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SYSTEM PACKAGING FOR MILLIMETER WAVE ANTENNAS

Abstract

A radio frequency package includes a first portion of an antenna array module, a second portion of the antenna array module, and a flexible cable. The first portion of the antenna array module provides a first wireless communication functionality and the second portion of the antenna array module provides a second wireless communication functionality. The flexible cable includes first surface directly coupled to the first portion of the antenna array module. The flexible cable also includes a second surface directly coupled to the second portion of the antenna array module. The flexible cable communicates signals between the first portion of the distributed antenna array module and the second portion of the antenna array module.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation of U.S. patent application Ser. No. 17/465,761, filed Sep. 2, 2021, entitled “SYSTEM PACKAGING FOR MILLIMETER WAVE ANTENNAS,” the disclosure of which is incorporated by reference in its entirety for all purposes.

BACKGROUND
[0002] The present disclosure relates generally to wireless communication systems and devices and, more specifically, to system packaging that accommodates wireless communication components while conserving space.
[0003] This section is intended to introduce the reader to various aspects of art that may be related to various aspects of the present disclosure, which are described and/or claimed below. This discussion is believed to be helpful in providing the reader with background information to facilitate a better understanding of the various aspects of the present disclosure. Accordingly, it should be understood that these statements are to be read in this light, and not as admissions of prior art.
[0004] Generally, radio frequency devices may include a package, such as a system in package (SiP). A system-in-package incorporates substrates, dies, multiple integrated circuits, and/or passive devices into a single package. The system-in-package may be made of semiconducting material, such as silicon. For example, the substrates and dies may include silicon on which the integrated circuits are fabricated. The substrates, dies, and devices may be coupled by wires bonded to the package or by solder joints (e.g., solder balls or pads). By way of example, the dies may be stacked (e.g., two-and-a-half-dimensional (2.5D) or three-dimensional (3D) stack structure) to combine the dies into the same package rather than placing them on a printed circuit board. In some instances, the system-in-package may also include multiple packages that are stacked (e.g., using a package on package (POP) technique) or have dies embedded in substrate.
[0005] By way of example, radio frequency devices that support communication over millimeter wave (mmWave) range frequencies often provide support at frequencies at or near 30 GHz. In some instances, radio frequency devices may also support the mmWave communication over additional mmWave bands for broader frequency coverage, such as for 30-300 GHz. Multiple antennas (e.g., an antenna array) of the radio frequency devices may send signals that are combined to form a beam (e.g., a beamformed signal) for communicating over the mmWave. To enable consistent coverage (e.g., from base stations associated with the mmWave communications), the radio frequency devices may include multiple antenna arrays positioned in different parts of the radio frequency devices. However, fitting these multiple antenna arrays in the system-in-package of the radio frequency devices may take up space and undesirably increase the size of the radio frequency devices.
SUMMARY
[0006] A summary of certain embodiments disclosed herein is set forth below. It should be understood that these aspects are presented merely to provide the reader with a brief summary of these certain embodiments and that these aspects are not intended to limit the scope of this disclosure. Indeed, this disclosure may encompass a variety of aspects that may not be set forth below.
[0007] In one embodiment, a radio frequency package includes a first distributed portion (e.g., a

first portion) of an antenna array module, a second distributed portion (e.g., a second portion) of the antenna array module, and a flexible cable. The first distributed portion of the antenna array module provides a first wireless communication functionality and the second distributed portion of the antenna array module provides a second wireless communication functionality. The flexible cable includes first surface directly coupled to the first distributed portion of the antenna array module. The flexible cable also includes a second surface directly coupled to the second distributed portion of the antenna array module. The flexible cable communicates signals between the first distributed portion of the distributed antenna array module and the second distributed portion of the antenna array module. The energy between array module on either side of cable maybe communicated via a physical electrical connection or by means of electromagnetic coupling or combination of both. The purpose of this embodiment is to eliminate the need for bulky connectors at mmWave and high frequencies. The cables also bring in control, RF and intermediate frequencies as well as power from the main board to a remote mmWave antenna array.

[0008] In another embodiment, a system package includes a first distributed portion of an antenna array module, a second distributed portion of the antenna array module, and multiple solder balls. The first distributed portion of the antenna array module provides a first wireless communication function and the second distributed portion of the antenna array module provides a second wireless communication function. The first distributed portion, second distributed portion, or both, include one or more cavities that provide a direct communication path between components in the one or more cavities and the first distributed portion, second distributed portion, or both. The multiple solder balls couples the first distributed portion of the antenna array module and the second distributed portion of the antenna array module.

[0009] In yet another embodiment, a system-in-package includes a first distributed portion of an antenna array module, a second distributed portion of the antenna array module, a transceiver, and a power management circuitry. The first distributed portion of the antenna array module provides a first wireless communication functionality, in which the first distributed portion includes a first set of metal layers. The second distributed portion of the antenna array module provides a second wireless communication functionality, in which the second distributed portion includes a second set of metal layers, and in which the first distributed portion of the antenna array module directly couples to the second distributed portion of the antenna array module via an adhesive. The transceiver transmits transmission signals, receives reception signals, or a both, via one or more antennas of the antenna array module, in which the transceiver communicatively couples to the antenna array module. The power management circuitry controls power functions related to the transmission signals and the reception signals, in which the power management circuitry communicatively couples to the antenna array module.

[0010] Various refinements of the features noted above may exist in relation to various aspects of the present disclosure. Further features may also be incorporated in these various aspects as well. These refinements and additional features may exist individually or in any combination. For instance, various features discussed below in relation to one or more of the illustrated embodiments may be incorporated into any of the above-described aspects of the present disclosure alone or in any combination. The brief summary presented above is intended only to familiarize the reader with certain aspects and contexts of embodiments of the present disclosure without limitation to the claimed subject matter.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Various aspects of this disclosure may be better understood upon reading the following detailed description and upon reference to the drawings in which:

[0012] FIG. **1** is a block diagram of an electronic device, according to an embodiment of the present disclosure;
[0013] FIG. **2** is a perspective view of a notebook computer representing an embodiment of the electronic device of FIG. **1**;
[0014] FIG. **3** is a front view of a handheld device representing another embodiment of the electronic device of FIG. **1**;
[0015] FIG. **4** is a front view of another handheld device representing another embodiment of the electronic device of FIG. **1**;
[0016] FIG. **5** is a front view of a desktop computer representing another embodiment of the electronic device of FIG. **1**;
[0017] FIG. **6** is a front view and side view of a wearable electronic device representing another embodiment of the electronic device of FIG. **1**;
[0018] FIG. **7** is a schematic diagram of a system package of the electronic device of FIG. **1**, according to embodiments of the present disclosure;
[0019] FIG. **8** is a schematic diagram of a package of a left side panel with a distributed antenna array module of the system package of FIG. **7**, according to embodiments of the present disclosure;
[0020] FIG. **9**A is a schematic diagram of a package with a flexible cable providing a board-to-board connection, according to embodiments of the present disclosure;
[0021] FIG. **9**B is a schematic diagram of a package with a flexible cable coupling packaging on top of the flexible cable and below the flexible cable, according to embodiments of the present disclosure;
[0022] FIG. **9**C is a schematic diagram of a package with the flexible cable providing a connection between portions of a distributed antenna array module, according to embodiments of the present disclosure;
[0023] FIG. **10** is a schematic diagram of a package with power management circuitry directly coupled to a distributed antenna array module, according to embodiments of the present disclosure;
[0024] FIG. **11** is a schematic diagram of a package with a power management package, according to embodiments of the present disclosure;
[0025] FIG. **12** is a schematic diagram of a package with a distributed antenna array module having cavities, according to embodiments of the present disclosure;
[0026] FIG. **13** is a schematic diagram of a package with antennas disposed within the cavities of FIG. **12**, according to embodiments of the present disclosure;
[0027] FIG. **14** is a schematic diagram of a package of a back glass panel with a distributed antenna array module directly coupled to a main logic board and a transceiver/power management package, according to embodiments of the present disclosure; and
[0028] FIG. **15**A is a schematic diagram of a package of a left side panel with a distributed antenna array module, underfill, and shielding, according to embodiments of the present disclosure;
[0029] FIG. **15**B is a schematic diagram of the package with a distributed antenna array module having shielding on some portions of an antenna array module, according to embodiments of the present disclosure;
[0030] FIG. **16** is a schematic diagram of a package with direct coupling between portions of a distributed antenna array module, according to embodiments of the present disclosure;
[0031] FIG. **17** is schematic diagram of a package with a distributed antenna array module having a recess, according to embodiments of the present disclosure; and
[0032] FIG. **18** is schematic diagram of a package having a “T-shaped” structure, according to embodiments of the present disclosure.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

[0033] When introducing elements of various embodiments of the present disclosure, the articles “a,” “an,” and “the” are intended to mean that there are one or more of the elements. The terms “comprising,” “including,” and “having” are intended to be inclusive and mean that there may be additional elements other than the listed elements. Additionally, it should be understood that references to “one embodiment”, “an embodiment”, or “some embodiments” of the present disclosure are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features. Use of the term “approximately” or “near” should be understood to mean including close to a target (e.g., design, value, amount), such as within a margin of any suitable or contemplatable error (e.g., within 0.1% of a target, within 1% of a target, within 5% of a target, within 10% of a target, within 25% of a target, and so on).

[0034] As used herein, “panel” refers to a printed circuit board that includes one or more packages (e.g., system-in-packages that include substrates, dies, modules, and/or components) that may correspond to a particular side or portion of a radio frequency device. By way of example, a back glass panel may refer to the printed circuit board with the one or more packages for the back surface of the radio frequency device. Additionally, as used herein, “distributed” refers to physically reducing or fragmentizing into parts or portions (e.g., two or more). By way of example, a single antenna array module may include multiple layers that may be distributed, such that different parts or portions of the module may be disposed in various areas within a silicon package. By way of example, the single antenna array module may include sixteen layers and may be disposed on top of a main logic board within the package. The antenna array module may be distributed, such that a first portion of the antenna array module may include ten layers that are disposed on top of the main logic board while a second portion of the antenna array module may include six layers that are disposed on the bottom (e.g., underneath) of the main logic board. That is, instead of the antenna array module disposed on top of or below the main logic board as a single piece, smaller portions of the antenna array module are distributed about the main logic board. By distributing the antenna array module into the multiple portions, the dimensions associated with the single antenna array module may be distributed into smaller dimensions, which may be more efficiently placed between various portions and/or components of the package. In particular, the distribution may enable placement of other components in the package (e.g., around the main logic board) that may not fit if the antenna array module is placed about the main logic board as a single piece. The number of portions and/or the dimensions of the portions of the antenna array module may be based on the dimensions of other components and/or locations of the other components (e.g., co-locations) to be placed within the package. In some instances, the antenna array module may be distributed based on a functionality provided by the portions or components included in the portions. For example, the first portion may include antenna functionality circuitry while the second portion includes antennas and/or radio frequency routing circuitry for the antennas near 30 GHz. However, the radio frequency devices may also support communication over additional mmWave bands for broader frequency coverage, such as for 30-300 GHz. As such, the packaging for the radio frequency devices may include particular components to support the multiple protocols and capabilities. However, the dimensions for the overall packaging design may be limited to original dimensions associated with supporting a single protocol and capability (e.g., communication at the 30 GHz) to continue providing a portable and comfortable design for customer use.

[0035] As such, the present disclosure provides techniques for conserving space in a radio frequency packaging (e.g., a system-in-package) for various sides of a radio frequency device. In particular, the techniques may include conserving space in the package of a rear surface, a front surface, a left side, and/or a right side of the radio frequency device, for example, to facilitate adding and/or replacing components within the package to support various protocols and capabilities (e.g., for additional or new wireless communication support). In this manner, the package may conserve space while also enabling addition or replacement of wireless communication protocols and capabilities. Conserving space may result in package dimensions that are smaller, the same, or approximately the same as original dimensions of the package prior to adding components associated with the additional or replaced wireless communication protocol and capabilities. Additionally or alternatively, the present disclosure may also provide techniques for conserving space while generally maintaining a distance between particular components (e.g., spacing), co-location of particular components, or other locations of the components within the package for the particular side of the radio frequency device.

[0036] As will be discussed herein, conserving space within the system package for efficient packaging may include distributing one or more antenna array modules into multiple portions that may be placed separately within the package and/or a flexor cable that provides board-to-board functionality (e.g., instead of using a board-to-board connector) to carry signals between printed circuit boards. Conserving space within the system package may also include selectively including mold that accommodates components, the distributed portions of the antenna array module, and/or the flexor cable with the board-to-board connector functionality. Additionally, conserving space within the package may include forming cavities within the antenna array layer, such that antennas may be placed within the cavities for efficient space usage, as well as more direct communication between radio frequency circuitry and the antennas. Furthermore, the package may include underfill and/or shielding, a recess to a portion of the package to accommodate components, as well as direct coupling of components by using an adhesive material between printed circuit boards to provide a direct interface. In some instances, the package may include varying sizes and/or placements of components to create a “T-shaped” structure of the package (e.g., the package being wider at the top and narrower at the bottom).

[0037] Turning first to FIG. **1**, an electronic device **10** according to an embodiment of the present disclosure may include, among other things, one or more processor(s) **12**, memory **14**, nonvolatile storage **16**, a display **18**, input structures **22**, an input/output (I/O) interface **24**, a network interface **26**, a power source **28**, and a transceiver **20**. The various functional blocks shown in FIG. **1** may include hardware elements (including circuitry), software elements (including computer code stored on a computer-readable medium) or a combination of both hardware and software elements. It should be noted that FIG. **1** is merely one example of a particular implementation and is intended to illustrate the types of components that may be present in electronic device **10**.

[0038] By way of example, the electronic device **10** may represent a block diagram of the notebook computer depicted in FIG. **2**, the handheld device depicted in FIG. **3**, the handheld device depicted in FIG. **4**, the desktop computer depicted in FIG. **5**, the wearable electronic device depicted in FIG. **6**, or similar devices. It should be noted that the processor(s) **12** and other related items in FIG. **1** may be generally referred to herein as “data processing circuitry.” Such data processing circuitry may be embodied wholly or in part as software, hardware, or any combination thereof. Furthermore, the processor(s) **12** and other related items in FIG. **1** may be a single contained processing module or may be incorporated wholly or partially within any of the other elements within the electronic device **10**.

[0039] In the electronic device **10** of FIG. **1**, the processor(s) **12** may be operably coupled with a memory **14** and a nonvolatile storage **16** to perform various algorithms. For example, algorithms for adjusting input/output power of antennas may be saved in the memory **14** and/or nonvolatile storage **16**. Such algorithms or instructions executed by the processor(s) **12** may be stored in any suitable article of manufacture that includes one or more tangible, computer-readable media. Moreover, antenna gain lookup tables used for determining total transmission gains and/or total reception gains may be saved in the memory **14** and/or nonvolatile storage **16**. Specifically, one or more codebooks may be stored in the memory **14** and/or nonvolatile storage **16**. The tangible, computer-readable media may include the memory **14** and/or the nonvolatile storage **16**, individually or collectively, to store the algorithms or instructions. The memory **14** and the nonvolatile storage **16** may include any suitable articles of manufacture for storing data and executable instructions, such as random-access memory, read-only memory, rewritable flash memory, hard drives, and optical discs. In addition, programs (e.g., an operating system) encoded on such a computer program product may also include instructions that may be executed by the

processor(s) **12** to enable the electronic device **10** to provide various functionalities.
[0040] In certain embodiments, the display **18** may be a liquid crystal display (LCD), which may facilitate users to view images generated on the electronic device **10**. In some embodiments, the display **18** may include a touch screen, which may facilitate user interaction with a user interface of the electronic device **10**. Furthermore, it should be appreciated that, in some embodiments, the display **18** may include one or more light-emitting diode (LED) displays, organic light-emitting diode (OLED) displays, active-matrix organic light-emitting diode (AMOLED) displays, or some combination of these and/or other display technologies.
[0041] The input structures **22** of the electronic device **10** may enable a user to interact with the electronic device **10** (e.g., pressing a button to increase or decrease a volume level). The I/O interface **24** may enable the electronic device **10** to interface with various other electronic devices, as may the network interface **26**. The network interface **26** may include, for example, one or more interfaces for a personal area network (PAN), such as a BLUETOOTH® network, for a local area network (LAN) or wireless local area network (WLAN), such as an 802.11x WI-FI® network, and/or for a wide area network (WAN), such as a 3.sup.rd generation (3G) cellular network, universal mobile telecommunication system (UMTS), 4.sup.th generation (4G) cellular network, long term evolution (LTE®) cellular network, long term evolution license assisted access (LTE-LAA) cellular network, 5.sup.th generation (5G) cellular network, and/or New Radio (NR) cellular network. In particular, the network interface **26** may include, for example, one or more interfaces for using a Release-15 cellular communication standard of the 5G specifications that include the millimeter wave (mmWave) frequency range (e.g., 30-300 GHz). The transceiver **20** of the electronic device **10**, which includes the transmitter and the receiver, may allow communication over the aforementioned networks (e.g., 5G, Wi-Fi, LTE-LAA, and so forth).
[0042] The network interface **26** may also include one or more interfaces for, for example, broadband fixed wireless access networks (e.g., WIMAX®), mobile broadband Wireless networks (mobile WIMAX®), asynchronous digital subscriber lines (e.g., ADSL, VDSL), digital video broadcasting-terrestrial (DVB-T®) network and its extension DVB Handheld (DVB-H®) network, ultra-wideband (UWB) network, alternating current (AC) power lines, and so forth.
[0043] In some embodiments, the electronic device **10** communicates over the aforementioned wireless networks (e.g., WI-FI®, WIMAX®, mobile WIMAX®, 4G, LTE®, 5G, and so forth) using the transceiver **20**. The transceiver **20** may include circuitry useful in both wirelessly receiving the reception signals at the receiver and wirelessly transmitting the transmission signals from the transmitter (e.g., data signals, wireless data signals, wireless carrier signals, radio frequency signals). Indeed, in some embodiments, the transceiver **20** may include the transmitter and the receiver combined into a single unit, or, in other embodiments, the transceiver **20** may include the transmitter separate from the receiver. The transceiver **20** may transmit and receive radio frequency signals to support voice and/or data communication in wireless applications such as, for example, PAN networks (e.g., BLUETOOTH®), WLAN networks (e.g., 802.11x WI-FI®), WAN networks (e.g., 3G, 4G, 5G, NR, and LTE® and LTE-LAA cellular networks), WIMAX® networks, mobile WIMAX® networks, ADSL and VDSL networks, DVB-T® and DVB-H® networks, UWB networks, and so forth. As further illustrated, the electronic device **10** may include the power source **28**. The power source **28** may include any suitable source of power, such as a rechargeable lithium polymer (Li-poly) battery and/or an alternating current (AC) power converter.
[0044] In certain embodiments, the electronic device **10** may take the form of a computer, a portable electronic device, a wearable electronic device, or other type of electronic device. Such computers may be generally portable (such as laptop, notebook, and tablet computers), or generally used in one place (such as desktop computers, workstations, and/or servers). In certain embodiments, the electronic device **10** in the form of a computer may be a model of a MacBook®, MacBook® Pro, MacBook Air®, iMac®, Mac® mini, or Mac Pro® available from Apple Inc. of Cupertino, California. By way of example, the electronic device **10**, taking the form of a notebook

computer **10**A, is illustrated in FIG. **2** in accordance with one embodiment of the present disclosure. The depicted notebook computer **10**A may include a housing or enclosure **31**, a display **18**, input structures **22**, and ports of an I/O interface **24**. In one embodiment, the input structures **22** (such as a keyboard and/or touchpad) may be used to interact with the computer **10**A, such as to start, control, or operate a graphical user interface (GUI) and/or applications running on computer **10**A. For example, a keyboard and/or touchpad may allow a user to navigate a user interface and/or an application interface displayed on display **18**.

[0045] FIG. **3** depicts a front view of a handheld device **10**B, which represents one embodiment of the electronic device **10**. The handheld device **10**B may represent, for example, a portable phone, a media player, a personal data organizer, a handheld game platform, or any combination of such devices. By way of example, the handheld device **10**B may be a model of an iPhone® available from Apple Inc. of Cupertino, California. The handheld device **10**B may include an enclosure **31** to protect interior components from physical damage and/or to shield them from electromagnetic interference. The enclosure **31** may surround the display **18**. The I/O interfaces **24** may open through the enclosure **31** and may include, for example, an I/O port for a hardwired connection for charging and/or content manipulation using a standard connector and protocol, such as the Lightning connector provided by Apple Inc. of Cupertino, California, a universal serial bus (USB), or other similar connector and protocol. The interfaces **24** may be associated with wiring and connectors within the radio frequency packaging of the electronic device **10**. The wiring and connectors may result in particular areas within a system package of the electronic device **10** that are available for placing components to facilitate supporting multiple wireless communication protocols and capabilities. By way of example, and as will be discussed in detail FIG. **7**, if the electronic device **10**B is positioned upward along a positive z-axis **29** and facing a positive y-axis **25**, an antenna array of a right side panel of the electronic device **10**B may be disposed and radiate signals in the positive x-axis **27**. Similarly, an antenna array of a left side panel may be disposed and radiate signals in the negative x-axis **27**, an antenna array of a front glass panel (e.g., front surface panel) may be disposed and radiate signals in the positive y-axis **25**, and an antenna array of a back glass panel (e.g., rear surface panel) may be disposed and radiate signals in the negative y-axis **25**.

[0046] The input structures **22**, in combination with the display **18**, may allow a user to control the handheld device **10**B. For example, the input structures **22** may activate or deactivate the handheld device **10**B, navigate user interface to a home screen, a user-configurable application screen, and/or activate a voice-recognition feature of the handheld device **10**B. Other input structures **22** may provide volume control, or may toggle between vibrate and ring modes. The input structures **22** may also include a microphone that may obtain a user's voice for various voice-related features, and a speaker that may enable audio playback and/or certain phone capabilities. The input structures **22** may also include a headphone input that may provide a connection to external speakers and/or headphones.

[0047] FIG. **4** depicts a front view of another handheld device **10**C, which represents another embodiment of the electronic device **10**. The handheld device **10**C may represent, for example, a tablet computer, or one of various portable computing devices. By way of example, the handheld device **10**C may be a tablet-sized embodiment of the electronic device **10**, which may be, for example, a model of an iPad® available from Apple Inc. of Cupertino, California.

[0048] Turning to FIG. **5**, a computer **10**D may represent another embodiment of the electronic device **10** of FIG. **1**. The computer **10**D may be any computer, such as a desktop computer, a server, or a notebook computer, but may also be a standalone media player or video gaming machine. By way of example, the computer **10**D may be an iMac®, a MacBook®, or other similar device by Apple Inc. of Cupertino, California. It should be noted that the computer **10**D may also represent a personal computer (PC) by another manufacturer. A similar enclosure **31** may be provided to protect and enclose internal components of the computer **10**D, such as the display **18**.

In certain embodiments, a user of the computer **10**D may interact with the computer **10**D using various peripheral input structures **22**, such as the keyboard **22**A or mouse **22**B (e.g., input structures **22**), which may connect to the computer **10**D.

[0049] Similarly, FIG. **6** depicts a wearable electronic device **10**E representing another embodiment of the electronic device **10** of FIG. **1** that may be configured to operate using the techniques described herein. By way of example, the wearable electronic device **10**E, which may include a wristband **23**, may be an Apple Watch® by Apple Inc. of Cupertino, California. However, in other embodiments, the wearable electronic device **10**E may include any wearable electronic device such as, for example, a wearable exercise monitoring device (e.g., pedometer, accelerometer, heart rate monitor), or other device by another manufacturer. The display **18** of the wearable electronic device **10**E may include a touch screen display **18** (e.g., LCD, LED display, OLED display, active-matrix organic light emitting diode (AMOLED) display, and so forth), as well as input structures **22**, which may allow users to interact with a user interface of the wearable electronic device **10**E.

[0050] With the foregoing in mind, FIG. **7** is schematic diagram of a system package **30** of the electronic device **10** of FIG. **1**. Although the depicted embodiment shows multiple panels on different sides and on the same layer of the electronic device **10**, the systems described herein also apply to stacked panels, such as a three-dimensional (3D) stack of printed circuit boards. That is, one or more of the panels may positioned on top of or beneath one or more other panels, for example, in a z-axis **29** in a 3D space. Moreover, at least one of the panels may include a redistribution printed circuit board that provides a connection between the panels that are coupled to it.

[0051] In the depicted embodiment, the system package **30** includes packaging for a front glass panel **32** (e.g., front surface panel or cover glass panel), a main logic board **33** with a back glass panel **34**, a left side panel **36**, and a right side panel **38**. Although the following descriptions describe the panels **32**, **34**, **36**, and **38** as disposed respectively on the front, back, left, and right side of the electronic device **10**, which represents a particular embodiment, the system package **30** described herein may additionally or alternatively include panel(s) disposed at other areas of the electronic device **10** that may include one or more antennas. For example, the system package **30** may also include top side or bottom side panels disposed respectively at the top or bottom of the electronic device **10**, adjacent to the left side panel **36** and the right side panel **38**. Moreover, although the following descriptions describe an antenna array, which represents a particular embodiment, the system package **30** described herein may additionally or alternatively include multiple antenna arrays.

[0052] The main logic board **33** may include the back glass panel **34**, a power management circuitry **39**, the transceiver **20**, an antenna array selector **37**, an application processor **35**, and a first antenna array **50**A. The application processor **35** may be coupled to the power management circuitry **39** to control power functions, including those related to wireless communications. The power management circuitry **39** may include one or more integrated circuits and control power (e.g., via the processor **12**) provided to components of the main logic board **33** and/or the electronic device **10**, including, for example, the transceiver **20** and/or the antenna array selector **37**. By way of example, the power management circuitry **39** may control supplying power to the main logic board **33** board, providing power to components on or coupled to the main logic board **33**, the panels **32**, **34**, **36**, and/or **38**, selecting a power source, power sequencing, converting direct current (DC) for specific power related functions, charging a battery of the electronic device **10**, and so forth.

[0053] As shown, the transceiver **20** may be coupled to the antenna array selector **37**, the first antenna array **50**A of the back glass panel **34**, and components of the front glass panel **32**. The antenna array **50**A includes multiple antennas that transmit and/or receive wireless signals, and that may form a directional beam using signals emitted by each of the antennas. The transceiver **20**, as previously discussed with respect to FIG. **1**, is a device that includes a transmitter and a receiver in a single package, and may transmit and receive data via wireless signals communicated on particular radio frequency using the antennas of the first antenna array **50**A. Specifically, the transceiver **20** may include a transmitter and a receiver that include components that facilitate transmission and reception of wireless signals, such as those sent and received between electronic devices **10** using mmWave communication technology or any other suitable communication protocol. When communicating on the mmWave frequencies, an electronic device **10** may utilize beamforming techniques to form the directional beam, as previously mentioned. The transmitter of the transceiver **20** may include one or more phase shifters, transmitter power detectors, and power amplifiers. The transmitter phase shifters may modulate (e.g., phase-shift) transmission signals (e.g., wireless signals transmitted from antennas of the first antenna array **50**A) and may form a beam that may be steered in a particular direction (e.g., the directional beam), such as towards another electronic device (e.g., an electronic device **10**, a base station). The power amplifiers may amplify power level of transmission signals. Specifically, the power amplifiers may be supplied with a power amplifier supply voltage to control the amount of amplification provided by the power amplifiers (e.g., increase or decrease amplification, which may affect the antenna gain at the corresponding antennas). The transmitter power detectors may measure power of the transmission signals sent from the antennas of the first antenna array **50**A.

[0054] The receiver of the transceiver **20** may include one or more receiver phase shifters, low noise amplifiers, and receiver power detectors. The receiver phase shifters and the receiver power detectors may function similarly to the transmitter phase shifters and the transmitter power detectors. The low noise amplifiers may amplify the power level of reception signals (e.g., wireless signals received at antennas of the first antenna array **50**A). Additional components in the transmitter and/or the receiver may include, but are not limited to, filters, mixers, and/or attenuators.

[0055] The antenna array selector **37**, which may be coupled to the transceiver **20**, may activate or enable communication from one or more of the antennas of the antenna arrays **50**, such as the first antenna array **50**A. For example, based on data throughput, the antenna array selector **37** may selectively enable a number of antennas to accommodate the data throughput. As shown, the antenna array **50**A is disposed at the back glass panel **34**. The back glass panel **34** may include one or more printed circuit boards that are coupled to a rear surface (e.g., a back glass) of the electronic device **10**. As shown, the first antenna array **50**A may include an M×N array of first band antennas **51** (Band 1), second band antennas **53** (Band 2), and third band antennas **55** (Band 3). The M×N array may refer to M rows (e.g., one or more rows) and N columns (e.g., one or more columns) of antennas in which the number of rows, column, and/or antennas in the rows and columns may include any number antennas suitable for the particular application (e.g., communications over the mmWave). Additionally, although the following descriptions describe the antenna arrays **50** with a particular number of first band antennas **51**, second band antennas **53**, and third band antennas **55**, which represent particular embodiments, the antenna arrays **50** may include one or more of any of the first band antennas **51**, second band antennas **53**, and/or third band antennas **55**. The first band antennas **51** may enable communication in a first band or range of frequencies, the second band antennas **52** may enable communication in a second band or range of frequencies, and the third band may enable communication in a third band or range of frequencies. In some embodiments, the first band, the second band, and the third band may include different ranges of frequencies. By way of example, the first band may include low-band frequencies, such as 700 MHz to 1.0 GHZ, the second band antennas **53** may enable communication in mid-band frequencies, such as 1.8 GHz to 2.2 GHZ, and the third band antennas **55** may enable communication in high-band frequencies, such as 20 GHz to 80 GHz.

[0056] Additionally, the transceiver **20** may be coupled to a power management module **41** and an amplifier radio frequency integrated circuit (RFIC) **42** of the front glass panel **32**. Briefly, and as will be discussed in detail below, the power management module **41** may provide power for the power amplifier of the transceiver **20** to amplify power for the transmission signals. The amplifier RFIC **42** may provide mixing circuitry to demodulate radio frequency signals received by the transceiver **20** and modulate intermediate frequency signals to radio frequency signals for transmitting transmission signals from the transceiver **20**.

[0057] In some embodiments, the application processor **35** may control the antenna array selector **37** and/or the transceivers **20** (e.g., through the antenna selector **37**), and by extension, the antenna arrays **50** of the front glass panel **32**, the back glass panel **34**, the left side panel **36**, and/or the right side panel **38**. That is, the antenna array selector **37** may enable one or more of the antennas of the one or more antenna arrays **50** (e.g., antenna arrays **50**A-D) to transmit or receive wireless signals via the transceivers **20**. In some embodiments, the antenna array selector **37** may enable antennas of the right side panel **38** to transmit signals contributing to a beamformed signal directed to the right with respect to the electronic device **10**. By way of example, if the electronic device **10**B of FIG. **3** is positioned upward in the positive z-axis **29** and facing the positive y-axis **25**, the right side panel **38** may be disposed and radiate signals in the positive x-axis **27**. The application processor **35** may also be communicatively coupled to the power management circuitries **29** of each of the front glass panel **32**, the main logic board **33**, the back glass panel **34**, the left side panel **36**, and the right side panel **38** to control power related functions with respect to each of the panels.

[0058] The application processor **35** may include one or more microprocessors, one or more “general-purpose” microprocessors, one or more special-purpose microprocessors, and/or one or more application specific integrated circuits (ASICS), or some combination thereof. For example, the application processor **35** may include one or more reduced instruction set (RISC) processors. In some instances, the application processor **35** may perform processing (e.g., execute software programs and/or instructions) for specification functions, such as specific wireless communication related functions. The specific functions may include receiving or generating wireless signals, selecting particular antennas for transmitting or receiving signals using the antenna array selector **37**, selecting an amplification level to amplify transmission signals using the power management circuitry **39**, determining gain of the wireless signals transmitted and/or received from a particular transmitter and/or receiver associated with a particular antenna of the antenna array **50**, and so forth. In some instances, the application processor **35** may be integrated with the processor **12** and perform additional functions related to the wireless communications, such as functions related to the display **18**, adjusting bandwidth consumption, and so forth.

[0059] In some embodiments, the application processor **35** may communicate with one or more memory devices (not shown), such as the memory **14** of FIG. **1**, for processing instructions to perform the functions related to wireless communications. The memory device may store information such as control software, configuration data, etc. In some embodiments, the application processor **35** and the memory device may be external to the main logic board **33** and/or the system package **30**. The memory device may include a tangible, non-transitory, machine-readable-medium, such as a volatile memory (e.g., a random access memory (RAM)) and/or a nonvolatile memory (e.g., a read-only memory (ROM)). The memory may store a variety of information and may be used for various purposes. For example, the memory device may store machine-readable and/or processor-executable instructions (e.g., in the form of software or a computer program) for the application processors **35** to execute, such as instructions for enabling communication from a particular antenna transmitting or receiving signals contributing to a beamformed signal transmitted or received in a particular beam direction at a particular frequency. The memory device may include one or more storage devices (e.g., nonvolatile storage devices) that may include read-only memory (ROM), flash memory, a hard drive, or any other suitable optical, magnetic, or solid-state storage medium, or a combination thereof.

[0060] As shown, the system package **30** also includes the front glass panel **32**, which may include one or more printed circuit boards that are coupled to a cover glass associated with the display **18**. The front glass panel **32** may include a second antenna array **50**B having M×N first band antennas

51, M×N second band antennas **53**, and/or M×N third band antennas **55**. The antennas of the second antenna array **50**B function similarly to the antennas of the first antenna array **50**A of the main logic board **33**. That is, by way of example, the first band antennas **51** may communicate wireless signals on low-bands frequencies (e.g., 700 MHz to 1.0 GHZ), the second band antennas **53** may communicate wireless signals on mid-band frequencies (e.g., 1.8 GHz to 2.2 GHz), and the third band antennas **55** may communicate wireless signals on high-band frequencies (e.g., 20 GHz to 80 GHz).

[0061] The front glass panel **32** may also include the amplifier RFIC **42** (e.g., a low noise amplifier (LNA) and power amplifier (PA) radio frequency integrated circuit (RFIC)) and the power management module **41**. The amplifier RFIC **42** may include circuitry between antennas and mixing circuitry that, for example, process a signal at an incoming radio frequency (RF) before the signal is converted or demodulated to a lower intermediate frequency (IF) for processing (e.g., converting from RF to IF). By way of example, the amplifier RFIC **42** may include a processor **12** that processes instructions for functions performed by the amplifier RFIC **42** (e.g., instructions related to frequency conversion, transmitting signals from particular antennas and having particular amplification, receiving signals at particular antennas, etc.) and/or a memory **14** storing the instructions related to functions performed by the amplifier RFIC **42**. In some embodiments, the amplifier RFIC **42** may include a band-pass filter to pass frequencies within a particular range and/or a stop-band filter to filter frequencies out the particular range, a low noise amplifier to increase a signal strength of an incoming signal, a local oscillator that generates a radio frequency signal at an offset from the incoming signal to be mixed with the incoming signal, and/or a mixer that mixes the incoming signal with a signal from the local oscillator to convert the incoming signal to the intermediate frequency. A power convertor (e.g., a direct current (DC)-to-DC convertor (DC-DC convertor)) of the power management module **41** may supply power to the power amplifier of the electronic device **10**, for example, for amplifying a transmission signal. As such, dynamically changing the supply voltage from the power convertor may correspondingly change the amount of amplification to the transmission signal from the power amplifier. Furthermore, an average power tracking (APT) of the power management module **41** may change the DC supply voltage based on an output power level to maintain linearity of the power amplifier while efficiency may be improved (e.g., reduce unnecessary power consumption by the power amplifier).

[0062] As illustrated, the system package **30** also includes the left side panel **36**, which may include one or more printed circuit boards that are connected to a left side of the electronic device **10**. The left side panel **36** may also include a power management circuitry **39**, a transceiver **20**, and third antenna array **50**C. Similarly, the system package **30** includes a right side panel **38**. The right side panel **38** also may also include a power management circuitry **39**, a transceiver **20**, and a fourth antenna array **50**D. The power management circuitry **39**, the transceivers **20**, and the antenna arrays **50** may operate and function similarly to the power management circuitry **39**, the transceiver **20**, and the antenna array **50**A, as discussed with respect to the main logic board **33**. As shown, the third antenna array **50**C and the fourth antenna array **50**D include Mx N first band antennas **51**, second band antennas **53**, and third band antennas **55**. As previously mentioned, by way of example, the first band antennas **51** may communicate wireless signals on low-band frequencies, the second band antennas **53** may communicate wireless signals on mid-band frequencies, and the third band antennas **55** may communicate wireless signals on high-band frequencies.

[0063] As previously discussed, integrating the antennas of the antenna arrays **50**, the transceivers **20**, and the power management circuitry **39**, within the same particular area within a package of the panels of the system package **30** may be difficult. Specifically, a transceiver **20** and an antenna array **50** may be co-located (e.g., near each other in the same or approximately the same area) in the package so that the transceiver **20** may efficiently control amplification, phase, gain, and so forth, of the wireless signals while minimizing signal loss and noise that may otherwise result from longer communication pathways between the transceiver **20** and the antenna array **50** (e.g., not co-located). Similarly, the power management circuitry **39** may be co-located with the transceiver **20** and the antenna array module **60** so that the transceiver **20** may efficiently control power related functions for the wireless signals from the antennas of the antenna array **50** while also minimizing signal loss and noise. Moreover, the electronic device **10** may include additional antennas for higher data throughput via the antennas and/or to provide higher gain of the wireless signals from the antennas. In some instances, the electronic device **10** may include additional components and/or additional antennas to accommodate a carrier aggregation that is unique to a particular wireless carrier. As will be described herein, the system package **30** may efficiently accommodate the co-located components, the additional number of antennas, other components, and/or package specifications, while conserving space (e.g., maintain initial system package **30** dimensions after adding additional components and antennas). Although the following descriptions describe space conservation packaging techniques applied to a particular panel of the system package **30**, the techniques may also apply to the other panels of the system package **30**. By way of example, descriptions of the space conservation packaging techniques applied to the front glass panel **32** may also apply to the main logic board **33**, the back glass panel **34**, the left side panel **36**, and/or the right side panel **38**.

[0064] To illustrate, FIG. **8** is schematic diagram of a package **40**A of the left side panel **36** with a distributed antenna array module **60**, which includes the third antenna array **50**C. The antenna array module **60** (e.g., assembly) is distributed into two portions: a first antenna array module portion **60**A (e.g., having a first antenna substrate or system in package (SIP) substrate) and a second antenna array module portion **60**B (e.g., having a second antenna substrate) that are connected or electrically coupled by solder balls **63**. Although the following descriptions of the antenna array module **60** describe two antenna array module portions **60**A, **60**B, which represents a particular embodiment, the package **40**A may instead include one or more antenna array module portions **60**A, **60**B (e.g., two, three, six, etc.). Additionally, although the following descriptions describe the antenna array module portions **60**A, **60**B as including a particular number of antenna array layers and/or having particular dimensions, which represents a particular embodiment, the package **40**A may instead include the antenna array module portions **60**A, **60**B as including one or more antenna array layers and/or having varying dimensions (e.g., varying height, width, and/or length of the portions). Briefly, and as will be described in detail herein, fragmentizing the antenna array module **60** into the distributed antenna array module portions **60**A, **60**B may facilitate placing the antenna array circuitry in multiple available areas within the package **40**A rather than restricting placement to one larger area of the package **40**A. By freeing up the larger area, the antenna array module portions **60**A, **60**B may be placed according to other components (e.g., dimensions of the other components) within the package **40**A. That is, the antenna array module portions **60**A, **60**B may be placed in smaller spaces and/or gaps within the package **40**A while providing the same overall functionality of the antenna array module portion **60** as a single piece. Also, freeing up the larger area enables fitting additional components in the package **40**A and/or within spaces or gaps between the antenna array module portions **60**A, **60**B.

[0065] The solder balls **63** may be placed between silicon components, such as but not limited to modules, boards, packages, and/or the like, to provide contact that enables a communication path between the silicon components. In some embodiments, as depicted, the package **40**A may include solder balls **63** placed between the antenna array module portions **60**A, **60**B. In additional or alternative embodiments, the package **40**A may include the solder balls **63** placed between the antenna array layers within the antenna array module portions **60**A, **60**B, as well as between the modules, boards, packages, and/or other components within the package **40**A. By way of example, the solder balls **63** may be placed on pads on the first antenna array module portion **60**A to provide contact and a communication path to the second antenna array module portion **60**B.

[0066] The package **40**A of the left side panel **36** may also include mold **61**. The mold **61** may be a cured resin or rubber that is fixed to the one or more printed circuit boards of the package **40**A. In other implementations, the mold **61** may be formed by solidification of a liquid, resin, or a gel placed on the top of the printed circuit boards. The liquid, resin, or gel may then be cured in place to produce the mold **61**. In general, the mold **61** may embed or encase the silicon components, such as modules, boards, packages, and/or the like of the package **40**A. The mold **61** may provide support to the modules, boards, packages, and/or other components. In some embodiments, the mold **61** may be carved or cut to accommodate the silicon components of the package **40**A. By way of example, the mold **61** may be carved to accommodate new or different placements of the distributed antenna array module portions **60**A, **60**B (e.g., portions). Moreover, the mold **61** may be distributed into multiple pieces. In particular, as the number of smaller silicon pieces of the silicon components increases, such as by distributing a single piece of a silicon component (e.g., the antenna array module **60**) into multiple portions (e.g., the first and the second antenna array module portions **60**A, **60**B) that are placed in various areas of the package **40**A and have various dimensions, the number of pieces of mold **61** may correspondingly increase. The placement of the mold **61** and/or the dimensions of the pieces of mold **61** may be based on the positioning or layout of the pieces of the silicon component (e.g., distributed pieces of the silicon component).

[0067] As shown, the left side panel **36** also includes the transceiver **20**, the power management circuitry **39**, and the antenna array module portions **60**A, **60**B of the antenna array module **60** (e.g., including the antenna array **50**C). Additionally, the left side panel **36** may include a flexible circuit **48** and radio frequency components **62**A, **62**B. The flexible circuit **48** may include a stiffener **56**, a flex cable **49** (e.g., a flexor), and a connector **57**. The transceiver **20**, the power management circuitry **39**, and the antenna array **50**C may operate as discussed with respect to FIG. **7**.

[0068] Generally, the flexible circuit **48** may include one or more components that enable communication between other components coupled to the flexible circuit **48**. That is, the flexible circuit **48** may be communicatively coupled to components (e.g., of packages and/or on printed circuit boards) to provide a connection or communicative pathway to other components on the same printed circuit board or another printed circuit board of the electronic device **10** (e.g., another printed circuit board of the same panel or another panel of the system package **30**). By way of example, and as depicted, the flexible circuit **48** may communicatively couple to the first antenna array module portion **60**A to enable communication between the first antenna array module portion **60**A and other components. The stiffener **56** of the flexible circuit **48** may include material that provides mechanical support to the components of the flexible circuit **48** during assembly. Specifically, the stiffener **56** may provide stiffness or hardness to areas that are too flexible to perform intended functions. By way of example, the stiffener **56** may provide rigidness in a package of the flexible circuit **48**.

[0069] The flex cable **49** may include a flexible substrate that allows the flexible circuit **48** to conform to a particular shape or flex during its use. In some instances, the flex cable **49** may include a cable that provides a board-to-board (B2B) connection from the flexible circuit **48** to the components mounted on the same printed circuit board or another printed circuit board of the electronic device **10**. By way of example, the flex cable **49** may provide a connection to the main logic board **33**. The connector **57** may be an interconnector between the flexible circuit **48** and the printed circuit board that is coupled to the flexible circuit **48**. That is, the connector **57** provide a board-to-board connection (B2B). In the depicted embodiment, the connector **57** provides a connection between the flex cable **49** and the first antenna array module portion **60**A. As previously mentioned, the solder balls **63**, which provide contact enabling a communication path between contacted components, may provide the contact between the connector **57** and the first antenna array module portion **60**A. The connector **57** may provide a path for communicating data from the flex cable **49** (e.g., data received from the components mounted on the same or another printed circuit board of the electronic device **10**).

[0070] Additionally, the package **40**A of the left side panel **36** may include radio frequency components **62**, such as a first radio frequency component **62**A and a second radio frequency component **62**B that are disposed on top (e.g., with respect to the z-axis **29**) of the second antenna array module portion **60**B. The radio frequency components **62** may include capacitors, inductors, filters, active silicon devices, and/or other radio frequency components that facilitate radio frequency communication. The package **40**A may include the power management circuitry **39** near both of the antenna array module portions **60**A, **60**B for efficient communication (e.g., enabling short communication paths and thus lower latency between power management circuitry **39** and the antenna array module portions **60**A, **60**B). By way of another example, the package **40**A of the left side panel **36** may also include the transceiver **20** near the antenna array module portions **60**A, **60**B for efficient communication. That is, a reduced path may provide faster and strong signal communication.

[0071] In some embodiments, the power management circuitry **39** may be placed in a different area of the package **40**A of the left side panel **36**. In the depicted embodiment, the power management circuitry **39** may be placed in an upright manner with respect to first antenna array module portion **60**A. That is, a bottom surface (e.g., with respect to the z-axis **29**) of the power management circuitry **39** may be positioned on top (e.g., with respect to the z-axis **29**) of the first antenna array module portion **60**A and a top surface (e.g., with respect to the z-axis **29**) of the power management circuitry **39** may be positioned beneath (e.g., with respect to the z-axis **29**) the second antenna array module portion **60**B. In additional or alternative embodiments, the side surfaces (e.g., with respect to the x-axis **27**) of the power management circuitry **39** may be positioned vertically (e.g., with respect to the z-axis **29**) towards the first antenna array module portion **60**A and/or the second antenna array module portion **60**B. In some embodiments, the power management circuitry **39** may connect to different silicon components (e.g., the transceiver **20**) within the package **40**A. In additional or alternative embodiments, an area adjacent to the power management circuitry **39** (e.g., connecting to the first antenna array module portion **60**A and/or the second antenna array module portion **60**B) may include other mounted or soldered components. By way of example, the area adjacent to the power management circuitry **39** may include capacitors for tuning and/or decoupling and/or filters for filtering or removing unintended components or features from a signal. In additional or alternative embodiments, the area adjacent to the power management circuitry **39** may include components made from other semiconductor materials, such as from group III-V of the periodic table and/or from silicon-on-insulator (SOI). These semiconductor components may provide better power consumption and power sensitivity (e.g., power detection) than the silicon components.

[0072] Thus, these space conservation packaging techniques applied to package **40**A of the left side panel **36** provides an efficient design for strategically distributing the antenna array module **60** and/or the mold **61** into a number of portions having particular dimensions. The package **40**A includes placing the distributed portions of the antenna array module **60** (e.g., the first antenna array module portion **60**A and the second antenna array module portion **60**B) to fit the package while maintaining the co-location of the transceiver **20**, the power management circuitry **39**, and the antenna array module portions **60**A, **60**B including the third antenna array **50**C, enabling a space-efficient package. By fragmentizing and distributing the antenna array module **60** into the first antenna array module portion **60**A and the second antenna array module portion **60**B, such that the antenna array module portions **60**A, **60**B may be placed in multiple areas of the package **40**A, the package **40**A gains more free space to add additional components, for example, for new wireless communication parameters (e.g., adding more antennas to provide higher throughput). In particular, the antenna array module portions **60**A, **60**B may be placed in any x-y-z space (e.g. three-dimension (3D) space as indicated by the y-axis **25**, the x-axis **27**, and the z-axis **29**) of the package **40**A. Moreover, each of the antenna array module portions **60**A, **60**B may be strategically distributed to provide a particular antenna array use. By way of example, and as depicted, the first antenna array module portion **60**A may provide the antenna array functionality and/or the antenna array **50** with the antennas, while the second antenna array module portion **60**B provides the antenna array routing circuitry. The antenna array routing circuitry may refer to circuitry that routes signals from the transceiver **20** to the antenna array **50**.

[0073] Additionally or alternatively to the package **40**A of FIG. **8**, the package **40** may include a flex cable **49** without the connector **57**. To illustrate, FIG. **9**A is a schematic diagram of a package **40**B of the left side panel **36** with a flexible cable **49** providing a board-to-board connection. That is, instead of the connector **57** of FIG. **8**, the flex cable **49** may provide the board-to-board connection in the package **40**B. Eliminating the connector **57** from the package **40**A of FIG. **8** may reduce the overall height of the flexible circuit **48**. That is, the dimensions of the flexible circuit **48** may decrease with respect to the z-axis **29** of the 3D space, providing additional space within the package **40**B. As shown, the package **40**B may include the transceiver **20** and the first and second antenna array module portions **60**A, **60**B. These components may function similarly as described with respect to FIG. **8**.

[0074] In the depicted embodiment, the flex cable **49** replaces the connector **57** from the package **40**A of FIG. **8**. In particular, the flex cable **49** provides the functionalities of the connector **57** and thus, obviates the need for the connector **57**, the stiffener **56**, as well as the solder balls **63** that connect the connector **57** to the first antenna array module portion **60**A. That is, because the flex cable **49** is supposed to be flexible, the package **40**B may not use the stiffener **56** for support. The flex cable **49** may provide signal content directly between coupled components (e.g., without any intermediary or intervening components). For example, the flex cable **49** may communicatively couple the first antenna array module portion **60**A to the main logic board **33**, and thus, may provide direct communication between the first antenna array module portion **60**A and the main logic board **33** (e.g., the transceiver **20** of the main logic board **33**), without any intermediary or intervening components. As such, the package **40**B may eliminate or not include the connector **57** of the package **40**A of FIG. **8** and, instead, use the flex cable **49** for routing data and providing a direct communication path between the first antenna array module portion **60**A and the main logic board **33**. In some embodiments, the flex cable **49** may communicatively couple multiple components of the same package, such as the first antenna array module portion **60**A and the second antenna array module portion **60**B. As such, the flex cable **49** may communicate data between both the first antenna array module portion **60**A, the second antenna array module portion **60**B, and/or components on the main logic board **33**.

[0075] As previously mentioned, the package **40**B of the left side panel **36** gains additional space along the z-axis **29** of the 3D space when compared to the package **40**A of FIG. **8** by eliminating the connector **57**. The additional space may accommodate additional and/or different components, such as additional antennas. For example, the package **40**B of the left side panel **36** may include the antenna array module **60** with additional layers for additional antennas and/or circuitry supporting antenna functions. The additional layers may include third band antennas **55** and/or circuitry supporting the third band antennas **55** (e.g., high-band antennas) for mmWave communications.

[0076] In some embodiments, and as will be discussed in detail with respect to FIG. **12** and FIG. **13**, the first antenna array module portion **60**A may include cavities **74**. Antennas **75** (e.g., the first band antennas **51**, the second band antennas **53**, and the third band antennas **55**) may be placed inside the cavities **74**. That is, the antenna array module **60**, which includes the antennas **75** of the antenna array **50**C, may be distributed into multiple portions to enable a controller or a processor of the electronic device **10** (e.g., processor **12** of FIG. **1**) to locally control the antennas **75**. The first antenna array module portion **60**A may include the antenna routing circuitry (e.g., circuitry from the transceiver **20** to the antenna array **50**C), as well as the cavities **74** with the individual antennas **75**. Specifically, the package **40**B may include the first antenna array module portion **60**A with a distributed antenna array **50**C within one or more portions having one or more antennas **75**. In some embodiments, each antenna **75** may be placed in a respective cavity **74**. In such embodiments, the first antenna array module portion **60**A may efficiently provide the appropriate antenna routing to each antenna **75** disposed in the respective cavity **74**. By way of example, the first antenna array module portion **60**A may enable the processor to locally control amplification for reception signals or transmission signals from the antennas **75**. In some embodiments, the first antenna array module portion **60**A may be distributed to include one or more portions having one or more capacitors or silicon devices for tuning the antennas **75**, radio frequency band switches, and/or other antenna related components. The cavities **74** with the antennas **75** may enable radiating wireless signals from the left side of the electronic device **10** (e.g., from the negative x-axis **27**). Similarly, cavities **74** with the antennas **75** of a package **40**B of the right side panel **38** may enable radiating wireless signals from the right side of the electronic device **10**.

[0077] FIG. **9**B is schematic diagram of a package **40**C of the left side panel **36** with the flex cable **49** coupling packaging to a flex top surface **46** of the flex cable **49** and to a bottom flex surface **52** of the flex cable **49** (e.g., vertical communication within the package **40**C). As shown, the package **40**C may include the power management circuitry **39**, the transceiver **20**, the stiffener **56**, the first antenna array module portion **60**A, and the second antenna array module portion **60**B. These components may function similarly as described with respect to FIG. **8**. As previously mentioned, the package **40**C may include the flex cable **49** that provides the same or approximately the same functions provided by the connector **57**, which is eliminated in the package **40**C as compared to the package **40**A shown in FIG. **8**. As such, the flex cable **49** may provide general flexor functions, such as providing a physically flexible or bendable communication pathway that may carry data signals between components on printed circuit boards coupled to a first side or end of the flex cable **49** and components connected to a second side or end of the flex cable **49**.

[0078] The flex cable **49** may transfer data between components coupled above and/or below on the flex top surface **46** and/or the flex bottom surface **52** of the flex cable **49**. To illustrate, the first antenna array module portion **60**A couples to the flex bottom surface **52** of the flex cable **49** and the second antenna array module portion **60**B couples to the flex top surface **46** the flex cable **49** via solder balls **63**. In additional or alternative embodiments, the flex cable **49** may couple to and communicate with components mounted on either end of the flex cable **49**. In some embodiments, the components may be mounted directly onto the flex cable **49** (e.g., without solder balls **63**).

[0079] Moreover, by eliminating the connector **57** (e.g., of package **40**A of FIG. **8**) and providing the corresponding functionality in the flex cable **49**, the package **40**C of the left side panel **36** may gain free space **59**. By way of example, the free space **59** may include a 20 millimeter.sup.2 (mm.sup.2) to 25 mm.sup.2 area. The free space **59** may accommodate upgrading the size of existing components (e.g., to increase the functionality or resources provided by those components), adding new components, and/or deconstructing certain silicon components (e.g., packages, modules, and/or layers of the portions) and adding the deconstructed silicon components to the free space **59** to decrease the overall 1 size of the package **40**C and/or the electronic device **10**.

[0080] As shown, the power management circuitry **39** and the transceiver **20** are placed on top of the second antenna array module portion **60**B (e.g., with respect to the z-axis **29**), which represents a particular embodiment. In other embodiments, the power management circuitry **39** and the transceiver **20** may be placed inside a silicon portion of an embedded die that is placed on top of the second antenna array module portion **60**B (e.g., with respect to the z-axis **29**), such that the power management circuitry **39** and the transceiver **20** are no longer visible from outside the embedded die. Additionally or alternatively, the power management circuitry **39** and the transceiver **20** may be placed on top of the flex cable **49** (e.g., with respect to the z-axis **29**) or elsewhere in the package **40**C, and the second antenna array module portion may be combined with the first antenna array module portion **60**A (e.g., in antenna layer constructed as a single piece). In any case, the power management circuitry **39** and the transceiver **20**, as well as the other components, may be moved and/or distributed to be efficiently placed within the package **40**C based on co-location and/or packaging size specifications associated with the left side panel **36**.

[0081] In some instances, for example, if the package **40**C includes an amplifier RFIC **42**, the package **40**C may fit the amplifier RFIC **42** in the free space **59** gained from eliminating the connector **57** of the package **40**A of FIG. **8**. In some embodiments, the package **40**C may gain additional area by deconstructing silicon or distributing silicon components, such as the first antenna array module portion **60**A. To communicate data between the amplifier RFIC **42** and the antennas associated with the amplifier RFIC **42**, the antennas may be placed or coupled to the flex cable **49**, opposite the amplifier RFIC **42**. To illustrate, FIG. **9**C is a schematic diagram of the package **40**D of the front glass panel **32** with the flex cable **49** coupling antennas of the first antenna array module portion **60**A and the amplifier RFIC **42**. As shown, the package **40**D may include the power management circuitry **39**, the transceiver **20**, the first and second antenna array module portions **60**, and the amplifier RFIC **42**. These components may function similarly as described with respect to FIG. **8**.

[0082] As previously mentioned, by eliminating the connector **57** of the package **40**A of FIG. **8** and including the same functionality in the flex cable **49**, as well as deconstructing the silicon, the package **40**D may gain free space **59**. The additional space may provide an area to place the amplifier RFIC **42** near or co-located with the antenna array module portions **60**A, **60**B. As previously discussed, the amplifier RFIC **42** may efficiently amplify and/or convert signals when placed closed to the antennas that transmit and/or receive the wireless signals due the short travel distance. The distance may be based on the dimensions and/or a number of antennas in an antenna array **50**. By way of example, the distance may range from approximately 0 to 50 mm (e.g., 10 mm, 20 mm, 30 mm) for a 1×2 antenna array **50**, a 2×4 antenna array **50**, or a 1×8 antenna array **50**.

[0083] As such, the space conservation packaging techniques applied to the package **40**D of the front glass panel **32** including elimination of the connector **57** of the package **40**A of FIG. **8** and/or enabling the flex cable **49** to receive data from components (e.g., on or off package) and to communicate data to coupled panels on the package **40**D, may provide space to place the amplifier RFIC **42** near the antennas of the first antenna array module portion **60**A and the second antenna array module portion **60**B, while enabling more efficient wireless communication.

[0084] In some embodiments, the antenna array module portions **60**A, **60**B may be further distributed into multiple portions or segments. For example, and as shown, the first antenna array module portion **60**A may be distributed into portions that each include one or more antennas. In some embodiments, the antennas may be distributed based on antenna type (e.g., first band antennas **51**, second band antennas **53**, or third band antennas **55**), antenna circuitry, antenna use (e.g., for transmission or reception), and so forth. To illustrate, the depicted embodiment shows the first antenna array module portion **60**A distributed into six portions **64**A-F based on the antenna type. That is, each of the portions **64** include one or more of the first band antenna **51**, the second band antenna **53**, and/or the third band antenna **55** of the first antenna array module portion **60**A. In some embodiments, each of the portions **64** may also include the circuitry to support the respective antenna(s). By way of example, the antenna array module **60** may include sixteen metal layers (e.g., silicon layers) that include the antennas, antenna circuitry for functionality and routing, and so forth. The antenna array module **60** may be distributed into the second antenna array module portion **60**B and six smaller portions **64**A-F (e.g., making up the first antenna array module portion **60**A). By way of example, the second antenna array module portion **60**B may include ten metal layers with wireless communication routing. Additionally, the six portions **64**A-F of the first antenna array module portion **60**A may be coupled to the flex cable **49**. Since the flex cable **49** is flexible, such that the flex cable **49** may be bendable to various angles (e.g., 0° up to 360°), the antennas of the first antenna array module portion **60**A may be positioned at the corresponding various angles (e.g., positioned in a tilted manner) while remaining coupled to the flex cable **49**. In contrast, antennas disposed on a plane (e.g., printed circuit board) may be limited to a positioning range smaller than the positioning range for the flex cable **49**. For example, antennas fixed to the plane may be positioned perpendicular (e.g., 90°) with respect to the plane, while antennas coupled to the flexible cable **49** may be positioned at various angles including non-perpendicular angles (e.g., between 1° and 359°, between 10° and 350°, between 30° and 330°, between 50° and 310°, and so on) with respect to the plane by bending the flexible cable **49**. As such, the antennas coupled to the flex cable **49** may radiate wireless signals at the non-perpendicular angles.

[0085] The signals communicated over high-band frequencies (e.g., signals communicated over mm Wave) may be more susceptible to signal loss than signals communicated over mid-band or low-band frequencies. As such, the package **40**D of the front glass panel **32** may include the amplifier RFIC **42** and the third band antennas **55** (e.g., high-band antennas) of the antenna array portions on either and opposite sides of the flex cable **49**. That is, the flex cable **49** may provide a shorter path for communication between the amplifier RFIC **42** and the third band antennas **55** (e.g., when compared to communication paths between the amplifier RFIC **42** and the first band or second band antennas **51**, **53**). Additionally or alternatively, the package **40**D may position the antennas in a sequential or alternating manner, such as from the negative to the positive x-axis **27** (e.g., a first portion **64**A including a first band antenna **51** and a second band antenna **53**, a second portion **64**B including a third band antenna **55**, a third portion **64**C including a first band antenna **51** and a second band antenna **53**, and so forth).

[0086] FIG. **10** illustrates a schematic diagram of a package **40**E of the left side panel **36** with the power management circuitry **39** directly coupled to the distributed antenna array module **60** including the first antenna array module portion **60**A and the second antenna array module portion **60**B. As shown, the package **40**E includes the transceiver **20**, the power management circuitry **39**, and the antenna array module **60** including the first antenna array module portion **60**A and the second antenna array module portion **60**B electrically coupled via solder balls **63**. The package **40**E also includes the flexible circuit **48** and first and second radio frequency components **62**A, **62**B (e.g., capacitors, inductors, filters, active silicon devices, and/or other like radio frequency components). As previously discussed, the flexible circuit **48** may include the stiffener **56**, the flex cable **49**, and a connector **57**. These components may operate as discussed with respect to FIGS. **7** and **8**. Although the following descriptions describe the package **40**E with a distributed antenna array module **60** with the first antenna array module portion **60**A and the second antenna array module portion **60**B, which represents a particular embodiment, the package **40**E may instead include a single antenna array module **60** and a power control module coupled via the solder balls **63**. Specifically, the power control module may operate similar to the power management module **41**, as described with respect to FIG. **7**.

[0087] As shown, the power management circuitry **39** may be placed adjacent to the antenna array module **60** including the first antenna array module portion **60**A and the second antenna array module portion **60**B, such that the power management circuitry **39** is directly coupled to the antenna array module **60** and thus, is co-located to the antenna array module **60**. In the depicted embodiment, a bottom side of the power management circuitry **39** that is facing the negative z-axis **29** may be coupled to the first antenna array module portion **60**A while a top side facing the positive z-axis **29** of the power management circuitry **39** is coupled to the second antenna array module portion **60**B. The power management circuitry **39** may be in direct contact with the antenna array module **60**, such that the power management circuitry **39** does not use interconnecting materials (e.g., solder balls **63**) to connect or communicate with the antenna array module **60**. In particular, the power management circuitry **39** may directly couple to or attach to an exposed surface of the antenna array module **60**. The power management circuitry **39** may also be co-located to the transceiver **20**. The co-location of the power management circuitry **39** to the transceiver **20** and the antenna array module **60** may enable the power management circuitry **39** to efficiently control power related functions for wireless signals from the antennas of the antenna array module **60** while reducing or minimizing signal loss and/or noise.

[0088] The package **40**E of the left side panel **36** may also include integrated passive devices **65** (IPD), such as resistors, inductors, capacitors, and/or baluns. Here, the integrated passive devices **65** are coupled (e.g., directly coupled) to the second antenna array module portion **60**B. Generally, the integrated passive devices **65** may enable or facilitate impedance tuning and/or matching to reduce or minimize power loss and enhance wireless signal transmission. Impedance matching may facilitate transferring a signal from a source to a load (e.g., an antenna for transmission) with reduced or minimal signal loss (e.g., reducing or minimizing signal reflection along the path from the source to the load).

[0089] Moreover, the package **40**E of the left side panel **36** includes the first radio frequency component **62**A and the second radio frequency component **62**B on top of the second antenna array module portion **60**B (e.g., with respect to the z-axis **29**). The dimensions of the radio frequency components **62** may be based on available space within the package **40**E, and the available space may be based on the co-location of the power management circuitry **39**, transceiver **20**, and antenna array module **60**, as well as the number of antennas for communicating using the left side panel **36**.

[0090] In some embodiments, the packaging may include a system-in-package (SiP) for the power management circuitry **39**. To illustrate, FIG. **11** is a schematic diagram of a package **40**F of the left side panel **36** with a power management package **70**. The power management package **70** may be a system-in-package for the power management circuitry **39** that includes one or more integrated circuits enclosed in one or more chip carrier packages that are stacked (e.g., using a package on package (POP) technique). The power management package **70** may perform power-related functions for the left side panel **36**. The one or more integrated circuit dies may be stacked vertically on a substrate and may be internally coupled by wires bonded to the package or by solder bumps that are used to join the integrated circuit dies together in the stack. The power management package **70** may also include supporting circuitry to support the power-related functions.

[0091] In some embodiments, the power management package **70** may have a large z-axis **29** volume or depth to support the integrated circuit dies and/or the circuitry in the package. By way of example, the power management package **70** may have height ranging from 0.1 mm to 2.5 mm (e.g., 0.5 mm, 2 mm, 2.5 mm, and so forth). To provide space for the power management package **70**, the package **40**F may include smaller or shorter antennas in the antenna array module **60**, such as the depicted first antenna array module portion **60**A. In particular, the width of the antenna array module **60** along the x-axis **27** may be reduced to gain free space for placing the power management package **70**. Additionally or alternatively to reducing the dimension of the antenna array module **60** along the x-axis **27**, the height along the z-axis **29** and/or the length along the y-axis **25** may be reduced to provide the free space. In this manner, the package **40**F gains free space that was previously used by the larger antenna array module **60**. The package **40**F with the smaller antennas provides space for silicon components (e.g., modules, boards, and/or packages) adjacent to the first antenna array module portion **60**A.

[0092] Moreover, since the power management package **70** is a separate package, for example, from the other components attached to the printed circuit boards in the package **40**F, the power management package **70** may be tested individually. By way of example, testing may include a test of each of the integrated circuit dies, components within the power management package **70** (e.g., passive and/or active devices), the supporting circuitry, routing between the dies and/or circuitry, connectivity to other silicon components within the package **40**F of the left side panel **36**.

[0093] Additionally, by using smaller or shorter antennas in the first antenna array module portion **60**A, such that the first antenna array module portion **60**A may be shortened along the x-axis **27** (e.g., in width) and the power management package **70** may be placed in the freed space, free space **59**. The radio frequency components **62**, which may include resistive components, may be replaced with larger resistive components, including but not limited to, larger resistors, inductors, capacitors, resonators (e.g., acoustic and/or mechanical), and so forth, that are surface mount components. By way of example, the larger resistive components may have dimensions in a range of approximately 0.2 mm×0.1 mm (e.g., 0.008 inches×0.005 inches) to 2.0 mm×2.5 mm. That is, the power management circuitry **39** that was previously placed on top of the wider first antenna array module portion **60**A (e.g., along the z-axis **29**) in the package **40**E of FIG. **10** may be replaced with the power management package **70**. The replacement provides the package **40**F with additional space along the z-axis **29** (e.g., in height) on top of the first antenna array module portion **60**A. Moreover, removing the power management circuitry **39** provides the package **40**F with space to extend the second antenna array module portion **60**B along the x-axis **27**. The additional free space in both the x-axis **27** and the z-axis **29** directions within the 3D space of the package **40**F may accommodate different dimensions of the radio frequency components **62**, including different dimensions of resistive components. For example, the radio frequency components **62**, such as inductors and/or capacitors, may include taller radio frequency components **62**, such as buck convertors, boost convertors, and/or buck-boost convertors. Additionally or alternatively, the radio frequency components **62** may include larger capacitors, which store energy more efficiently than smaller capacitors.

[0094] In some embodiments, and as previously mentioned, the package **40** may include pockets or cavities that are formed in a portion of the antenna array module **60**. In particular, the cavities may be formed by removing, drilling, layering out, laser drilling, sand blasting, and the like, portions of the antenna array module **60**. In some embodiment, the antenna array module **60** may be composed of laminate or ceramic material. Thus, by removing portions of the laminate or ceramic material, the package **40** may expose surfaces of antennas and make the antennas more easily accessible. As such, the exposed areas of the antennas may connect to other components, such as capacitors, switches, diodes, amplifiers (e.g., low noise amplifiers, power amplifiers), receivers, and so forth. The connection between the antennas and the other components may provide a variety of wireless communication functions, such as tuning the antennas using the other components. To illustrate, FIG. **12** is a schematic diagram of a package **40**G of the left side panel **36** with cavities **74** in the first antenna array module portion **60**A. As shown, the package **40**G includes the transceiver **20**, the antenna array module **60** including the first antenna array module portion **60**A and the second antenna array module portion **60**B that are electrically coupled via solder balls **63**, the radio frequency components **62**, the connector **57** that couples to the main logic board **33** (as indicated by the dashed line box) via the flex cable **49**, and the power management package **70**. These components may operate as discussed with respect to FIGS. **7** and **8**. Additionally, although the following descriptions describe the package **40**G with a distributed antenna array module **60** with the first antenna array module portion **60**A and the second antenna array module portion **60**B, which represents a particular embodiment, the package **40**G may instead include a single antenna array module **60** electrically coupled to a power control circuitry **39** (e.g., on top of the single antenna array module **60** with respect to the z-axis **29**) via solder balls **63**. The power control circuitry may operate similar to the power management module **41**, as described with respect to FIG. **7**.

[0095] As shown, the package **40**G of the left side panel **36** includes the first antenna array module portion **60**A having sub-antenna array portions **72**, including a first sub-antenna array portion **72**A, a second sub-antenna array portion **72**B, a third sub-antenna array portion **72**C, and a fourth sub-antenna array portion **72**D. Each of the sub-antenna array portions **72** may include one or more antennas, such as the first band antennas **51**, the second band antennas **53**, and/or the third band antennas **55**. Additionally or alternatively, the sub-antenna array portions **72** may include routing related to the wireless communications, such as routing between components utilized when transmitting the transmission signals and/or receiving the reception signals, and the antennas. In some embodiments, the sub-antenna array portions **72** may include mold (e.g., pieces of mold) and/or dielectric materials with a high dielectric constant (e.g., high k).

[0096] In some embodiments, by implementing the sub-antenna array portions **72** that include antennas and/or antenna functionality (e.g., routing between components), the package **40**G may provide additional space within the first antenna array module portion **60**A. For example, the first antenna array module portion **60**A may include cavities **74** (e.g., gaps or air pockets). The cavities **74** may encase components that may otherwise be coupled to the first antenna array module portion

60A. As shown, the package **40**G includes cavities **74** along the bottom side (e.g., with respect to the z-axis **29**) of the first antenna array module portion **60**A. As previously mentioned, the antenna array module **60**, including the first antenna array module portion **60**A and the second antenna array module portion **60**B, includes a silicon substrate. The cavities **74** may be formed by an etching process or a similar process that may form cavities **74** within the antenna substrate of the first antenna array module portion **60**A. Although the depicted embodiment shows cavities **74** along the bottom side, which represents a particular embodiment, the package **40**G may include cavities **74** anywhere within the first antenna array portion **60**A, such as along the top side in the positive z-axis **29**, right side in the positive x-axis **27**, left side in the negative x-axis **27**, in the middle rather than a side, and so forth.

[0097] To illustrate the cavities **74** encapsulating components, FIG. **13** is a schematic diagram of a package **40**H of the left side panel **36** including antennas **75** disposed within the cavities **74** of FIG. **12**. As shown, each of the cavities **74** include at least one respective antenna **75**, which may include the first band antennas **51**, the second band antennas **53**, and/or the third band antennas **55**. In some embodiments, the package **40**H may include additional antennas **75** (e.g., in the cavities **74**) to accommodate mmWave communication. In some embodiments, the left side panel **36** may include, be mounted to, or be placed adjacent to a side glass of the electronic device **10**. In such embodiments, the antennas **75** in the cavities **74** may be positioned on the side of the electronic device **10** in the positive or negative x-axis **27** and radiate through the side glass, such that signals from these antennas **75** radiate towards or away from the electronic device **10** (e.g., rather than downwards in the negative z-axis **29**). In some embodiments, the antennas **75** in the cavities **74** may replace antennas positioned elsewhere within the electronic device **10**, such as antennas **75** that may otherwise be positioned next to a USB connector, a power button, etc. That is, the cavities **74** provide space for placement of the antennas **75** (e.g., components in the cavities **74**) and other circuitry of the first antenna array module **60**A. In some embodiments, the antennas **75** in the cavities **74** may be positioned along an edge of the electronic device **10**, such that the antennas **75** may radiate through the edge. The antennas **75** in the cavities **74** radiating wireless signals may be stronger than wireless signals radiated from antennas **75** elsewhere in the package **40**H (e.g., disposed further from the edge than the antennas **75** in the cavities **74**) due to the close proximity between the antennas **75** in the cavities **74** and the edge.

[0098] FIG. **14** is a schematic diagram of a package **40**I of the back glass panel **34** with the main logic board **33** adjacent to the antenna array module **60**, and that are both adjacent to a transceiver and power management package **80**. That is, the antenna array module **60** is in the positive x-axis **27** with respect to the main logic board **33** and the transceiver and power management package **80** is in the positive z-axis **29** with respect to the main logic board **33** and the antenna array module **60**. The package **40**I may also include the integrated passive devices **65** (e.g., radio frequency inductance passive devices). Placing the main logic board **33**, the transceiver and power management package **80**, and the antenna array module **60** adjacently (as depicted) may provide more efficient routing, lower signal loss, and reduce power consumption due to not using solder balls **63** and/or the proximity of the components when compared to stacking the transceiver and power management package **80** on top of the main logic board **33**, further stacked on top of the antenna array module **60**.

[0099] The transceiver and power management package **80** may be a system-in-package and include the power management circuitry **39** and the transceiver **20** and function as described with respect to FIG. **7** and FIG. **8**. Similarly, the integrated passive devices **65** may function as described with respect to FIG. **10**. Although the following descriptions describe the package **40**I with the antenna array module **60**, which represents a particular embodiment, the package **40**I may instead include the antenna array **50** with the first band antennas **51**, the second band antennas **53**, and/or the third band antennas **55** (e.g., without routing and function circuitry). For the reasons previously discussed, the transceiver and power management package **80**, with the power management circuitry **39** and the transceiver **20**, and the antenna array module **60** may be co-located. Additionally, the main logic board **33** may also be co-located to the transceiver and power management package **80** and the antenna array module **60** to facilitate communicating configuration data for components of the power management circuitry **39**, the transceiver **20**, and/or the antenna array module **60**.

[0100] In some embodiments, and as depicted, the solder balls **63** may connect and enable communication between the various packages and components. By way of example, the main logic board **33** may communicate with the antenna array module **60** by passing signals through the transceiver and power management package **80**. That is, the transceiver and power management package **80** may function as an intermediary communication path between the main logic board **33** and the antenna array layer **60**. Although the depicted embodiment shows the main logic board **33** placed adjacent to the antenna array module **60**, which represents a particular embodiment, the package may be configured in a 3D stack that includes the main logic board **33** placed in parallel to the antenna array module **60**. For example, the main logic board **33** may be coupled to a bottom side of the transceiver and power management package **80** (e.g., in the negative z-axis **29** with respect to the transceiver and power management package **80**) and the antenna array module **60** may be coupled to a top side of the transceiver and power management package **80** (e.g., in the positive z-axis **29** with respect to the transceiver and power management package **80**), or vice versa. In some embodiments, the integrated passive devices **65** may directly couple (e.g., without solder balls **63**) to the transceiver and power management package **80** and the antenna array module **60**.

[0101] FIG. **15**A is a schematic diagram of a package **40**J of the left side panel **36** having underfill and shielding for the antenna array module **60**. As shown, the package **40**J may include a power management circuitry **39**, a transceiver **20**, and a flexible circuit **48**. As previously mentioned, the flexible circuit **48** may include the stiffener **56**, the flex cable **49**, and a connector **57** (not shown). The package **40**J may also include the antenna array module **60** that is distributed into three portions, including the first antenna array module portion **60**A, the second antenna array module portion **60**B, the third antenna array module portion and **60**C. Although the following discussions describe three portions of the antenna array module **60**, which represents a particular embodiment, the system package **30** described herein may include one or more portions of the antenna array module **60** (e.g., one, greater than one, two, five, sixteen, and so forth). As previously mentioned, distribution of the antenna array module **60** into the one or more portions having a particular number of layers may be based on a functionality, a device type, an application type, and so forth, to be supported by each of the one or more portions. In some embodiments, the placement and/or the dimensions of each of the one or more portions may be based on surrounding components, bandwidth to be supported, carrier to be support, and/or packaging size. The power management circuitry **39**, the transceiver **20**, the flexible circuit **48**, and the antenna array module **60** may operate or provide functionalities as previously described.

[0102] The package **40**J may include a package underfill **86** that encapsulates and/or surrounds the solder balls **63**. Although the following descriptions describe the package underfill **86** with respect to the antenna array module **60**, which represents a particular embodiment, the system package **30** described herein may include package underfill **86** in any area of the system package **30** that includes solder balls **63**, solder pads, through vias, and/or any other coupling or intermediate components (e.g., surrounds the transceiver and power management package **80** and/or the power management circuitry **39**). In some embodiments, the package underfill **86** may also encapsulate silicon components, such as passive or active devices, dies, printed circuit boards, and so on, to provide mechanical support. Generally, the package underfill **86** may protect the solder balls **63** from mechanical stress, such as by providing support or alleviating the stress between the solder balls **63** and substrates supported by the solder balls **63** (e.g., the second antenna array module portion **60**B and the third antenna array module portion **60**C). The package underfill **86** may include any adhesive materials, such as epoxy (e.g., a silver-filled epoxy or another conductive material that fills the epoxy).

[0103] In some embodiments, the package underfill **86** may also provide thermal stress support, such as by dissipating heat from surrounding substrates (e.g., substrates of the second antenna array module portion **60**B and the third antenna array module portion **60**C) to other areas of the system package **30**, such as other panels or areas of the electronic device **10**. In this manner, heat may be prevented from concentrating in one particular area of the package **40**J of the left side panel **36**. The package underfill **86** may also be mixed with other materials, such as ceramic or metallic materials, to provide additional functions, such as the thermal dissipation.

[0104] The package underfill **86** may be in liquid form, near liquid form, or initially in liquid form to flow into any gaps (e.g., areas around the solder balls **63** between the first antenna array module portion **60**A and the second antenna array module portion **60**B and the second antenna array module portion **60**B and the third antenna array module portion **60**C). After settling into the gaps, the package underfill **86** may undergo a curing process to harden.

[0105] The package **40**J may also include shielding **88** (e.g., conformal shielding). In particular, the package underfill **86** may prevent shielding **88** from falling into gaps or between the spaces, as those areas are filled with the package underfill **86**. As shown, the shielding **88** may be placed around whole portions (e.g., without gaps or spacing between components or substrates) of the package **40**J. The shielding **88** may include an outer conductive coating layer that provides package-to-package isolation. In particular, he isolation may provide protection from electromagnetic interference (EMI), providing compliance with Federal Communications Commission (FCC) standards at a component or board level. In some embodiments, the shielding **88** may be placed around portions of the package **40**J that emit signals that may cause disruption (e.g., noise) if left unblocked.

[0106] To illustrate, FIG. **15**B is a schematic diagram of a package **40**K of the left side panel **36** with shielding **88** disposed about some portions of the first antenna array module portion **60**A. The first antenna array module portion **60**A may be distributed into sub-antenna array portions **72**, as described with respect to FIG. **12**. In the depicted embodiment, a first sub-antenna array portion **72**A, a second sub-antenna array portion **72**B, and a third sub-antenna array portion **72**C may include shielding **88** on each exposed surface (e.g., wall). However, a fourth sub-antenna array portion **72**D and a fifth sub-antenna array portion **72**E may not include shielding on each exposed surface area. In particular, as depicted, one exposed surface **89** (e.g., wall) of each of the sub-antenna array portions **72**D, **72**E do not include shielding. The shielding **88** provided may be based on a threshold level of noise emitted from each of the sub-antenna array portions **72**. For example, the first through the third sub-antenna array portions **72**A-C may emit more noise than the fourth and fifth sub-antenna array portions **72**D and **72**E, and, as such, may be equipped with more shielding **88**.

[0107] In some embodiments, the package **40** may include direct coupling between silicon components, such as between multiple substrates. To illustrate, FIG. **16** is a schematic diagram of a package **40**L of the left side panel **36** with the first antenna array module portion **60**A directly coupled to the second antenna array portion **60**B. That is, the first and the second antenna array module portions **60**A and **60**B may be directly coupled (e.g., by stacking) using an adhesive material and without using soldering, such as the solder balls **63**. Specifically, the second antenna array module portion **60**B may be placed on top of the first antenna array module portion **60**A (e.g., in the positive z-axis **29**) and coupled using the adhesive material, such as conductive epoxy. In particular, the adhesive material may electrically couple signals from the second antenna array module portion **60**B to the first antenna array module portion **60**A. In the depicted embodiment, the package **40**L of the left side panel **36** with the adhesive material that couples substrates of the first and the second antenna array module portions **60**A and **60**B, may not use package underfill **86** since there is no intermediate connection between the substrates (e.g., no solder balls **63**).

[0108] FIG. **17** is schematic diagram of a package **40**M of the left side panel **36** with a recess **90** (e.g., recessed area) cut out or carved out from a substrate (e.g., antenna substrate) of the antenna array module (e.g., the second antenna array module portion **60**B). In particular, the second antenna array module portion **60**B may include the recess **90** to accommodate, for example, additional or different components (e.g., taller components as compared to the package **40**G of FIG. **12** while maintaining similar dimensions. The amount, shape, and/or dimensions of the recess **90** may be based at least on the components to be placed within the recess **90**. Moreover, the package **40**M with components in the recess **90** may include the distributed form of the antenna array module **60** including the first and the second antenna array module portions **60**A and **60**B. By way of example, the components may have a height (e.g., space along the z-axis **29**) range between 0.5 mm to 1.2 mm. The dimensions, such as the height, of the recess **90** may be based on the components and have a corresponding height of at least 0.5 mm to 1.2 mm. Breaking apart the antenna array module **60** into multiple portions may continue creating usable space within the package **40**M to accommodate adding or expanding components, as well as freeing up space constraints associated with certain components (e.g., placing the power management circuitry **39** and the transceiver **20** in close proximity to the antenna array module **60**).

[0109] In some embodiments, the package **40** of the left side panel **36** may be wider towards the top of the package in the positive z-axis **29** and narrower at the bottom of the package in the negative z-axis **29**, or vice versa. To illustrate, FIG. **18** is schematic diagram of a package **40**N of the left side panel **36** with relatively wider top portion **92** and a narrower bottom portion **94**, creating a “t-shaped” structure. The relatively wider top portion **92** and narrower bottom portion **94**, or vice versa, enables placement of various sized components and/or modules in the appropriate portion of the structure. For example, if the first antenna array module portion **60**A is wider than second antenna array module portion **60**B (e.g., along the x-axis **27**), then the first antenna array module portion **60**A may be placed in the relatively wider top portion **92** and the second antenna array module portion **60**B may be placed in the relatively narrower bottom portion **94** of the structure.

[0110] Since the top portion **92** is wider, the top portion **92** may accommodate more and/or larger components than the bottom portion **94**. By way of example, the top of the package **40**N may have a length of approximately 0.1 mm to 100 mm (e.g., 0.2 mm, 10 mm to 50 mm, such as 10 mm, 20 mm, 25 mm, 30 mm, 40 mm, and so on) in the x-axis **27** direction while the bottom of the package **40**N has a length less than the length of the top of the package **40**N in the x-axis **27** direction. For example, the top portion **92** of the package **40**N may have a length of 0.023 mm to 0.0235 mm in the x-axis **27** direction while the bottom portion **94** of the package **40**N may have a length of 0.022 mm in the x-axis **27** direction. As another example, the top portion **92** and the bottom portion **94** of the package **40**N may have the same length. That is, the depicted package **40**N of FIG. **18** illustrates a T-shape, but in additional or alternative embodiments, the bottom portion **94** may be wider than the top portion **92** (e.g., corresponding to an upside-down T-shape or L-shape), or they be of the same width, as shown in at least FIGS. **8**, **9**B, **10**, **11**, **12**, **15**A, and **15**B above.

[0111] As such, the techniques described herein facilitate efficient modification of a radio frequency package at various sides of a radio frequency device (e.g., a back glass side, a front glass side, a left side, and/or a right side of the radio frequency device). The space conservation packaging techniques described herein may enable adding and/or replacing components to provide additional or new wireless communication support while conserving space, maintaining a distance between particular components (e.g., spacing), co-location of particular components, or other particular position based specifications, within the radio frequency package for a particular side of the radio frequency device. Some space conservation packaging techniques, such as distributing a substrate (e.g., the antenna array module) into smaller portions for various placement throughout a package may also allow parallel manufacturing of the smaller portions with the smaller number of layers. In this manner, the package may be efficiently produced in a shorter time period than manufacturing the package without the distributed substrate.

[0112] The techniques presented and claimed herein are referenced and applied to material objects and concrete examples of a practical nature that demonstrably improve the present technical field and, as such, are not abstract, intangible or purely theoretical. Further, if any claims appended to the end of this specification contain one or more elements designated as "means for [perform]ing [a function] . . . " or "step for [perform]ing [a function] . . . ," it is intended that such elements are to be interpreted under 35 U.S.C. 112(f). However, for any claims containing elements designated in any other manner, it is intended that such elements are not to be interpreted under 35 U.S.C. 112(f).

Claims

1-20. (canceled)

21. A radio frequency package, comprising: a first portion of an antenna array module; and a second portion of the antenna array module, wherein the first portion of the antenna array module, the second portion of the antenna array module, or both, is distributed into a plurality of sub-antenna array portions, wherein a shielding is disposed on one or more exposed surfaces of one or more sub-antenna array portions of the plurality of sub-antenna array portions.

22. The radio frequency package of claim 21, wherein the shielding is disposed on each exposed surface of a first sub-antenna array portion of the one or more sub-antenna array portions.

23. The radio frequency package of claim 22, wherein the shielding is not disposed on at least one exposed surface of a second sub-antenna array portion of the one or more sub-antenna array portions.

24. The radio frequency package of claim 21, wherein the shielding is based at least in part on a threshold level of noise emitted from each of the plurality of sub-antenna array portions.

25. The radio frequency package of claim 21, wherein each of the plurality of sub-antenna array portions comprises one or more dielectric materials, mold pieces, antennas, or any combination thereof.

26. The radio frequency package of claim 21, wherein the shielding comprising a conformal shielding.

27. The radio frequency package of claim 21, comprising power management circuitry configured to manage power supplied to the radio frequency package, wherein the power management circuitry is directly coupled to the first portion of the antenna array module and the second portion of the antenna array module.

28. The radio frequency package of claim 27, wherein the power management circuitry is arranged between the first portion of the antenna array module and the second portion of the antenna array module.

29. The radio frequency package of claim 28, comprising: a plurality of solder balls coupling the first portion to the second portion; and a package underfill disposed in gaps between the plurality of solder balls, the first portion, the second portion, the power management circuitry, or any combination thereof.

30. A system package disposed on a first printed circuit board, comprising: a first portion of an antenna array module configured to provide a first wireless communication function; a second portion of the antenna array module configured to provide a second wireless communication function different than the first wireless communication function, wherein a shielding is disposed on one or more first exposed surfaces of the first portion, the second portion, or both; and a flex circuit coupling the system package to a second system package disposed on a second printed circuit board.

31. The system package of claim 30, wherein the shielding is not disposed on one or more second exposed surfaces of the first portion, the second portion, or both.

32. The system package of claim 30, wherein the flex circuit and the first portion of the antenna array module are disposed on top of the second portion of the antenna array module.

33. The system package of claim 30, wherein the first portion of the antenna array module, the second portion of the antenna array module, or both, is distributed into a plurality of sub-antenna array portions, wherein the shielding is disposed on one or more exposed surfaces of one or more sub-antenna array portions of the plurality of sub-antenna array portions, and wherein the shielding is based at least in part on a threshold level of noise emitted from each of the plurality of sub-antenna array portions.

34. The system package of claim 30, wherein the first wireless communication function comprises circuitry configured to route signals associated with wireless communications, and wherein the second wireless communication function comprises one or more antennas, mold, high dielectric materials, or any combination thereof.

35. The system package of claim 30, wherein the flex circuit comprises: a flex cable that communicates signals between the first printed circuit board and the second printed circuit board; and a flex connector configured to communicate signals between the flex cable and the first portion of the antenna array module, the second portion of the antenna array module, or both.

36. The system package of claim 35, wherein the flex circuit comprises a stiffener configured to provide rigidness to the flex cable and the flex connector.

37. A system-in-package, comprising: a first portion of an antenna array module comprising routing circuitry; a second portion of the antenna array module comprising one or more antennas, wherein a shielding is disposed on one or more first exposed surfaces of the first portion, the second portion, or both; and power management circuitry configured to manage power supplied to the system-in-package.

38. The system-in-package of claim 37, wherein the power management circuitry is directly coupled between the first portion of the antenna array module and the second portion of the antenna array module.

39. The system-in-package of claim 37, wherein the first portion of the antenna array module, the second portion of the antenna array module, or both, is distributed into a plurality of sub-antenna array portions.

40. The system-in-package of claim 39, wherein the shielding is disposed on one or more exposed surfaces of one or more sub-antenna array portions of the plurality of sub-antenna array portions.
