The first integrated circuit **2** is interposed between the second integrated circuit **35** and the package substrate **4**.

[0247] As illustrated in FIG. **22**, the packaged module **2200** further includes one or more discrete components **12**, such as load capacitors, and one or more supports **15**. In an embodiment, the first integrated circuit **2** is a first system on a chip (SoC) and includes at least a portion of a baseband subsystem and the second integrated circuit **35** is second system on a chip (SoC). In an embodiment, the footprint of the second integrated circuit **35** is larger than the footprint of the first integrated circuit **2** such that at least a portion of the perimeter of the second integrated circuit **35** overhangs the first integrated circuit **2**. The one or more supports **15** provide support to the second integrated circuit **35** under the overhang and between the second integrated circuit **35** and the package substrate **4**. The oscillator assembly **3** is disposed between the second integrated circuit **35** and the substrate **4** and under the overhang formed by the second integrated circuit **35**.

[0248] FIG. **23** comprises another embodiment of a radio frequency packaged module **2300** for use in a wireless device. FIG. **23** illustrates a cross section of the packaged module **2300** that includes an oscillator assembly **25** having conductive pillars **31** and an antenna in a package component. The antenna in a package component includes a radio frequency component **36** within a radio frequency shielding structure **9**, and an antenna **10** external to the radio fre-

quency shielding structure **9** that is vertically integrated with the oscillator assembly **25** according to an embodiment. FIG. **23** is not necessarily drawn to scale.

[0249] The packaged module **2300** includes a package substrate **4** that supports the oscillator assembly **25**, the radio frequency component **36**, and the antenna **10**. The oscillator assembly **25** is interposed between the radio frequency component **36** and the package substrate **4**.

[0250] As illustrated in FIG. **23**, the oscillator assembly **25** further includes the one or more pillars **31**, a lid **32**, load capacitors **27**, a crystal **28**, oscillator circuitry **29**, and one or more filters, such as surface acoustic wave (SAW) filter **32** disposed within a cavity formed within the oscillator assembly **25**. Additional details of the oscillator assembly **25** are illustrated in FIGS. **10A1**, **10A2**, **10B1**, **10B2**, and **10C**.

[0251] In an embodiment, the radio frequency component **36** is a radio frequency front end module (FEM) or front end integrated circuit (FEIC). The shielding structure **9** can include a shielding layer formed over the radio frequency component **36** such that the antenna **10** is unshielded opposite the common package substrate **4**. In an embodiment, the oscillator assembly **25** generates clock signals used in the radio frequency component **36**.

[0252] FIG. **23** also illustrates the radio frequency component **36**, shielding structure **9**, and antenna **10** without a top shielding layer in plan view. The radio frequency shielding structure **9** can shield the radio frequency component **36** from electromagnetic interference from the integrated antenna **10** and/or from other components outside of the radio frequency shielding structure **9**. Alternatively or additionally, the radio frequency shielding structure **9** can shield the antenna **10** and/or other components from electromagnetic interference from the radio frequency component **36**.

[0253] Accordingly, the antenna **10** can be integrated in the packaged module **2300** and the radio frequency shielding structure **9** can reduce electromagnetic interference between components of the packaged module **2300**. In an embodiment, the pillars **31** formed within and along the side of the oscillator assembly are conductive and provide a ground path between the radio frequency shielding structure **9** and the package substrate **4**. The radio frequency component **36**, shielding structure **9**, and antenna **10** may be implemented as described above with respect to FIGS. **3**, **3**A, and **3**B.

[0254] FIG. **24** comprises another embodiment of a radio frequency packaged module **2400** for use in a wireless device. FIG. **24** illustrates a cross section of the packaged module **2400** that includes a stacked filter assembly **24** and an antenna in a package system. The antenna in a package system includes one or more radio frequency components **36** within a radio frequency shielding structure **9** and an antenna **10** external to the radio frequency shielding structure **9** according to an embodiment. FIG. **24** is not necessarily drawn to scale.

[0255] The radio frequency shielding structure **9** can shield the radio frequency components **36** from electromagnetic interference from the integrated antenna **10** and/or from other components outside of the radio frequency shielding structure **9**. Alternatively or additionally, the radio frequency shielding structure **9** can shield the antenna **10** and/or other components from electromagnetic interference from the radio frequency components **36**. The radio frequency component **36**, shielding structure **9** and antenna **10** may be implemented as described above with respect to FIGS. **3**, **3**A, and **3**B.

[0256] Accordingly, the antenna **10** can be integrated in the packaged module **2400** and the radio frequency shielding structure **9** can reduce electromagnetic interference between components of the packaged module **2400**. In an embodiment, the one or more radio frequency components **36** form at least a portion of a radio frequency front end integrated circuit (FEIC) or a radio frequency front end module (FEM).

[0257] A multi-layer substrate **38** supports the stacked filter assembly **24** and the radio frequency components **36**. The multi-layer substrate **38** includes the ground plane **39**. Vias **40** can electrically connect the radio frequency shielding structure **9** to the ground plane **39**. The stacked filter assembly **24** can filter a signal associated with the radio frequency components **36**. In an embodiment, the stacked filter **24** assembly comprises surface mount discrete components, such as resistor, capacitors, and inductors. In an embodiment, the stacked filter assembly **24** is described above and illustrated in FIGS. **8A1**, **8A2**, **8B1**, **8B2**, **8C1**, **8C2**, **8D1**, and **8D2**.

[0258] FIG. **25** comprises another embodiment of a radio frequency packaged module **2500** for use in a wireless device. FIG. **25** illustrates a cross section of the packaged module **2500** that includes an oscillator assembly **3** and a ground plane **21** between an antenna **18** and a radio frequency component **16** that is vertically integrated with the oscillator assembly **3** according to an embodiment. FIG. **25** is not necessarily drawn to scale.

[0259] A multi-layer substrate **17** supports the radio frequency component **16** and the oscillator assembly **3** on a first side and includes the ground plane **21** and the antenna **18** on a second side. The oscillator assembly **3** is interposed between the radio frequency component **16** and the multi-layer substrate **17**. The ground plane **21** is positioned between the antenna **18** and the radio frequency component **16**. The ground plane **21** can shield the radio frequency component **16**, the oscillator assembly **3**, and other components of the packaged module **2500** from electromagnetic interference from the antenna **18**. Alternatively or additionally, the ground plane **21** can shield the antenna **18** from electromagnetic interference from the radio frequency component **16** and the other components of the packaged module **2500**. Accordingly, the antenna **18** can be integrated in the packaged module **2500** and the ground plane **21** can reduce electromagnetic interference between components of the packaged module **2500**.

[0260] As illustrated in FIG. **25**, the packaged module **2500** further includes an insulating layer **22** disposed between the antenna layer **18** and the ground plane **21**, other layers **23** (e.g., including signal routing and/or passive components), vias **20** extending from the ground plane **21** to the first side of the multi-layer substrate **17**, and solder bumps **19**. Molding material, not shown, can encapsulate the packaged module **2500** and through mold vias can extend through the molding material. The antenna **18** may comprise a portion of an antenna in a package. Embodiments of the antenna in a package are described with respect to FIG. **7** above.

[0261] In an embodiment, the radio frequency component **16** is a radio frequency front end module (FEM) or front end integrated circuit (FEIC) and the oscillator assembly **3** is used to provide a clock signal for the radio frequency component **16**.

[0262] FIG. **26** comprises another embodiment of a radio frequency packaged module **2600** for use in a wireless

device. FIG. **26** illustrates a cross section of the packaged module **2600** that includes an oscillator assembly **25** having conductive pillars **31** and a ground plane **21** between an antenna **18** and a radio frequency component **16** that is vertically integrated with the oscillator assembly **25** according to an embodiment. FIG. **26** is not necessarily drawn to scale.

[0263] A multi-layer substrate **17** supports the radio frequency component **16** and the oscillator assembly **25** on a first side and includes the ground plane **21** and the antenna **18** on a second side. The oscillator assembly **25** is interposed between the radio frequency component **16** and the multi-layer substrate **17**. The ground plane **21** is positioned between the antenna **18** and the radio frequency component **16**. The ground plane **21** can shield the radio frequency component **16** and other components of the packaged module **2600** from electromagnetic interference from the antenna **18**. Alternatively or additionally, the ground plane **21** can shield the antenna **18** from electromagnetic interference from the radio frequency component **16** and the other components of the packaged module **2600**. Accordingly, the antenna **18** can be integrated in the packaged module **2600** and the ground plane **21** can reduce electromagnetic interference between components of the packaged module **2600**. The antenna **18** may comprise a portion of an antenna in a package. Embodiments of the antenna in a package are described with respect to FIG. **7** above.

[0264] As illustrated in FIG. **26**, the packaged module **2600** further includes an insulating layer **22** disposed between the antenna layer **18** and the ground plane **21**, other layers **23** (e.g., including signal routing and/or passive components), vias **20** extending from the ground plane **21** to the first side of the multi-layer substrate **17**, and solder bumps **19**. Molding material, not shown, can encapsulate the packaged module **2600** and through mold vias can extend through the molding material. In an embodiment, the radio frequency component **16** is a radio frequency front end module (FEM) or front end integrated circuit (FEIC).

[0265] The oscillator assembly **25** further includes the one or more pillars **31**, a lid **32**, load capacitors **27**, a crystal **28**, oscillator circuitry **29**, and one or more filters, such as surface acoustic wave (SAW) filter **32**, disposed within a cavity formed within the oscillator assembly **25**. Additional details of the oscillator assembly **25** are illustrated in FIGS. **10**A**1**, **10**A**2**, **10**B**1**, **10**B**2**, and **10**C.

[0266] In an embodiment, the oscillator assembly **25** provides a clock signal for use with the radio frequency component **16**. In an embodiment, the one or more conductive pillars **31** are in electrical communication with the vias **20** and the solder balls **19** to provide a ground path from the ground plane **21** to the solder balls **19**.

[0267] FIG. **27** comprises another embodiment of a radio frequency packaged module **2700** for use in a wireless device. FIG. **27** illustrates a cross section of the cross section of a packaged module **2700** that includes a ground plane **21** between an antenna **18** and a radio frequency component **16**, and a first integrated circuit **2** that is vertically integrated with the radio frequency component **16** according to an embodiment. FIG. **27** is not necessarily drawn to scale.

[0268] A multi-layer substrate **17** supports the radio frequency component **16** and the first integrated circuit **2** on a first side and includes the ground plane **21** and the antenna **18** on a second side. The radio frequency component **16** is interposed between the first integrated circuit **2** and the multi-layer substrate **17**. The ground plane **21** is positioned between the antenna **18** and the radio frequency component **16**. The antenna **18** may form a part of an antenna in a package system. Embodiments of an antenna in a package system are described above with respect to FIG. **7**.

[0269] The ground plane **21** can shield the radio frequency component **16**, the first integrated circuit **2**, and other components of the packaged module **2700** from electromagnetic interference from the antenna **18**. Alternatively or additionally, the ground plane **21** can shield the antenna **18** from electromagnetic interference from the radio frequency component **16**, the first integrated circuit **2**, and the other components of the packaged module **2700**. Accordingly, the antenna **18** can be integrated in the packaged module **2700** and the ground plane **21** can reduce electromagnetic interference between components of the packaged module **2700**.

[0270] As illustrated in FIG. **27**, the packaged module **2700** further includes an insulating layer **22** disposed between the antenna layer **18** and the ground plane **21**, other layers **23** (e.g., including signal routing and/or passive components), vias **20** extending from the ground plane **21** to the first side of the multi-layer substrate **17**, and solder bumps **19**. Molding material, not shown, can encapsulate the packaged module **2600** and through mold vias can extend through the molding material. In an embodiment, the radio frequency component **16** is a radio frequency front end module (FEM) or front end integrated circuit (FEIC) and the first integrated circuit is a system on a chip (SoC) and includes at least a portion of a baseband subsystem. The solder balls **19** are shown soldered to corresponding pads on the first integrated circuit **2**. In an embodiment, the footprint of the first integrated circuit **2** is greater than the footprint of the radio frequency component **16** such that a periphery of the first integrated circuit **2** extends over the radio frequency component **16** to provide an overhang. Additional componentry can be placed between the first integrated circuit **2** and the multi-layer substrate **17** within the overhang and supported by the multi-layer substrate **17**.

Wireless Communication Devices

[0271] FIG. **28**A is a schematic diagram of one example of a wireless communication device **650**. The wireless communication device **650** includes a first antenna **641**, a wireless personal area network (WPAN) system **651**, a transceiver **652**, a processor **653**, a memory **654**, a power management block **655**, a second antenna **656**, and a front end system **657**.

[0272] Any of the suitable combination of features disclosed herein can be implemented in the wireless communication device **650**. For example, the WPAN system **651** and/or the front end system **657** can be implemented in a radio frequency module using any of the features described above and/or in the sections below.

[0273] The WPAN system **651** is a front end system configured for processing radio frequency signals associated with personal area networks (PANs). The WPAN system **651** can be configured to transmit and receive signals associated with one or more WPAN communication standards, such as signals associated with one or more of Bluetooth, ZigBee, Z-Wave, Wireless USB, INSTEON, IrDA, or Body Area Network. In another embodiment, a wireless communication device can include a wireless local area network (WLAN) system in place of the illustrated WPAN system, and the WLAN system can process Wi-Fi signals.

[0274] FIG. **28**B is a schematic diagram of another example of a wireless communication device **660**. The illustrated wireless communication device **660** of FIG. **39**B is a device configured to communicate over a PAN. This wireless communication device **660** can be relatively less complex than the wireless communication device **650** of FIG. **28**A. As illustrated, the wireless communication device **660** includes an antenna **641**, a WPAN system **651**, a transceiver **662**, a processor **653**, and a memory **654**. The WPAN system **660** can include any suitable combination of features disclosed herein. For example, the WPAN system **651** can be implemented in a radio frequency module using any of the features described above and/or in the sections below.

[0275] FIG. **29**A is a schematic diagram of another example of a wireless communication device **810**. The wireless communication device **810** includes a baseband system **801**, a transceiver **802**, a front-end system **803**, one or more antennas **804**, a power management system **805**, a memory **806**, a user interface **807**, and a battery **808**.

[0276] The wireless communication device **810** can be used communicate using a wide variety of communications technologies, including, but not limited to, 2G, 3G, 4G (including LTE, LTE-Advanced, and LTE-Advanced Pro), 5G, WLAN (for instance, Wi-Fi), WPAN (for instance, Bluetooth and ZigBee), WMAN (for instance, WiMAX), and/or GPS technologies.

[0277] The transceiver **802** generates RF signals for transmission and processes incoming RF signals received from the antennas **804**. It will be understood that various functionalities associated with the transmission and receiving of RF signals can be achieved by one or more components that are collectively represented in FIG. **29**A as the transceiver **802**. In one example, separate components (for instance, separate circuits or dies) can be provided for handling certain types of RF signals.

[0278] The front-end system **803** aids in conditioning signals transmitted to and/or received from the antennas **804**. In the illustrated embodiment, the front-end system **803** includes one or more power amplifiers (PAs) **811**, one or more low noise amplifiers (LNAs) **812**, one or more filters **813**, one or more switches **814**, and one or more duplexers **815**. However, other implementations are possible.

[0279] For example, the front-end system **803** can provide a number of functionalities, including, but not limited to, amplifying signals for transmission, amplifying received signals, filtering signals, switching between different bands, switching between different power modes, switching between transmission and receiving modes, duplexing of signals, multiplexing of signals (for instance, diplexing or triplexing), or some combination thereof.

[0280] Any of the suitable combination of features disclosed herein can be implemented in the wireless communication device **810**. For example, the front end system **803** can be implemented in a radio frequency module using any of the features described above and/or in the sections below.

[0281] In certain implementations, the wireless communication device **810** supports carrier aggregation, thereby providing flexibility to increase peak data rates. Carrier aggregation can be used for both Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD), and may be used to aggregate a plurality of carriers or channels. Carrier aggregation includes contiguous aggregation, in which contiguous carriers within the same operating frequency band are aggregated. Carrier aggregation can also be non-contiguous, and can include carriers separated in frequency within a common band or in different bands.

[0282] The antennas **804** can include antennas used for a wide variety of types of communications. For example, the antennas **804** can include antennas for transmitting and/or receiving signals associated with a wide variety of frequencies and communications standards.

[0283] In certain implementations, the antennas **804** support MIMO communications and/or switched diversity communications. For example, MIMO communications use multiple antennas for communicating multiple data streams over a single radio frequency channel. MIMO communications benefit from higher signal to noise ratio, improved coding, and/or reduced signal interference due to spatial multiplexing differences of the radio environment. Switched diversity refers to communications in which a particular antenna is selected for operation at a particular time. For example, a switch can be used to select a particular antenna from a group of antennas based on a variety of factors, such as an observed bit error rate and/or a signal strength indicator.

[0284] The wireless communication device **810** can operate with beamforming in certain implementations. For example, the front-end system **803** can include phase shifters having variable phase controlled by the transceiver **802**. Additionally, the phase shifters are controlled to provide beam formation and directivity for transmission and/or reception of signals using the antennas **804**. For example, in the context of signal transmission, the phases of the transmit signals provided to the antennas **804** are controlled such that radiated signals from the antennas **804** combine using constructive and destructive interference to generate an aggregate transmit signal exhibiting beam-like qualities with more signal strength propagating in a given direction. In the context of signal reception, the phases are controlled such that more signal energy is received when the signal is arriving to the antennas **804** from a particular direction. In certain implementations, the antennas **804** include one or more arrays of antenna elements to enhance beamforming.

[0285] The baseband system **801** is coupled to the user interface **807** to facilitate processing of various user input and output (I/O), such as voice and data. The baseband system **801** provides the transceiver **802** with digital representations of transmit signals, which the transceiver **802** processes to generate RF signals for transmission. The baseband system **801** also processes digital representations of received signals provided by the transceiver **802**. As shown in FIG. **39**C, the baseband system **801** is coupled to the memory **806** of facilitate operation of the wireless communication device **810**.

[0286] The memory **806** can be used for a wide variety of purposes, such as storing data and/or instructions to facilitate the operation of the wireless communication device **810** and/or to provide storage of user information.

[0287] The power management system **805** provides a number of power management functions of the wireless communication device **810**. In certain implementations, the power management system **805** includes a PA supply control circuit that controls the supply voltages of the power amplifiers **811**. For example, the power management system **805** can be configured to change the supply voltage(s) provided to one or more of the power amplifiers **811** to improve efficiency, such as power added efficiency (PAE).

[0288] As shown in FIG. **29**A, the power management system **805** receives a battery voltage from the battery **808**. The battery **808** can be any suitable battery for use in the wireless communication device **810**, including, for example, a lithium-ion battery.

[0289] FIG. **29**B illustrates an example of a system board assembly for use in wireless devices, such as, but not limited to, wireless device **650**, **660**, **810** and **4000**. Any suitable principles and advantages associated with these system board assemblies can be implemented with any of the RF modules discussed herein. FIG. **29**B illustrates a system board assembly **2240** with RF module **2210** and other component(s) **2242** disposed on a system board **2244** according to an embodiment. The system board **2244** can be any suitable application board, such as a phone board for a mobile phone. The RF module **2210** can be, but not limited to the RF modules**100**, **200**, **300**, **400**, **500**, **600**, **700**, **800**, **900**, **1000**, **1100**, **1200**, **1300**, **1400**, **1500**, **1600**, **1700**, **1800**, **1900**, **2000**, **2100**, **2200**, **2300**, **2400**, **2500**, **2600**, and **2700**. The other component(s) **2242** can include any other circuitry on the system board **2244**, such as other RF circuitry, a baseband processor, memory, load capacitors associated with a crystal, pre-filters, post filters modulators, demodulators, down converters, the like, or any suitable combination thereof. The system board assembly **2240** further includes connectivity to provide signal interconnections, packaging, such as for example, an overmold, and the like.

[0290] FIG. **30** is an example block diagram illustrating a wireless device **4000** including a SiP **4100**, where the SiP **4100** includes a SoC **4102**, an FEIC **4104**, and a crystal **4108**. In an embodiment, the wireless device **4000** includes a portable transceiver **4000**. In an embodiment, SoC **4102** includes a baseband subsystem **4010**, receiver **4070**, and transmitter **4050**. The crystal **4108** supplies clock information for the SoC **4102**. In an embodiment, SiP **4100** includes any suitable features of one or more of the SiPs **200**, **300**, **400**, **500**, **600**, **700**, **800**, **900**, **1000**, **1100**, **1200**, **1300**, **1400**, **1500**, **1600**, **1700**, **1800**, **1900**, **2000**, **2100**, **2200**, **2300**, **2400**, **2500**, **2600** or **2700**.

[0291] The illustrated wireless device **4000** includes a speaker **4002**, a display **4004**, a keyboard **4006**, and a microphone **4008**, all connected to the baseband subsystem **4010**. A power source **4042**, which may be a direct current (DC) battery or other power source, is also connected to the baseband subsystem **4010** to provide power to the wireless device **4000**. In a particular embodiment, wireless device **4000** can be, for example but not limited to, a portable telecommunication device such as a mobile cellular telephone. The speaker **4002** and the display **4004** receive signals from baseband subsystem **4010**. Similarly, the keyboard **4006** and the microphone **4008** supply signals to the baseband subsystem **4010**. The keyboard **4006** can be implemented by a touch screen displayed by the display **4004** in certain implementations.

[0292] The baseband subsystem **4010** includes a microprocessor (μP) **4020**, memory **4022**, analog circuitry **4024**, and a digital signal processor (DSP) **4026** in communication by way of bus **4028**. Bus **4028**, although shown as a single bus, may be implemented using multiple buses connected as desired among the subsystems within the baseband subsystem **4010**. The baseband subsystem **4010** may also include one or more of an application specific integrated circuit (ASIC) **4032** or a field programmable gate array (FPGA) **4030**.

[0293] The microprocessor **4020** and memory **4022** provide the signal timing, processing, and storage functions for wireless device **4000**. The analog circuitry **4024** provides the analog processing functions for the signals within baseband subsystem **4010**. In FIG. **107**, the baseband subsystem **4010** provides control signals to a transmitter **4050**, a receiver **4070**, and a power amplifier circuit **4080**.

[0294] A wireless device can include more or fewer components than illustrated in FIG. **30**. The control signals provided by the baseband subsystem **4010** control the various components within the wireless device **4000**. The function of the transmitter **4050** and the receiver **4070** may be integrated into a transceiver.

[0295] The illustrated baseband subsystem **4010** also includes an analog-to-digital converter (ADC) **4034** and digital-to-analog converters (DACs) **4036** and **4038**. In this example, the DAC **4036** generates in-phase (I) and quadrature-phase (Q) signals provided to signal lines **4040** connected to a modulator **4052**. The ADC **4034**, the DAC **4036**, and the DAC **4038** also communicate with the microprocessor **4020**, the memory **4022**, the analog circuitry **4024**, and the DSP **4026** by way of bus **4028**. The DAC **4036** converts the digital communication information within baseband subsystem **4010** into an analog signal for transmission to the modulator **4052** by way of connection **4040**. Connection **4040**, while shown as two directed arrows, carries the information that is to be transmitted by the transmitter **4050** after conversion from the digital domain to the analog domain.

[0296] The transmitter **4050** includes the modulator **4052**, which modulates the analog information on connection **4040** and provides a modulated signal to upconverter **4054**. The upconverter **4054** transforms the modulated signal to an appropriate transmit frequency and provides the upconverted signal to the power amplifier circuit **4080**. The power amplifier circuit **4080** amplifies the signal to an appropriate power level for the system in which the wireless device **4000** is designed to operate.

[0297] The data on connection **4040** is generally formatted by the baseband subsystem **4010** into in-phase (I) and quadrature (Q) components. The I and Q components may take different forms and be formatted differently depending upon the communication standard being employed.

[0298] The front-end module **4104** includes the power amplifier (PA) circuit **4080** and a switch/low noise amplifier (LNA) circuit **4072** including a low noise amplifier. In an embodiment, the switch/low noise amplifier circuit **4072** further includes an antenna system interface that may include, for example, a diplexer (or a duplexer) having a filter pair that allows simultaneous passage of both transmit signals and receive signals.

[0299] The power amplifier circuit **4080** supplies the amplified transmit signal to the switch/low noise amplifier circuit **4072**. The amplified transmit signal is supplied from the front-end module **4004** to the antenna **4060** when the switch is in the transmit mode.

[0300] A signal received by antenna **4060** will be provided from the switch/low noise amplifier circuit **4072** of the front-end module **4004** to the receiver **4070** when the switch is in the receive mode. The low noise amplifier amplifies the received signal.

[0301] If implemented using a direct conversion receiver (DCR), the downconverter **4074** converts the amplified received signal from an RF level to a baseband level (e.g.,

to a direct current (DC) level), or a near-baseband level (e.g., approximately 100 kHz). Alternatively, the amplified received RF signal may be downconverted to an intermediate frequency (IF) signal in certain applications. The downconverted signal is provided to the filter **4076**. The filter **4076** includes at least one filter stage to filter the received downconverted signal.

[0302] The filtered signal is sent from the filter **4076** to the demodulator **4078**. The demodulator **4078** recovers the transmitted analog information and supplies a signal representing this information by way of connection **4086** to the ADC **4034**. The ADC **4034** converts the analog information to a digital signal at baseband frequency and the signal propagates by way of bus **4028** to the DSP **4026** for further processing.

[0303] Many other variations of radio frequency modules than those described herein will be apparent from this disclosure. Different combinations of the components illustrated in SiPs **200**, **300**, **400**, **500**, **600**, **700**, **800**, **900**, **1000**, **1100**, **1200**, **1300**, **1400**, **1500**, **1600**, **1700**, **1800**, **1900**, **2000**, **2100**, **2200**, **2300**, **2400**, **2500**, **2600** or **2700** are possible to form a variety of SiPs that can be used in wireless devices to provide smaller footprints, reduced parasitic capacitance, decreased signal cross-coupling, the like, or any combination thereof.

Internet of Things Applications

[0304] One example application of the radio frequency modules herein is to enable various objects with wireless connectivity, such as for Internet of things (IoT). IoT refers to a network of objects or things, such as devices, vehicles, and/or other items that are embedded with electronics that enable the objects to collect and exchange data (for instance, machine-to-machine communications) and/or to be remotely sensed and/or controlled. The front end systems, embodied in radio frequency modules herein, can be used to enable wireless connectivity of various objects, thereby allowing such objects to communicate in an IoT network. The radio frequency modules discussed herein can be implemented in IoT applications to enable wireless connectivity to expand the way consumers manage information and their environment. Such radio frequency modules can enable the new and emerging IoT applications, which can bring people and things closer to vital information wherever it is desired. Although IoT is one example application of radio frequency modules herein, the teachings herein are applicable to a wide range of technologies and applications. Some example IoT applications will now be discussed.

[0305] IoT devices can be implemented in automotive systems. From telematics to infotainment systems, lighting, remote keyless entry, collision avoidance platforms, toll transponders, video displays, vehicle tracking tools, and the like, front end systems in accordance with any suitable principles and advantages discussed herein can help enable convenience and safety features for the connected vehicle.

[0306] IoT devices can be implemented in connected home environments. Front end systems in accordance with any suitable principles and advantages discussed herein can allow homeowners greater control over their home environment. IoT devices can be implemented in a host of devices including smart thermostats, security systems, sensors, light switches, smoke and carbon monoxide alarms, routers, high definition televisions, gaming consoles and much more.

[0307] IoT devices can be implemented in industrial contexts. From smart city applications to factory automation, building controls, commercial aircraft, vehicle tracking, smart metering, LED lighting, security cameras, and smart agriculture functions, front ends systems in accordance with any suitable principles and advantages discussed herein can enable these applications and meet specifications.

[0308] IoT devices can be implemented in machine-to-machine contexts. IoT devices can enable machine-to-machine communications that can transform the way organizations do business. From manufacturing automation to telemetry, remote control devices, and asset management, radio frequency modules discussed herein can provide cellular, short-range, and global positioning solutions that support a wide range of machine-to-machine applications.

[0309] IoT devices can be implemented in medical applications. radio frequency modules in accordance with any suitable principles and advantages discussed herein can enable medical devices and the communication of information that is improving the care of millions of people worldwide. Radio frequency modules in accordance with any suitable principles and advantages discussed herein can be integrated into product designs that enable the miniaturization of medical devices and enhance data transmission.

[0310] IoT devices can be implemented in mobile devices. The communication landscape has changed in recent years as consumers increasingly seek to be connected everywhere and all the time. Radio frequency modules in accordance with any suitable principles and advantages discussed herein can be compact, energy and cost efficient, meeting size and performance constraints, while enabling a great consumer experience. Wireless mobile devices, such as smartphones, tablets and WLAN systems, can include a radio frequency module in accordance with any suitable principles and advantages discussed herein.

[0311] IoT devices can be implemented in smart energy applications. Utility companies are modernizing their systems using computer-based remote control and automation that involves two-way communication. Some benefits to utilities and consumers include optimized energy efficiency, leveling and load balancing on the smart grid. Radio frequency modules in accordance with any suitable principles and advantages discussed herein can be implemented in smart meters, smart thermostats, in-home displays, ZigBee/802.15.4, Bluetooth, and Bluetooth low energy applications.

[0312] IoT devices can be implemented in wearable devices. Wearable devices, such as smartwatches, smart eyewear, fitness trackers and health monitors, can include radio frequency modules in accordance with any suitable principles and advantages discussed herein to enable relatively small form factor solutions that consume relatively low power and enable always on connectivity. This can allow applications to run in the background for lengthy periods of time without a battery recharge, for example.

[0313] Any suitable principles and advantages discussed herein can implemented in an IoT network, IoT object, a vehicle, industrial equipment, a corresponding front end system, a corresponding radio frequency module, a corresponding circuit board, the like, or any suitable combination thereof. Some examples will now be discussed.

[0314] FIG. **31** is a schematic diagram of one example of an IoT network **210**. The IoT network **210** includes a smart home **201**, a smart vehicle **202**, a wearable **203**, a mobile device **204**, a base station **205**, a smart hospital **206**, a smart

factory **207**, and a smart satellite **208**. One or more of the IoT-enabled objects of FIG. **31** can include a radio frequency module including a front end system, such as a front end module and/or front-end integrated circuit, implemented in accordance with the teachings herein.

[0315] The smart home **201** is depicted as including a wide variety of IoT-enabled objects, including an IoT-enabled router **211**, an IoT-enabled thermostat **212**, an IoT-enabled meter **213**, IoT-enabled laptop **214**, and an IoT-enabled television **215**. Although various examples of IoT-enable objects for a smart home are shown, a smart home can include a wide variety of IoT-enabled objects. Examples of such IoT-enabled objects include, but are not limited to, an IoT-enabled computer, an IoT-enabled laptop, an IoT-enabled tablet, an IoT-enabled computer monitor, an IoT-enabled television, an IoT-enabled media system, an IoT-enabled gaming system, an IoT-enabled camcorder, an IoT-enabled camera, an IoT-enabled modem, an IoT-enabled router, an IoT-enabled kitchen appliance, an IoT-enabled telephone, an IoT-enabled air conditioner, an IoT-enabled washer, an IoT-enabled dryer, an IoT-enabled copier, an IoT-enabled facsimile machine, an IoT-enabled scanner, an IoT-enabled printer, an IoT-enabled scale, an IoT-enabled home assistant (for instance, a voice-controlled assistant device), an IoT-enabled security system, an IoT-enabled thermostat, an IoT-enabled smoke detector, an IoT-enabled garage door, an IoT-enabled lock, an IoT-enabled sprinkler, an IoT-enabled water heater, and/or an IoT-enabled light.

[0316] As shown in FIG. **31**, the smart vehicle **202** also operates in the IoT network **200**. The smart vehicle **202** can include a wide variety of IoT-enabled objects, including, but not limited to, an IoT-enabled infotainment system, an IoT-enabled lighting system, an IoT-enabled temperature control system, an IoT-enabled lock, an IoT-enabled ignition, an IoT-enabled collision avoidance system, an IoT-enabled toll transponder, and/or an IoT-enabled vehicle tracking system. In certain implementations, the smart vehicle **202** can communicate with other smart vehicles to thereby provide vehicle-to-vehicle (V2V) communications. Furthermore, in certain implementations the smart vehicle **202** can operate using vehicle-to-everything (V2X) communications, thereby communicating with traffic lights, toll gates, and/or other IoT-enabled objects.

[0317] The wearable **203** of FIG. **31** is also IoT-enabled. Examples of IoT-enabled wearables include, but are not limited to, an IoT-enabled watch, an IoT-enabled eyewear, an IoT-enabled fitness tracker, and/or an IoT-enabled biometric device.

[0318] The IoT network **210** also includes the mobile device **204** and base station **205**. Thus, in certain implementations user equipment (UE) and/or base stations of a cellular network can operate in an IoT network and be IoT-enabled. Furthermore, a wide variety of IoT-enabled objects can communication using existing network infrastructure, such as cellular infrastructure.

[0319] With continuing reference to FIG. **31**, IoT is not only applicable to consumer devices and objects, but also to other applications, such as medical, commercial, industrial, aerospace, and/or defense applications. For example, the smart hospital **206** can include a wide variety of IoT-enabled medical equipment and/or the smart factory **207** can include a wide variety of IoT-enabled industrial equipment. Furthermore, airplanes, satellites, and/or aerospace equipment can also be connected to an IoT network. Other examples of IoT applications include, but are not limited to, asset tracking, fleet management, digital signage, smart vending, environmental monitoring, city infrastructure (for instance, smart street lighting), toll collection, and/or point-of-sale.

[0320] Although various examples of IoT-enabled objects are illustrated in FIG. **31**, an IoT network can include a wide variety of types of objects. Furthermore, any number of such objects can be present in an IoT network. For instance, an IoT network can include millions or billions of IoT-enable objects or things.

[0321] IoT-enabled objects can communicate using a wide variety of communication technologies, including, but not limited to, Bluetooth, ZigBee, Z-Wave, 6LowPAN, Thread, Wi-Fi, NFC, Sigfox, Neul, and/or LoRaWAN technologies. Furthermore, certain IoT-enabled objects can communicate using cellular infrastructure, for instance, using 2G, 3G, 4G (including LTE, LTE-Advanced, and/or LTE-Advanced Pro), and/or 5G technologies.

[0322] FIG. **32**A is a schematic diagram of one example of an IoT-enabled watch **310**. The IoT-enabled watch **310** illustrates one example of a smart wearable that can include a radio frequency module implemented in accordance with one or more features disclosed herein.

[0323] FIG. **32**B is a schematic diagram of one example of a front end system **301** for an IoT-enabled object, such as the IoT-enabled watch **310** of FIG. **32**A. The front end system **301** includes a first transceiver-side switch **303**, a second transceiver-side switch **304**, a first antenna-side switch **305**, a second antenna-side switch **306**, a first power amplifier **307**, a second power amplifier **308**, a duplexer **311**, a directional coupler **312**, a termination impedance **313**, a first band selection filter **315**, a second band selection filter **316**, and a third band selection filter **317**.

[0324] In the illustrated embodiment, the first transceiver-side switch **303** selects between a Band 26 transmit input pin (B26 TX IN) and a Band 13 transmit input pin (B13 TX IN). The second transceiver-side switch **303** controls connection of the output of the first power amplifier **307** to the first band selection filter **315** or the first band selection filter **316**. Thus, the first power amplifier **307** selectively amplifies Band 26 or Band 13, in this example. Additionally, the second power amplifier **308** amplifies a Band 12 transmit input pin (B12 TX IN). After suitable filtering by the band selection filters **315-317**, the second antenna-side switch **306** selects a desired transmit signal for providing to an antenna pin (ANT) via the duplexer **311** and the directional coupler **312**. As shown in FIG. **32**B, the directional coupler **312** is terminated by the termination impedance **313**. Additionally, the first antenna-side switch **305** provides a signal received on the antenna pin (ANT) to a desired receive output pin (four in this example) of the front end system **301**. The illustrated front end system **301** also includes various additional pins to provide additional functionality, such as enhanced monitoring of transmit power. For instance, front end system **301** includes a directional coupler output pin (CPL), and feedback pins (B12 RX, B13 RX, and B26 RX) for providing feedback signals associated with transmit signals (for Band 12, Band 13, and Band 26, respectively) generated by the power amplifiers.

[0325] The front end system **301** can be implemented in a radio frequency module that can incorporate one or more features described in the sections herein.

[0326] FIG. **33**A is a schematic diagram of one example of IoT-enabled vehicles **321***a*-**321***d*. Each of the IoT-enabled

vehicles **321***a*-**321***d* includes a radio frequency module for enabling wireless vehicle-to-vehicle communications. The IoT-enabled vehicles **321***a*-**321***d* can include a radio frequency module implemented in accordance with one or more features disclosed herein.

[0327] FIG. **33**B is a schematic diagram of another example of a front end system **325** for an IoT-enabled object. The front end system **325** includes an antenna-side switch **331**, a bypass switch **332**, an LNA **333**, and a bias and logic circuit **334**.

[0328] The front end system **325** includes control pins (C**0** and C**1**) for controlling the front end system **325** and a supply voltage pin (VDD) for powering the front end system **325**. The antenna-side switch **331** selectively connects an antenna pin (ANT) to a transmit signal pin (TX_IN) or a receive signal pin (RX_OUT). The LNA **333** includes an input connected to an LNA input pin (LNA_IN) and an output connected to the LNA output pin (LNA_OUT). The LNA **333** is selectively bypassed by the bypass switch **332**. Using external conductors and components, the LNA input pin (LNA_IN) can be connected to the receive signal pin (RX_OUT) either directly or indirectly (for instance, via a filter or other components). Furthermore, an external power amplifier can provide a transmit signal to the transmit signal pin (TX_IN).

[0329] The front end system **325** can be implemented in a radio frequency module that can incorporate one or more features described in the sections herein.

[0330] FIG. **34**A is a schematic diagram of one example of IoT-enabled industrial equipment **340**. In the illustrated embodiment, the IoT-enabled industrial equipment **340** includes heliostats **341** for reflecting light to a solar receiver and turbine **342**. The IoT-enabled industrial equipment **340** can include one or more radio frequency modules for a variety of purposes, such as providing angular positional control of the heliostats **341** to control concentration of solar energy directed toward the solar receiver and turbine **342**. The IoT-enabled industrial equipment **340** can include a radio frequency module implemented in accordance with one or more features disclosed herein.

[0331] FIG. **34**B is a schematic diagram of another example of a front end system **345** for an IoT-enabled object, such as the IoT-enabled industrial equipment **340** of FIG. **34**A.

[0332] The front end system **345** includes a logic control circuit **350**, a transceiver DC blocking capacitor **351**, a first antenna DC blocking capacitor **352**, a second antenna DC blocking capacitor **353**, an LNA **354**, a power amplifier **356**, an antenna-side switch **357**, a bypass switch **358**, and a transceiver-side switch **359**.

[0333] The front end system **345** includes control pins (CPS, CTX, CSD, ANT_SEL) for controlling the front end system **345**. The antenna-side switch **357** selectively connects either a first antenna pin (ANT**1**) or a second antenna pin (ANT**2**) to either an output of the power amplifier **356** or the bypass switch **358**/input to the LNA **354**. Additionally, the bypass switch **358** selectively bypasses the LNA **354**. Furthermore, the transceiver-side switch **359** selectively connected the transceiver pin (TR) to either an input of the power amplifier **356** or the bypass switch **358**/output to the LNA **354**. The DC blocking capacitors **351**-**353** serve to provide DC blocking to provide enhanced flexibility in controlling internal DC biasing of the front end system **345**.

[0334] The front end system **345** can be implemented in a radio frequency module that can incorporate one or more features described in the sections herein.

[0335] FIG. **35**A is a schematic diagram of one example of an IoT-enabled lock **360**. The IoT-enabled lock **360** illustrates one example of an IoT-enabled object that can include a radio frequency module implemented in accordance with one or more features disclosed herein.

[0336] FIG. **35**B is a schematic diagram of one example of a circuit board **361** for the IoT-enabled lock **360** of FIG. **35**A. The circuit board **361** includes a front end system **362**, which can be implemented in a radio frequency module that can incorporate one or more features described in the sections herein.

[0337] FIG. **36**A is a schematic diagram of one example of IoT-enabled thermostat **370**. The IoT-enabled thermostat **370** illustrates another example of an IoT-enabled object that can include a radio frequency module implemented in accordance with one or more features disclosed herein.

[0338] FIG. **36**B is a schematic diagram of one example of a circuit board **371** for the IoT-enabled thermostat **370** of FIG. **36**A. The circuit board **371** includes a front end system **372**, which can be implemented in a radio frequency module that can incorporate one or more features described in the sections herein.

[0339] FIG. **37**A is a schematic diagram of one example of IoT-enabled light **380**. The IoT-enabled light **380** illustrates another example of an IoT-enabled object that can include a radio frequency module implemented in accordance with one or more features disclosed herein.

[0340] FIG. **37**B is a schematic diagram of one example of a circuit board **381** for the IoT-enabled light **380** of FIG. **37**A. FIG. **37**B also depicts a base portion of the IoT-enabled light **380** for housing the circuit board **381**. The circuit board **381** includes a front end system **382**, which can be implemented in a radio frequency module that can incorporate one or more features described in the sections herein.

Additional Applications

[0341] Any of the embodiments described herein can be implemented in association with wireless communications devices, such as any suitable Internet of Things (IoT) device. The principles and advantages of the embodiments can be implemented in any suitable systems, packaged module, integrated circuit, or the like that could benefit from any feature of one or more embodiments described herein. The teachings herein are applicable to a variety of systems. Examples of such systems include, but are not limited to, mobile phones, tablets, base stations, network access points, customer-premises equipment (CPE), IoT-enabled objects, laptops, and wearable electronics. Thus, the embodiments herein can be included in various electronic devices, including, but not limited to, consumer electronic products. Although this disclosure includes some example embodiments, the teachings described herein can be applied to a variety of structures. Any of the principles and advantages discussed herein can be implemented in association with radio frequency circuits configured to process signals in a range from about 30 kHz to 300 GHz, such as in a range from about 450 MHz to 6 GHz, but not limited to implementation in association with radio frequency circuits.

[0342] Aspects of this disclosure can be implemented in various electronic devices. Examples of the electronic devices can include, but are not limited to, consumer elec-

tronic products, parts of the consumer electronic products such as integrated circuits and/or packaged radio frequency modules, uplink wireless communication devices, wireless communication infrastructure, electronic test equipment, etc. Examples of the electronic devices can include, but are not limited to, a mobile phone such as a smart phone, a wearable computing device such as a smart watch or an ear piece, a telephone, a television, a computer monitor, a computer, a modem, a hand-held computer, a laptop computer, a tablet computer, a personal digital assistant (PDA), a microwave, a refrigerator, an automobile, a stereo system, a DVD player, a CD player, a digital music player such as an MP3 player, a radio, a camcorder, a camera, a digital camera, a portable memory chip, a washer, a dryer, a washer/dryer, a copier, a facsimile machine, a scanner, a multi-functional peripheral device, a wrist watch, a clock, etc. Further, the electronic devices can include unfinished products.

Terminology

[0343] Unless the context requires otherwise, throughout the description and the claims, the words "comprise," "comprising," "include," "including" and the like are to be construed in an inclusive sense, as opposed to an exclusive or exhaustive sense; that is to say, in the sense of "including, but not limited to." The word "coupled", as generally used herein, refers to two or more elements that may be either directly connected, or connected by way of one or more intermediate elements. Likewise, the word "connected", as generally used herein, refers to two or more elements that may be either directly connected, or connected by way of one or more intermediate elements. Additionally, the words "herein," "above," "below," and words of similar import, when used in this application, shall refer to this application as a whole and not to any particular portions of this application. Where the context permits, words in the above Detailed Description using the singular or plural number may also include the plural or singular number, respectively. The word "or" in reference to a list of two or more items, that word covers all of the following interpretations of the word: any of the items in the list, all of the items in the list, and any combination of the items in the list.

[0344] Moreover, conditional language used herein, such as, among others, "can," "could," "might," "may," "e.g.," "for example," "such as" and the like, unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements and/or states. Thus, such conditional language is not generally intended to imply that features, elements and/or states are in any way required for one or more embodiments or that one or more embodiments necessarily include logic for deciding, with or without author input or prompting, whether these features, elements and/or states are included or are to be performed in any particular embodiment.

[0345] While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the disclosure. Indeed, the novel apparatus, methods, and systems described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the methods and systems described herein may be made without departing from the spirit of the disclosure. For example, while blocks are presented in a given arrangement, alternative embodiments may perform similar functionalities with different components and/or circuit topologies, and some blocks may be deleted, moved, added, subdivided, combined, and/or modified. Each of these blocks may be implemented in a variety of different ways. Any suitable combination of the elements and acts of the various embodiments described above can be combined to provide further embodiments. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the disclosure.

1. (canceled)

2. A packaged module for use in a wireless communication device, the packaged module comprising:

first radio frequency circuitry including baseband circuitry;

second radio frequency circuitry including a power amplifier configured to amplify a radio frequency signal;

a substrate and a first die supported by the substrate, the first die including at least the first radio frequency circuitry;

an oscillator assembly supported by the substrate and configured to provide a clock signal to the first die, the oscillator assembly supported by the substrate and disposed between the first die and the substrate; and

a filter supported by the substrate, including at least one passive component, and configured to filter a signal associated with the first radio frequency circuitry or the second radio frequency circuitry.

3. The packaged module of claim **2** wherein the at least one passive component of the filter includes first and second passive components, the first passive component spaced from the substrate by the second passive component.

4. The packaged module of claim **2** wherein at least a first overhanging portion of the first die extends beyond at least a portion of a periphery of the oscillator assembly.

5. The packaged module of claim **4** wherein the filter is disposed between the at least the first overhanging portion of the first die and the substrate.

6. The packaged module of claim **4** further comprising supports positioned between the at least a first overhanging portion of the first die and the substrate to provide support for the at least a first overhanging portion of the first die.

7. The packaged module of claim **2** wherein the substrate is includes a ground plane, a first side, and a second side opposite to the first side.

8. The packaged module of claim **7** further comprising an antenna on the first side of the substrate, and a second die supported by the substrate and including the second radio frequency circuitry, the second die disposed on the second side of the substrate, the ground plane being positioned between the antenna and the second die.

9. The packaged module of claim **2** further comprising a radio frequency shielding structure extending above the substrate, a second die supported by the substrate and in an interior of the radio frequency shielding structure, and an antenna supported by the substrate external to the radio frequency shielding structure.

10. The packaged module of claim **2** further comprising a second die, the first die, the oscillator assembly and the filter being disposed on a first side of the substrate, and the second die being disposed on a second side of the substrate opposite of the first side.

11. The packaged module of claim **2** further comprising a second die supported by the substrate and including the second radio frequency circuitry.

12. The packaged module of claim **2** wherein the first die and the oscillator assembly are disposed on a first side of the substrate, and the filter is disposed on a second side of the substrate opposite of the first side.

13. The packaged module of claim **2** wherein the oscillator assembly includes a crystal, a conductive pillar, and an enclosure configured to enclose the crystal, the conductive pillar formed at least partially within a side of the enclosure and extending from a top surface to a bottom surface of the enclosure.

14. A system board assembly comprising:

a system board;

a radio frequency module supported by the system board and including first radio frequency circuitry including baseband circuitry, second radio frequency circuitry including a power amplifier configured to amplify a radio frequency signal for transmission via an antenna, a substrate, and a first die supported by the substrate, the first die including at least the first radio frequency circuitry, the radio frequency module further including an oscillator assembly supported by the substrate and configured to provide a clock signal to the first die, the oscillator assembly supported by the substrate and disposed between the first die and the substrate, and the radio frequency module further including a filter supported by the substrate and including at least one passive component, the filter configured to filter a signal associated with the first radio frequency circuitry or the second radio frequency circuitry;

one or more radio frequency components; and

signal interconnections between the radio frequency module and the one or more components.

15. The system board assembly of claim **14** wherein the oscillator assembly includes a crystal, a conductive pillar, and an enclosure configured to enclose the crystal, the conductive pillar formed at least partially within a side of the enclosure and extending from a top surface to a bottom surface of the enclosure.

16. The system board assembly of claim **14** wherein the radio frequency module further includes a radio frequency shielding structure extending above the substrate and a second die supported by the substrate and disposed in an interior of the radio frequency shielding structure.

17. The system board assembly of claim **16** wherein the radio frequency module further includes the antenna supported by the substrate external to the radio frequency shielding structure.

18. A wireless communication device comprising:

an antenna configured to receive and transmit radio frequency signals; and

a radio frequency module including first radio frequency circuitry including baseband circuitry, second radio frequency circuitry including a power amplifier configured to amplify a radio frequency signal for transmission via the antenna, a substrate, and a first die supported by the substrate, the first die including at least the first radio frequency circuitry, the radio frequency module further including an oscillator assembly supported by the substrate and configured to provide a clock signal to the first die, the oscillator assembly supported by the substrate and disposed between the first die and the substrate, and the radio frequency module further including a filter supported by the substrate and including at least one passive component, the filter configured to filter a signal associated with the first radio frequency circuitry or the second radio frequency circuitry.

19. The wireless communication device of claim **18** wherein the radio frequency module further includes a second die, the oscillator assembly and the filter are disposed on a first side of the substrate, and the second die is disposed on a second side of the substrate opposite of the first side.

20. The wireless communication device of claim **19** wherein the second die includes the second radio frequency circuitry.

21. The wireless communication device of claim **18** wherein the at least one passive component of the filter includes first and second passive components, the first passive component stacked on the second passive component.

* * * * *