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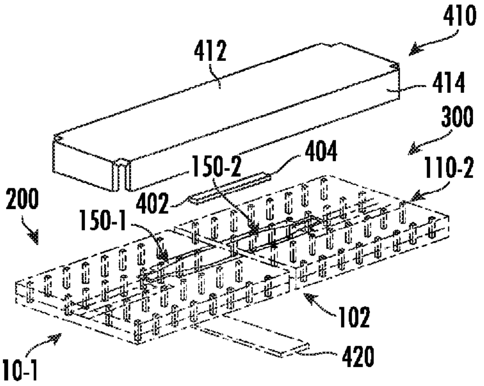

FIG. 2C

(57) **Abstract:** RF transmission lines include a first printed circuit board that includes a first stripline transmission line and a first non-stripline transmission line that is electrically connected to the first stripline transmission line, a second printed circuit board that includes a second stripline transmission line and a second non-stripline transmission line that is electrically connected to the second stripline transmission line, a metal signal trace connector that electrically connects a first signal trace of the first non-stripline transmission line to a second signal trace of the second non-stripline transmission line, and an RF shielding cover that covers the metal signal trace connector.

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ULTRA WIDEBAND BOARD-TO-BOARD TRANSITIONS FOR STRIPLINE RF TRANSMISISON LINES

FIELD

[0001] The present invention relates to communications systems and, more particularly, to transitions for stripline radio frequency ("RF") transmission lines.

BACKGROUND

[0002] A wide variety of printed circuit board based RF transmission lines are used in wired and wireless RF communications systems. For example, **FIG. 1A** is a schematic perspective view of a microstrip transmission line **10**. As shown in **FIG. 1A**, the microstrip transmission line **10** is implemented using a so-called "single layer" printed circuit board ("PCB") **20**, which refers to a PCB that has a single dielectric substrate with a metal layer on at least one major surface thereof. As shown in **FIG. 1A**, the single layer printed circuit board **20** includes a dielectric substrate **22**. A metal signal trace **24** is formed on an upper surface of the dielectric substrate **22**. The metal signal trace **24** serves as the signal conductor or "trace" of microstrip transmission line **10**. A metal ground plane **26** is formed on the lower surface of the dielectric substrate **22**. The metal ground plane **26** serves as the ground conductor of the microstrip transmission line **10**. RF signals can be input to microstrip transmission line **10**, and the RF energy travels through the portion of the dielectric substrate **22** that is between the metal signal trace **24** and the metal ground plane **26**. Microstrip transmission lines are widely used in RF communications systems. However, only the lower side of the dielectric substrate **22** is "shielded" by a ground conductor. As a result, RF energy can radiate outwardly through the edges of the dielectric substrate **22** and from the entirety of the top surface of the dielectric substrate **22** except for the portion covered by the metal signal trace **24**. Such signal radiation may be significant, and tends to increase with increasing frequency of the RF signal. Thus, while microstrip transmission lines are simple and inexpensive, they may exhibit relatively high insertion losses.

[0003] **FIG. 1B** is a schematic perspective view of a coplanar waveguide transmission line **30**, which is another type of RF transmission line. As shown in **FIG. 1B**, the coplanar waveguide transmission line **30** is implemented in a single layer PCB **40** that includes a dielectric substrate **42**. A metal signal trace **44** and a pair of metal ground planes **45-1**, **45-2** are formed on an upper surface of the dielectric substrate **42**. The metal ground planes **45-1, 45-2** are separated from the metal signal trace **44** by respective small gaps in the metallization. These small gaps (where the metal is omitted) typically have unvarying widths along the length of the coplanar waveguide transmission line **30**. The metal signal trace **44** serves as the signal conductor of the coplanar waveguide transmission line **30**. The metal ground planes **45-1, 45-2** serve as the ground conductor of coplanar waveguide transmission line **30**. RF signals can be input to coplanar waveguide transmission line **30**, and the RF energy, for the most part, travels in the portion of the dielectric substrate **42** adjacent the signal trace **44** and in the air above the signal trace **44** and between the signal trace **42** and the metal ground planes **45-1, 45-2**. Coplanar waveguide transmission lines may be even cheaper than microstrip transmission lines (since only one side of the dielectric substrate **42** is metallized), but tend to exhibit even higher insertion losses since only the sides of the transmission line are shielded by ground conductors.

[0004] **FIG. 1C** is a schematic perspective view of a grounded coplanar waveguide transmission line **50**, which is another type of RF transmission line. As shown in **FIG. 1C**, the grounded coplanar waveguide transmission line **50** is implemented in a single layer PCB **60** that includes a dielectric substrate **62**. A metal signal trace **64** and a pair of metal ground planes **65-1, 65-2** are formed on an upper surface of the dielectric substrate **62**. The metal ground planes **65-1, 65-2** are separated from the metal signal trace **64** by respective small gaps in the metallization. A metal ground plane **66** is formed on the lower surface of the dielectric substrate **62**. The metal signal trace **64** serves as the signal conductor of the grounded coplanar waveguide transmission line **50**. The metal ground planes **65-1, 65-2** and the metal ground plane **66** serve as the ground conductor of grounded coplanar waveguide transmission line **50**. A plurality of ground vias **68** extend through the dielectric substrate **62** to electrically connect the metal ground planes **65-1, 65-2** to the metal ground plane **66**. The ground vias **68** may be implemented as metal plated or metal filled through holes that extend through the dielectric substrate **62**. Two rows of plated through holes **68** are provided that extend through the dielectric substrate **62** on either side of the metal signal trace **64**. The plated through holes **68** may be spaced apart less than ¼ of a wavelength of the RF signals that are to be transmitted over the grounded coplanar waveguide transmission line **50**, which ensures that little or no RF energy may pass through the "walls" formed by the respective rows of plated through holes **68**. RF signals can be input to grounded coplanar waveguide transmission line **50**, and the RF energy travels through the portion of the dielectric substrate **62** that is between the metal signal trace **64** and the metal ground plane **66**. The metal ground planes **65-1, 65-2**, the metal ground plane **66**, and the two rows of plated through holes **68** all act as grounded shielding structures that block RF energy from escaping from the dielectric substrate **62**. Consequently, grounded coplanar waveguide transmission lines such as transmission line **50** may exhibit better insertion loss performance than the microstrip transmission line **10** or the coplanar waveguide transmission loss **30**.

[0005] **FIG. 1D** is a schematic perspective view of a stripline transmission line **70**, which is yet another type of RF transmission line. As shown in **FIG. 1D**, the stripline transmission line **10** is implemented in a multilayer PCB **80** that includes first and second dielectric substrates **82-1, 82-2**. In some cases, the multilayer PCB **80** may be formed by bonding two single layer PCBs together using a material such as a dielectric prepreg layer (one of the single layer PCBs may have metal on both major surfaces thereof, while the other only has metal on an outer major surface thereof). In the depicted embodiment, a metal signal trace **84** is formed on an upper surface of the lower dielectric substrate **82-1**, and a first metal ground plane **86-1** is formed on the lower surface of the lower dielectric substrate **82-1**. A second metal ground plane **86-2** is formed on the upper surface of the upper dielectric substrate **82-2**. While not shown in **FIG. 1D**, optionally, metal ground planes similar to metal ground planes **65-1, 65-2** may be formed on the upper surface of the lower dielectric substrate **82-1** to surround the metal signal trace **84**, and/or rows of plated through holes that are similar to plated through holes **68** may be provided, where the plated through holes extend through both dielectric substrates **82-1, 82-2** to electrically connect the first and second metal ground planes **86-1, 86-2**.

[0006] The metal signal trace **84** serves as the signal conductor of stripline transmission line **70**, and the metal ground planes **86-1, 86-2** serve as the ground conductor of the stripline transmission line **70**. RF signals can be input to stripline transmission line **70**, and the RF energy travels through the portion of the dielectric substrate **82** that is between the metal ground planes **86-1, 86-2**, which act as grounded shielding structures that block RF energy from escaping from the dielectric substrates **82-1, 82-2**. Stripline transmission lines exhibit excellent insertion loss performance (even better than grounded coplanar waveguides). However, stripline transmission lines require the use of more expensive multi-layer PCBs, and are more difficult to connect to other transmission lines.

SUMMARY

[0007] Pursuant to embodiments of the present invention, RF transmission lines are provided that include first and second PCBs. The first PCB that includes a first upper dielectric substrate, a first lower dielectric substrate, a first upper metal layer that is on an upper surface of the first upper dielectric substrate, the first upper metal layer including a first upper signal trace and a first upper ground plane, a first lower metal layer that is on a lower surface of the first lower dielectric substrate that forms a first lower ground plane, a first internal metal layer that is between the first upper dielectric substrate and the first lower dielectric substrate, the first internal metal layer including a first internal signal trace and a first internal ground plane. The second PCB includes a second dielectric substrate and a second upper metal layer that is on an upper surface of the second dielectric substrate, the second upper metal layer including a second upper signal trace. These RF transmission lines further include a metal signal trace connector that electrically connects the first upper signal trace to the second upper signal trace and an RF shielding cover that covers the metal signal trace connector.

[0008] In some embodiments, the RF shielding cover has an upper surface and at least one sidewall extending downwardly from the upper surface. In some embodiments, the second upper metal layer further comprises a second upper ground plane. In such embodiments, the RF shielding cover may be galvanically or capacitively connected to the first upper ground plane and to the second upper ground plane. The RF shielding cover, the first upper ground plane and the second upper ground plane substantially enclose the metal signal trace connector.

[0009] In some embodiments, the metal signal trace connector may be a longitudinally extending metal strip that has a first end that galvanically connects to the first upper signal trace and a second end that galvanically connects to the second upper signal trace. In other embodiments, the metal signal trace connector may be capacitively coupled to the first upper signal trace and to the second upper signal trace.

[0010] In some embodiments, the first upper signal trace comprises the signal conductor of a first stripline transmission line formed in the first printed circuit board, and the first upper ground plane and the first lower ground plane comprise the ground conductor of the first stripline transmission line. In such embodiments, the second dielectric substrate may be a second upper dielectric substrate, the second upper metal layer may further comprise a second upper ground plane, and the second printed circuit board may further include a second lower dielectric substrate, a second internal metal layer that is between the second upper dielectric substrate and the second lower dielectric substrate, the second internal metal layer including a second internal signal trace and a second internal ground plane, and a second lower metal layer that is on a lower surface of the second lower dielectric substrate that forms a second lower ground plane.

[0011] In some embodiments, the second upper signal trace may be the signal conductor of a second stripline transmission line formed in the second printed circuit board, and the second upper ground plane and the second lower ground plane may be the ground conductor of the second stripline transmission line.

[0012] In some embodiments, the RF transmission line may further include a metal ground connector that electrically connects the first lower ground plane to the second lower ground plane. The metal ground connector may, for example, be soldered to both the first lower ground plane and to the second lower ground plane.

[0013] In some embodiments, the second printed circuit board may further include a second lower metal layer that is on the lower surface of the second dielectric substrate that forms a second lower ground plane, and the second upper signal trace and the second lower ground plane may comprise the signal and ground conductors of a microstrip transmission line formed in the second printed circuit board. In some embodiments, the RF transmission line may further include a metal ground connector that electrically connects the first lower ground plane to the second lower ground plane.

[0014] In some embodiments, the second dielectric substrate is thicker than the first upper dielectric substrate and is thicker than the first lower dielectric substrate.

[0015] In other embodiments, the second printed circuit board may further include a second lower metal layer that is on the lower surface of the second dielectric substrate that forms a second lower ground plane, wherein the second upper metal layer further comprises a second upper ground plane, and the second upper signal trace comprises the signal conductor of a grounded coplanar waveguide transmission line that is formed in the second printed circuit board, and the second upper ground plane and the second lower ground plane comprise the ground conductor of the grounded coplanar waveguide transmission line. In such embodiments, the RF transmission line may further include a metal ground connector that electrically connects the first lower ground plane to the second lower ground plane and/or the second dielectric substrate may be thicker than the first upper dielectric substrate and may be thicker than the first lower dielectric substrate.

[0016] In still other embodiments, the second upper metal layer may further comprise a second upper ground plane, and the second upper signal trace may be the signal conductor of a coplanar waveguide transmission line that is formed in the second printed circuit board, and the second upper ground plane may be the ground conductor of the coplanar waveguide transmission line. The second dielectric substrate may be thicker than the first upper dielectric substrate and may be thicker than the first lower dielectric substrate.

[0017] In all of the above embodiments, the RF transmission line may further include a first conductive signal via that extends between the first internal signal trace and the first upper signal trace. Additionally, the first printed circuit board may further include first and second rows of ground vias that extend through the first upper dielectric substrate and the first lower dielectric substrate, the first and second rows of ground vias electrically connecting the first upper ground plane, the first internal ground plane, and the first lower ground plane. The first row of ground vias may be on a first side of the first internal signal trace and the second row of ground vias may be on a second side of the first internal signal trace. The first printed circuit board may also include a first additional dielectric layer that is interposed between the first upper dielectric substrate and the first lower dielectric substrate. In some embodiments, the first upper ground plane may surround the first upper signal trace on at least three sides.

[0018] Pursuant to further embodiments of the present invention, RF transmission lines are provided that include a first printed circuit board that includes a first stripline transmission line and a first non-stripline transmission line that is electrically connected to the first stripline transmission line, a second printed circuit board that includes a second stripline transmission line and a second non-stripline transmission line that is electrically connected to the second stripline transmission line, a metal signal trace connector that electrically connects a first signal trace of the first non-stripline transmission line to a second signal trace of the second non-stripline transmission line, and an RF shielding cover that covers the metal signal trace connector.

[0019] In some embodiments, the first non-stripline transmission line may be a microstrip transmission line, a coplanar waveguide transmission line, or a grounded coplanar waveguide transmission line.

[0020] In some embodiments, the RF shielding cover may have an upper surface and at least one sidewall extending downwardly from the upper surface. The RF shielding cover may be soldered to a first upper ground plane of the first stripline transmission line and to a second upper ground plane of the second stripline transmission line. The RF shielding cover, the first upper ground plane and the second upper ground plane may substantially enclose the metal signal trace connector.

[0021] In some embodiments, the metal signal trace connector may be a longitudinally extending metal strip that has a first end that galvanically connects to the first signal trace and a second end that galvanically connects to the second signal trace. In other embodiments, the metal signal trace connector may be capacitively coupled to the first signal trace and to the second signal trace.

[0022] In some embodiments, the first stripline transmission line may include a first upper ground plane and a first lower ground plane, and the second stripline transmission line may include a second upper ground plane and a second lower ground plane. The RF transmission line may further include a metal ground connector that electrically connects the first lower ground plane to the second lower ground plane. The metal ground connector may be soldered to both the first lower ground plane and to the second lower ground plane.

[0023] In some embodiments, the RF transmission line may further comprise a first conductive signal via that extends between a signal trace of the first stripline transmission line and the first signal trace of the first non-stripline transmission line.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] **FIG. 1A** is a schematic perspective view of a conventional microstrip transmission line.

[0025] **FIG. 1B** is a schematic perspective view of a conventional coplanar waveguide transmission line.

[0026] **FIG. 1C** is a schematic perspective view of a conventional grounded coplanar waveguide transmission line.

[0027] **FIG. 1D** is a schematic perspective view of a conventional stripline transmission line.

[0028] **FIG. 2A** is a schematic top perspective view of an RF transmission line according to embodiments of the present invention that includes a pair of stripline transmission lines that are connected using a stripline transition.

[0029] **FIG. 2B** is a schematic bottom perspective view of the RF transmission line of **FIG. 2A**.

[0030] **FIG. 2C** is a schematic partially exploded top perspective view of the RF transmission line of **FIG. 2A**.

[0031] **FIG. 2D** is a schematic fully exploded side perspective view of the RF transmission line of **FIG. 2A**.

[0032] **FIG. 3A** is a graph of the simulated return loss performance of the RF transmission line of **FIG. 2A**.

[0033] **FIG. 3B** is a graph of the simulated insertion loss performance of the RF transmission line of **FIG. 2A**.

[0034] **FIG. 4A** is a schematic side perspective view of an RF transmission line according to embodiments of the present invention that includes a stripline transmission line and a coplanar waveguide transmission line that are connected using a stripline-to-coplanar waveguide transition.

[0035] **FIG. 4B** is a schematic side perspective view of an RF transmission line according to embodiments of the present invention that includes a stripline transmission line and a grounded coplanar waveguide transmission line that are connected using a stripline-to-grounded coplanar waveguide transition.

[0036] **FIG. 4C** is a schematic side perspective view of an RF transmission line according to embodiments of the present invention that includes a stripline transmission line and a microstrip transmission line that are connected using a stripline-to-microstrip transition.

[0037] In this specification, like reference numerals will be used to refer to like elements. When multiple of the same element are included in certain of the embodiments disclosed herein, they may be referred to by two-part reference numerals that include two numbers separated by a hyphen (e.g., **20-1**). Such elements may be referred to individually by their full reference numeral and collectively by the first part of their reference numeral.

DETAILED DESCRIPTION

[0038] While stripline transmission lines may exhibit very low transmission losses, they are also expensive to implement. RF PCBs are significantly more expensive than standard PCBs, and strip line transmission lines require multilayer PCB structures that further increase both material and manufacturing costs. Thus, in many cases it is impractical to implement an entire communication system in a multilayer PCB structure to allow for the use of stripline transmission lines. Additionally, in many applications, certain components may be used in many different communication systems. For example, base station antennas include numerous PCB-based circuit components such as electromechanical phase shifters, calibration circuits, hybrid couplers, power dividers and the like that include RF transmission lines. The same circuit components (e.g., a particular phase shifter assembly) may be used in many different antenna designs. As a result, it is advantageous to implement these circuit components as standalone elements that are formed on their own PCBs so that the circuit components can readily be used in different antennas.

[0039] In communications systems where different PCB-based circuit components are formed on separate PCBs, it becomes necessary to interconnect transmission lines on the different PCBs. Conventionally, such connections are often implemented using cables such as coaxial cables. While coaxial cables can readily be connected to microstrip, coplanar waveguide and ground coplanar waveguide transmission lines, it is more difficult to connect a coaxial cable to a stripline transmission line as the signal trace is embedded between two dielectric substrates and ground planes and only exposed at the edges of the multilayer PCB. Additionally, coaxial cable connections are labor intensive to implement, and the solder joints between the coaxial cables and the PCB-based transmission lines may be potential source of passive intermodulation distortion, particularly if forces are applied to the cables after the solder joints are formed.

[0040] Pursuant to embodiments of the present invention, various RF transmission line transitions are provided that can be used to connect an RF transmission line implemented in a first PCB to an RF transmission line implemented in a second PCB. The RF transmission line transitions according to embodiments of the present invention may include, for example, stripline-to-stripline transitions, stripline-to-coplanar waveguide transitions, stripline-to-grounded coplanar waveguide transitions, and stripline-to-microstrip transitions. These transitions may be used to form RF transmission lines that span two (or more) printed circuit boards.

[0041] In one example embodiment, an RF transmission line is provided that includes a stripline-to-stripline transition. The RF transmission line spans first and second PCBs, each of which have a stripline transmission line implemented therein. Each PCB includes one or more conductive signal vias that electrically connect the signal trace of the respective stripline transmission line to a respective auxiliary signal trace that is formed in the top metal layer of the respective PCB. Each auxiliary signal trace may be a signal trace of a non-stripline transmission line such as a signal trace of (1) a coplanar waveguide transmission line, (2) a grounded coplanar waveguide transmission line or (3) a microstrip transmission line. The metal ground planes of the top metal layer of each printed circuit board are separated from the auxiliary signal traces and conductive signal vias by gaps in the metallization. A first end of a metal signal trace connector may be soldered or otherwise electrically connected to the first auxiliary signal trace and a second end of the metal signal trace connector may be soldered or otherwise electrically connected to the second auxiliary signal trace in order to electrically connect the auxiliary signal trace of the first PCB to the auxiliary signal trace of the second PCB. An RF shielding cover may be provided that covers the two auxiliary signal traces and the metal signal trace connector without contacting the auxiliary signal traces or the metal signal trace connector. The RF shielding cover may be soldered to the metal ground planes of the top metal layer of each printed circuit board, thereby electrically connecting the metal ground plane on the first PCB to the metal ground plane on the second PCB. The RF transmission line may optionally include a metal ground connector that electrically connects the metal ground plane on the bottom surface of the first PCB to the metal ground plane on the bottom surface of the second PCB.

[0042] In other example embodiments, RF transmission lines are provided in which a first PCB that includes a stripline transmission line is connected to a second PCB that includes a coplanar waveguide transmission line, a grounded coplanar waveguide transmission line, or a microstrip transmission line using similar transition elements.

[0043] Thus, according to some embodiments of the present invention, RF transmission lines are provided that include first and second PCBs. The first PCB that includes a first upper dielectric substrate, a first lower dielectric substrate, a first upper metal layer that is on an upper surface of the first upper dielectric substrate, the first upper metal layer including a first upper signal trace and a first upper ground plane, a first lower metal layer that is on a lower surface of the first lower dielectric substrate that forms a first lower ground plane, a first internal metal layer that is between the first upper dielectric substrate and the first lower dielectric substrate, the first internal metal layer including a first internal signal trace and a first internal ground plane. The second PCB includes a second dielectric substrate and a second upper metal layer that is on an upper surface of the second dielectric substrate, the second upper metal layer including a second upper signal trace. These RF transmission lines further include a metal signal trace connector that electrically connects the first upper signal trace to the second upper signal trace and an RF shielding cover that covers the metal signal trace connector.

[0044] In other embodiments, RF transmission lines are provided that include a first printed circuit board that includes a first stripline transmission line and a first non-stripline transmission line that is electrically connected to the first stripline transmission line, a second printed circuit board that includes a second stripline transmission line and a second non-stripline transmission line that is electrically connected to the second stripline transmission line, a metal signal trace connector that electrically connects a first signal trace of the first non-stripline transmission line to a second signal trace of the second non-stripline transmission line, and an RF shielding cover that covers the metal signal trace connector.

[0045] Embodiments of the present invention will now be discussed in further detail with reference to **FIGS. 2A-4C**.

[0046] **FIGS. 2A-2D** illustrate an RF transmission line according to embodiments of the present invention. In particular, **FIGS. 2A** and **2B** are schematic top and bottom perspective views of an RF transmission line **100** according to embodiments of the present invention that includes a pair of stripline transmission lines that are connected using a stripline-to-stripline transition. **FIG. 2C** is a schematic partially exploded top perspective view of the RF transmission line **100**, and **FIG. 2D** is a schematic fully exploded side perspective view thereof.

[0047] Referring to **FIGS. 2A-2D**, the RF transmission line **100** comprises a first printed circuit board **200** and a second printed circuit board **300**, each of which are multilayer printed circuit boards. The first and second printed circuit boards **200, 300** are separated by a gap **102** (see **FIG. 2C**). As shown best in **FIG. 2D**, the first printed circuit board **200** includes a first lower dielectric substrate **220** and a first upper dielectric substrate **250**. The first lower dielectric substrate **220** and the first upper dielectric substrate **250** may each comprise standard RF printed circuit board materials such as, for example, Taconic TSM-DS3, Arlon AD3003A, or Rogers RO3003 printed circuit board substrate materials. A first lower metal layer **210** is formed on the lower surface of the first lower dielectric substrate **210** and a first upper metal layer **260** is formed on the upper surface of the first upper dielectric substrate **250**. A first interlayer metal layer **230** is formed on the upper surface of the first lower dielectric substrate **220**. A first additional dielectric layer **240** is positioned between the first interlayer metal layer **230** and the first upper dielectric substrate **250**.

[0048] The first additional dielectric layer **240** may be used to adhere the upper portion of the first printed circuit board **200** to the lower portion of the first printed circuit board **200**. The first additional dielectric layer **240** may be formed using any suitable dielectric material such as, for example, a so-called "prepreg" material such as a fiberglass material or other composite fiber material that is pre-impregnated with a thermoset polymer matrix material (e.g., an epoxy resin). The composite fiber material may take the form of a weave. The epoxy resin (or other thermoset polymer matrix material) typically has adhesive properties, and a curing agent is included in the prepreg material. The prepreg material becomes flowable when heated and then acts as an adhesive to bind the fibers together and to other components that contact the major surfaces of the prepreg layer. While in the depicted embodiment, the first interlayer metal layer **230** is between the first lower dielectric substrate **220** and the first additional dielectric layer **240**, it will be appreciated that in other embodiments the first interlayer metal layer **230** may instead be between the first upper dielectric substrate **250** and the first additional dielectric layer **240**, and the first additional dielectric layer **240** may directly contact the upper surface of the first lower dielectric substrate **220**.

[0049] First through fourth rows **270-1** through **272-4** of first ground vias **272** extend through the first lower dielectric substrate **220**, the first interlayer metal layer **230**, the first additional dielectric layer **240**, and the first upper dielectric substrate **250**. The first ground vias **272** may each electrically interconnect portions of the first lower metal layer **220**, the first interlayer metal layer **230** and the first upper metal layer **260**. The first and second rows **270-1**, **270-2** of first ground vias **272** may extend along opposed outer edges of the first printed circuit board **200** in some embodiments. The third and fourth rows **270-3**, **270-4** of first ground vias **272** may extend between the first and second rows **270-1**, **270-2** of first ground vias **272**. The ground vias **272** in each of the first through fourth rows **270-1** through **270-4** may be spaced apart from each other by less than a quarter wavelength of a lowest frequency in an operating frequency range of the RF transmission line **100**. With this spacing, the ground vias **272** act as sidewalls of a waveguide structure and thus constrain the RF energy from travelling laterally beyond the ground vias **272**

[0050] A first stripline transmission line **110-1** and a first non-stripline transmission line **150-1** are formed in the first printed circuit board **200**. The first stripline transmission line **110-1** comprises a first lower metal ground plane **120-1**, a first metal signal trace **130-1**, and a first upper metal ground plane **140-1**. The first lower metal ground plane **120-1** is formed in the first lower metal layer **210**, the first metal signal trace **130-1** is formed in the first interlayer metal layer **230**, and the first upper metal ground plane **140-1** is formed in the first upper metal layer **260**. A first interlayer ground plane **132-1** may optionally be formed in the first interlayer metal layer **230** that surrounds the first metal signal trace **130-1** on three sides thereof. A gap **232** in the first interlayer metal layer **230** isolates the first metal signal trace **130-1** from the first interlayer ground plane **132-1**.

[0051] The first non-stripline transmission line **150-1** is implemented as a grounded coplanar waveguide transmission line **150-1**. The grounded coplanar waveguide transmission line **150-1** comprises a first lower metal ground plane **160-1**, a first non-stripline metal signal trace **170-1**, and a pair of first upper metal ground planes **180-1A, 180-1B**. The first lower metal ground plane **160-1** is formed in the first intermetal metal layer **230**, the first non-stripline metal signal trace **170-1** is formed in the first upper metal layer **260**, and the first upper metal ground planes **180-1A, 180-1B** are also formed in the first upper metal layer **260**. In particular, the first upper metal ground plane **140-1** extends in the first upper metal layer **260** toward the second printed circuit board **300**, thereby forming the pair of first upper metal ground planes **180-1A, 180-1B**. A gap **262** in the first upper metal layer **260** isolates the first metal signal trace **170-1** from the first upper metal ground planes **180-1A, 180-1B** and the first metal ground planes **140-1**.

[0052] The first through fourth rows **270-1** through **270-4** of first ground vias **272** provide RF shielding for both the first stripline transmission line **110-1** and the first non-stripline transmission line **150-1**. One or more first conductive signal vias **280** extend through the first lower dielectric substrate **220**, the first interlayer metal layer **230**, the first additional dielectric layer **240**, and the first upper dielectric substrate **250**. The first conductive signal vias **280** electrically connect the first metal signal trace **130-1** of the first stripline transmission line **110-1** to the first non-stripline metal signal trace **170-1** of the first non-stripline transmission line **150-1**. A gap **212** is formed in the first lower metal layer **210** that separates the metallization into a small first inner metallization **214** that is surrounded by a much larger first outer metallization **216**. The first outer metallization **216** forms the first lower metal ground plane **120-1**. The first conductive signal vias **280** extend through the first lower dielectric substrate **220** to electrically connect to the first inner metallization **214**. The first inner metallization **214** and the gap **212** are provided to electrically isolate the first conductive signal vias **280** from the first lower metal ground plane **120-1**.

[0053] The first ground vias **272** and the first conductive signal vias **280** may be metal-plated or metal-filled vias. Note that in **FIG. 2D** the openings in the first and second lower dielectric substrates **220, 320**, the first and second additional dielectric substrates **240, 340**, and the first and second upper dielectric substrates **250, 350** through which the ground vias **272** and conductive signal vias **280** extend are not shown to simplify the drawing.

[0054] As **FIGS. 2A-2D** and the above description makes clear, the first stripline transmission line **110-1** is formed in the left side of the first printed circuit board **200** and the first non-stripline transmission line **150-1** is formed in the right side of the first printed circuit board **100**. The first conductive signal vias **280** electrically connect the first stripline transmission line **110-1** to the first non-stripline transmission line **150-1**. As described below, by transitioning from a stripline transmission line to a non-stripline transmission line, the metal signal trace is brought to a top surface of the first printed circuit board **200** where it can more readily be electrically connected to a metal signal trace of the second printed circuit board **300**.

[0055] The second printed circuit board **300** has the same general construction as the first printed circuit board **200**, and like components may be identical in the two printed circuit boards **200, 300**. Thus, the second printed circuit board **300** includes a second lower dielectric substrate **320**, a second upper dielectric substrate **350**, a second lower metal layer **310** that is formed on the lower surface of the second lower dielectric substrate **310**, a second upper metal layer **360** is formed on the upper surface of the second upper dielectric substrate **350**, and a second interlayer metal layer **330** and a second additional dielectric layer **340** are formed between the upper surface of the second lower dielectric substrate **320** and the lower surface of the second upper dielectric substrate **350**. First through fourth rows **370-1** through **370-4** of second ground vias **372** extend through the second lower dielectric substrate **320**, the second interlayer metal layer **330**, the second additional dielectric layer **340**, and the second upper dielectric substrate **350**. The second ground vias **372** may be identical in shape and position to the first ground vias **272** and hence further description thereof is omitted.

[0056] A second stripline transmission line **110-2** and a second non-stripline transmission line **150-1** are formed in the second printed circuit board **300**. The second stripline transmission line **110-2** comprises a second lower metal ground plane **120-2**, a second metal signal trace **130-2**, and a second upper metal ground plane **140-2**. The second lower metal ground plane **120-2** is formed in the second lower metal layer **310**, the second metal signal trace **130-2** is formed in the second interlayer metal layer **330**, and the second upper metal ground plane **140-2** is formed in the second upper metal layer **360**. A second interlayer ground plane **132-2** may optionally be formed in the second interlayer metal layer **330** that surrounds the second metal signal trace **130-2** on three sides thereof. A gap **332** in the second interlayer metal layer **330** isolates the second metal signal trace **130-2** from the second interlayer ground plane **132-2**.

[0057] The second non-stripline transmission line **150-2** is implemented as a grounded coplanar waveguide transmission line **150-2** that comprises a second lower metal ground plane **160-2**, a second non-stripline metal signal trace **170-2**, and a pair of second upper metal ground planes **180-2A, 180-2B**. The second lower metal ground plane **160-2** is formed in the second intermetal metal layer **330**, the second non-stripline metal signal trace **170-2** is formed in the second upper metal layer **360**, and the second upper metal ground planes **180-2A, 180-2B** are also formed in the second upper metal layer **360**. A gap **362** in the second upper metal layer **360** isolates the second metal signal trace **170-2** from the second upper metal ground planes **180-2A, 180-2B** and the second metal ground planes **140-2**.

[0058] The first through fourth rows **370-1** through **370-4** of first ground vias **372** provide RF shielding for both the second stripline transmission line **110-2** and the second non-stripline transmission line **150-2**. One or more second conductive signal vias **380** extend through the second lower dielectric substrate **320**, the second interlayer metal layer **330**, the second additional dielectric layer **340**, and the second upper dielectric substrate **350**. The second conductive signal vias **380** electrically connect the second metal signal trace **130-2** of the second stripline transmission line **110-2** to the second non-stripline metal signal trace **170-2** of the second non-stripline transmission line **150-2**. A gap **312** is formed in the second lower metal layer **310** that separates the metallization into a small second inner metallization **314** that is surrounded by a much larger second outer metallization **316**. The second outer metallization **316** forms the second lower metal ground plane **120-2**. The second conductive signal vias **380** extend through the second lower dielectric substrate **320** to electrically connect to the second inner metallization **314**. The second inner metallization **314** and the gap **312** are provided to electrically isolate the second conductive signal vias **380** from the second lower metal ground plane **120-2**. The second ground vias **372** and the second conductive signal vias **380** may be metal-plated or metal-filled vias.

[0059] As **FIGS. 2A-2D** and the above description makes clear, the first stripline transmission line **110-1** is formed in the left side of the first printed circuit board **200** and the first non-stripline transmission line **150-1** is formed in the right side of the first printed circuit board **100**. The first conductive signal vias **280** electrically connect the first stripline transmission line **110-1** to the first non-stripline transmission line **150-1**. As described below, by transitioning from a stripline transmission line to a non-stripline transmission line, the metal signal trace is brought to a top surface of the first printed circuit board **200** where it can more readily be electrically connected to a metal signal trace of the second printed circuit board **300**.

[0060] The RF transmission line **100** further includes a metal signal trace connector **400**, an RF shield **410**, and a metal ground connector **420**. The metal signal trace connector **400** may comprise a strip of metal (e.g., sheet metal) that has a first end **402** and a second end **404**. The first end **402** of metal signal trace connector **400** may be soldered to the first non-stripline metal signal trace **170-1**, and the second end **404** of metal signal trace connector **400** may be soldered to the second non-stripline metal signal trace **170-2**, thereby providing an electrical connection therebetween. The metal signal trace connector **400** may span the gap **102** between the first printed circuit board **200** and the second printed circuit board **300**.

[0061] Referring to **FIG. 2C**, the RF shield **410** may comprise, for example, an open box-shaped structure. The RF shield **410** may be formed of cut and bent sheet metal. The RF shield **410** in the illustrated embodiment has an upper surface **412** and a plurality of sidewalls **414** extending downwardly from the upper surface **412**. The RF shield may be soldered to the first upper metal ground plane **140-1** and to the second upper metal ground plane **140-2**, thereby providing an electrical connection therebetween to provide a continuous ground reference between the first stripline transmission line **110-1** and the first non-stripline transmission line **170-1** on the one hand and second stripline transmission line **110-2** and the second non-stripline transmission line **170-2** on the other hand. The RF shield **410** also covers the metal signal trace connector **400** and in conjunction with the first and second metal layers **260, 360**, substantially encloses the metal signal trace connector **400**.

[0062] The metal ground connector **420** may comprise a strip of metal (e.g., sheet metal) that may be soldered to the first lower metal ground plane **120-1** and to the second lower metal ground plane **120-2**, thereby providing an electrical connection therebetween. While the first and second lower metal ground planes **120-1, 120-2** are electrically connected through the RF shield **410** and the ground vias **272, 372**, the more direct electrical connection through the metal ground connector **420** may provide improved transmission stability. The metal ground connector **420** may span the gap **102** between the first printed circuit board **200** and the second printed circuit board **300**.

[0063] An additional advantage of the RF transmission line **100** is that the transmission line includes signal traces **170-1, 170-2** that are at the topmost metal layers of the multilayer printed circuit boards **200, 300**. When the RF transmission line **100** is used in a larger system (e.g., in a base station antenna), a prototype antenna may be fabricated. In many instances, the return loss of the prototype antenna may not be satisfactory. When this occurs, the RF shield 410 may be removed and characteristics of the metal signal trace connector **400** such as its width, thickness, connection points to the signal traces **170-1, 170-2**, etc. may be changed to vary and hopefully improve the return loss performance. Once the return loss performance is acceptable, then production antennas may be manufactured based on the design of the metal signal trace connector **400** that provides acceptable return loss performance.

[0064] It will be appreciated that **FIGS. 2A-2D** may only show a portion of the first and second printed circuit boards **200, 300**. As **FIGS. 2A-2D** clearly show, the various metal "layers" (e.g., layers **210, 230, 260, 310, 330, 360**) may be patterned metal layers that are not continuous layers, but instead have portions where no metal is present. Each patterned metal layer may be formed, for example, by depositing a continuous metal layer on a surface (i.e., upper or lower) of a dielectric substrate, forming a mask on the continuous metal layer and then etching the continuous metal layer using the mask as an etch mask to form the patterned metal layer. Dielectric material may optionally be filled into the openings in the patterned metal layers, but more typically the gaps are simply filled with air. a patterned metal layer abuts a prepreg layer, the prepreg material may fill the openings in the patterned metal layer.

[0065] **FIGS. 3A** and **3B** are graphs illustrating the simulated return loss and insertion loss performance, respectively, of the RF transmission line **100**. As shown in **FIG. 3A**, the return loss is less than -25 dB in the range from 2.5 GHz through about 4.75 GHz, which is 47% of the bandwidth. This demonstrates that the RF transmission line **100** is an ultra-wideband transmission line. As shown in **FIG. 3B**, the insertion loss is less 0.13 dB over the range of 2.5-4.75 GHz.

[0066] **FIG. 4A** is a schematic side perspective view of an RF transmission line **500** according to embodiments of the present invention that includes a stripline transmission line and a coplanar waveguide transmission line that are connected using a stripline-to-coplanar waveguide transition. RF transmission line **500** includes the first printed circuit board of RF transmission line **100** that has the first stripline transmission line **110-1** and the first non-stripline transmission line **150-1**. As these structures/elements have already been described above, further description thereof will be omitted.

[0067] As shown in **FIG. 4A**, RF transmission line **500** further includes a second printed circuit board **502** that has a dielectric substrate **520** and a second upper metallization layer **560** formed on an upper surface of the dielectric substrate **520**. A second non-stripline transmission line **550-2** is formed in the second printed circuit board **502**. The second non-stripline transmission line **550-2** is implemented as a coplanar waveguide transmission line **550-2**. The coplanar waveguide transmission line **550-2** includes a second non-stripline metal signal trace **570-2** and a pair of second upper metal ground planes **580-2A, 580-2B**. The second non-stripline metal signal trace **570-2** and the second upper metal ground planes **580-2A, 580-2B** are formed in the second upper metal layer **560**. The RF transmission line **500** also includes the metal signal trace connector **400** and an RF shield **510** that is similar to RF shield **410**. RF shield **510**, however, includes a cutout **512** in one sidewall that ensures that the RF shield does not short circuit to second non-stripline metal signal trace **570-2**.

[0068] **FIG. 4B** is a schematic side perspective view of an RF transmission line **600** according to embodiments of the present invention that includes a stripline transmission line and a grounded coplanar waveguide transmission line that are connected using a stripline-to-grounded coplanar waveguide transition. RF transmission line **600** includes the first printed circuit board of RF transmission line **100** that has the first stripline transmission line **110-1** and the first non-stripline transmission line **150-1**. As these structures/elements have already been described above, further description thereof will be omitted.

[0069] As shown in **FIG. 4B**, RF transmission line **600** is very similar to RF transmission line **500**, except that RF transmission line **600** is a grounded coplanar waveguide transmission line such that coplanar waveguide transmission line **550-2** of RF transmission line **500** is replaced in RF transmission line **600** with a grounded coplanar waveguide transmission line **650-2**. Accordingly, RF transmission line **600** further includes a second printed circuit board **602** that is similar to second printed circuit board **502**, but further includes a second lower metallization layer **610** on a lower surface of dielectric substrate **520** which forms a second lower metal ground plane **620-2**. Additionally, a plurality of ground vias **672** electrically connect the second upper metal ground planes **580-2A, 580-2B** to the second lower metal ground plane **620-2**. The RF transmission line **600** also includes the metal signal trace connector **400**, the RF shield **510**, and the metal ground connector **420**.

[0070] **FIG. 4C** is a schematic side perspective view of an RF transmission line **700** according to embodiments of the present invention that includes a stripline transmission line and a microstrip transmission line that are connected using a stripline-to-microstrip transition. RF transmission line **500** includes the first printed circuit board of RF transmission line **100** that has the first stripline transmission line **110-1** and the first non-stripline transmission line **150-1**. As these structures/elements have already been described above, further description thereof will be omitted.

[0071] As shown in **FIG. 4C**, RF transmission line **700** further includes a second printed circuit board **702** that has a dielectric substrate **520**, a second upper metallization layer **760** formed on an upper surface of the dielectric substrate **520**, and a second lower metallization layer **760** formed on a lower surface of the dielectric substrate **520**. A second non-stripline transmission line **750-2** is formed in the second printed circuit board **502**. The second non-stripline transmission line **750-2** is implemented as a microstrip transmission line **750-2**. The microstrip transmission line **750-2** includes a second non-stripline metal signal trace **770-2** that is formed in the second upper metal layer **760** and a second lower metal ground plane **620-2** that is formed in the second lower metallization layer **760**. RF transmission line **700** also includes the metal signal trace connector **400**, an RF shield **710**, and the metal ground connector **420**

[0072] RF shield **710** is similar to RF shield **510**, but further includes a plurality of pins **714** that extend downwardly from the sidewalls thereof. These pins **714** extend through vias (not shown) in the dielectric substrate **520** to electrically connect to the second lower ground plane **620-2**.

[0073] It will be appreciated that many modifications may be made to the above described embodiments without departing from the scope of the present invention.

[0074] Herein, references are made to one element such as a blind ground via "vertically overlapping" another element such as a transmission line segment. Such references to two "vertically overlapping" elements means that a vertical axis (i.e., an axis that extends perpendicularly to the multilayer printed circuit board structures according to embodiments of the present invention) extends through both elements.

[0075] Herein references are made to printed circuit boards. It will be appreciated that the term printed circuit board is used broadly to refer to a dielectric layer that has a metal layer (which may or may not be patterned) adhered to at least one major surface thereof.

[0076] The present invention has been described above with reference to the accompanying drawings. The invention is not limited to the illustrated embodiments; rather, these embodiments are intended to fully and completely disclose the invention to those skilled in this art. In the drawings, like numbers refer to like elements throughout. Thicknesses and dimensions of some elements may not be to scale.

[0077] Spatially relative terms, such as "under", "below", "lower", "over", "upper", "top", "bottom" and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. It will be understood that the spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as "under" or "beneath" other elements or features would then be oriented "over" the other elements or features. Thus, the exemplary term "under" can encompass both an orientation of over and under. The device may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein interpreted accordingly.

[0078] Well-known functions or constructions may not be described in detail for brevity and/or clarity. As used herein the expression "and/or" includes any and all combinations of one or more of the associated listed items.

[0079] It will be appreciated that aspects of all embodiments disclosed herein may be combined in different ways to provide numerous additional embodiments. Thus, it will be appreciated that elements discussed above with respect to one specific embodiment may be incorporated into any of the other embodiments, either alone or in combination.

[0080] It will be understood that, although the terms first, second, etc. may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another. For example, a first element could be termed a second element, and, similarly, a second element could be termed a first element, without departing from the scope of the present invention.

What is claimed is:

1. A radio frequency ("RF") transmission line, comprising:

a first printed circuit board that includes a first upper dielectric substrate, a first lower dielectric substrate, a first upper metal layer that is on an upper surface of the first upper dielectric substrate and including a first upper signal trace and a first upper ground plane, a first lower metal layer that is on a lower surface of the first lower dielectric substrate that forms a first lower ground plane, a first internal metal layer that is between the first upper dielectric substrate and the first lower dielectric substrate, the first internal metal layer including a first internal signal trace and a first internal ground plane;

a second printed circuit board that includes a second dielectric substrate and a second upper metal layer that is on an upper surface of the second dielectric substrate, the second upper metal layer including a second upper signal trace;

a metal signal trace connector that electrically connects the first upper signal trace to the second upper signal trace; and

an RF shielding cover that covers the metal signal trace connector.

2. The RF transmission line of Claim 1, wherein the RF shielding cover comprises an upper surface and at least one sidewall extending from the upper surface toward the metal signal trace connector.

3. The RF transmission line of Claim 1, wherein the RF shielding cover is galvanically connected to the first upper ground plane.

4. The RF transmission line of Claim 1, wherein the second upper metal layer further comprises a second upper ground plane, and the RF shielding cover is galvanically connected to the first upper ground plane and to the second upper ground plane.

5. The RF transmission line of Claim 4, wherein the RF shielding cover, the first upper ground plane and the second upper ground plane substantially enclose the metal signal trace connector.

6. The RF transmission line of Claim 1, wherein the metal signal trace connector is a longitudinally extending metal strip that has a first end that galvanically connects to the first upper signal trace and a second end that galvanically connects to the second upper signal trace.

7. The RF transmission line of Claim 1, wherein the metal signal trace connector is capacitively coupled to the first upper signal trace and to the second upper signal trace.

8. The RF transmission line of Claim 1, wherein the first upper signal trace comprises the signal conductor of a first stripline transmission line formed in the first printed circuit board, and the first upper ground plane and the first lower ground plane comprise the ground conductor of the first stripline transmission line.

9. The RF transmission line of Claim 8, wherein the second dielectric substrate is a second upper dielectric substrate, the second upper metal layer further comprises a second upper ground plane, and the second printed circuit board further includes a second lower dielectric substrate, a second internal metal layer that is between the second upper dielectric substrate and the second lower dielectric substrate, the second internal metal layer including a second internal signal trace and a second internal ground plane, and a second lower metal layer that is on a lower surface of the second lower dielectric substrate that forms a second lower ground plane.

10. The RF transmission line of Claim 9, wherein the second upper signal trace comprises the signal conductor of a second stripline transmission line formed in the second printed circuit board, and the second upper ground plane and the second lower ground plane comprise the ground conductor of the second stripline transmission line.

11. The RF transmission line of Claim 10, further comprising a metal ground connector that electrically connects the first lower ground plane to the second lower ground plane.

12. The RF transmission line of Claim 11, wherein the metal ground connector is soldered to both the first lower ground plane and to the second lower ground plane.

13. The RF transmission line of Claim 1, wherein the second printed circuit board further includes a second lower metal layer that is on the lower surface of the second dielectric

substrate that forms a second lower ground plane, and wherein the second upper signal trace and the second lower ground plane comprise the signal and ground conductors of a microstrip transmission line formed in the second printed circuit board.

14. The RF transmission line of Claim 13, wherein the second dielectric substrate is thicker than the first upper dielectric substrate and is thicker than the first lower dielectric substrate.

15. The RF transmission line of Claim 14, further comprising a metal ground connector that electrically connects the first lower ground plane to the second lower ground plane.

16. The RF transmission line of Claim 1, wherein the second printed circuit board further includes a second lower metal layer that is on the lower surface of the second dielectric substrate that forms a second lower ground plane, wherein the second upper metal layer further comprises a second upper ground plane, and wherein the second upper signal trace comprises the signal conductor of a grounded coplanar waveguide transmission line that is formed in the second printed circuit board, and the second upper ground plane and the second lower ground plane comprise the ground conductor of the grounded coplanar waveguide transmission line.

17. The RF transmission line of Claim 16, further comprising a metal ground connector that electrically connects the first lower ground plane to the second lower ground plane.

18. The RF transmission line of Claim 16, wherein the second dielectric substrate is thicker than the first upper dielectric substrate and is thicker than the first lower dielectric substrate.

19. The RF transmission line of Claim 1, wherein the second upper metal layer further comprises a second upper ground plane, and wherein the second upper signal trace comprises the signal conductor of a coplanar waveguide transmission line that is formed in the second printed circuit board, and the second upper ground plane comprises the ground conductor of the coplanar waveguide transmission line.

20. The RF transmission line of Claim 19, wherein the second dielectric substrate is thicker than the first upper dielectric substrate and is thicker than the first lower dielectric substrate.

21. The RF transmission line of Claim 1, further comprising a first conductive signal via that extends between the first internal signal trace and the first upper signal trace.

22. The RF transmission line of Claim 1, the first printed circuit board further comprising first and second rows of ground vias that extend through the first upper dielectric substrate and the first lower dielectric substrate, the first and second rows of ground vias electrically connecting the first upper ground plane, the first internal ground plane, and the first lower ground plane.

23. The RF transmission line of Claim 22, wherein the first row of ground vias is on a first side of the first internal signal trace and the second row of ground vias is on a second side of the first internal signal trace.

24. The RF transmission line of Claim 1, wherein the first printed circuit board further comprising a first additional dielectric layer that is interposed between the first upper dielectric substrate and the first lower dielectric substrate.

25. The RF transmission line of Claim 1, wherein the first upper ground plane surrounds the first upper signal trace on at least three sides.

26. A radio frequency ("RF") transmission line, comprising:

a first printed circuit board that includes a first stripline transmission line and a first non-stripline transmission line that is electrically connected to the first stripline transmission line;

a second printed circuit board that includes a second stripline transmission line and a second non-stripline transmission line that is electrically connected to the second stripline transmission line;

a metal signal trace connector that electrically connects a first signal trace of the first non-stripline transmission line to a second signal trace of the second non-stripline transmission line; and

an RF shielding cover that covers the metal signal trace connector.

27. The RF transmission line of Claim 26, wherein the first non-stripline transmission line comprises a microstrip transmission line, a coplanar waveguide transmission line, or a grounded coplanar waveguide transmission line.

28. The RF transmission line of Claim 26, wherein the RF shielding cover comprises an upper surface and at least one sidewall extending downwardly from the upper surface.

29. The RF transmission line of Claim 28, wherein the RF shielding cover is soldered to a first upper ground plane of the first stripline transmission line and to a second upper ground plane of the second stripline transmission line.

30. The RF transmission line of Claim 29, wherein the RF shielding cover, the first upper ground plane and the second upper ground plane substantially enclose the metal signal trace connector.

31. The RF transmission line of Claim 26, wherein the metal signal trace connector is a longitudinally extending metal strip that has a first end that galvanically connects to the first signal trace and a second end that galvanically connects to the second signal trace.

32. The RF transmission line of Claim 26, wherein the metal signal trace connector is capacitively coupled to the first signal trace and to the second signal trace.

33. The RF transmission line of Claim 26, wherein the first stripline transmission line includes a first upper ground plane and a first lower ground plane, and wherein the second stripline transmission line includes a second upper ground plane and a second lower ground plane.

34. The RF transmission line of Claim 33, further comprising a metal ground connector that electrically connects the first lower ground plane to the second lower ground plane.

35. The RF transmission line of Claim 34, wherein the metal ground connector is soldered to both the first lower ground plane and to the second lower ground plane.

36. The RF transmission line of Claim 26, further comprising a first conductive signal via that extends between a signal trace of the first stripline transmission line and the first signal trace of the first non-stripline transmission line.

37. A base station antenna comprising the RF transmission line of any of Claims 1-25.

38. A base station antenna comprising the RF transmission line of any of Claims 26-36.

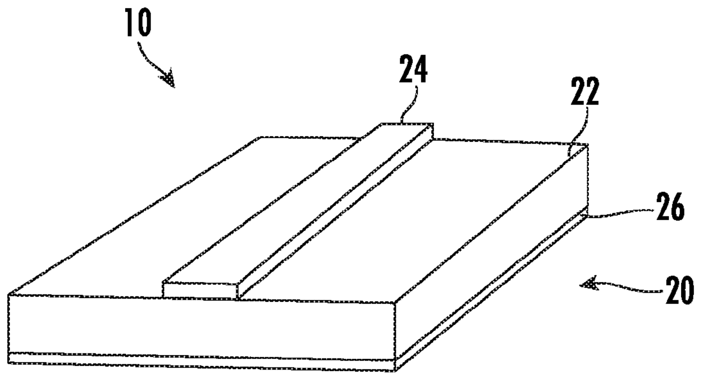


FIG. 1A

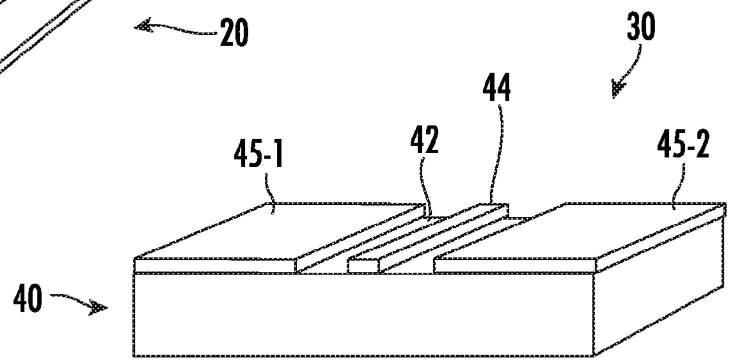


FIG. 1B

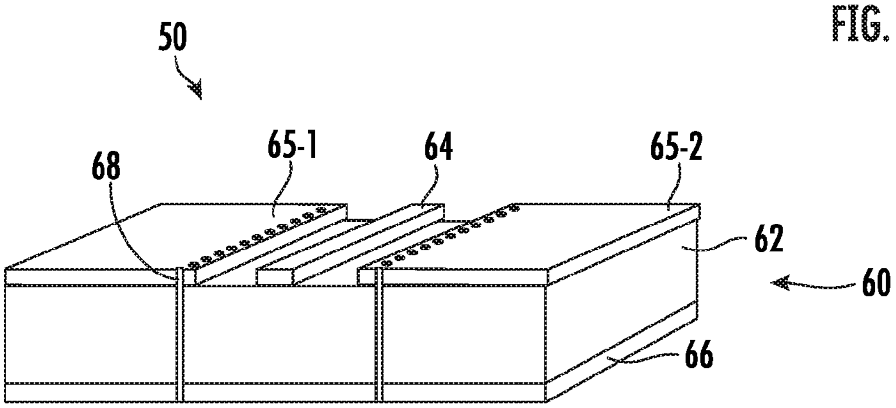


FIG. 1C

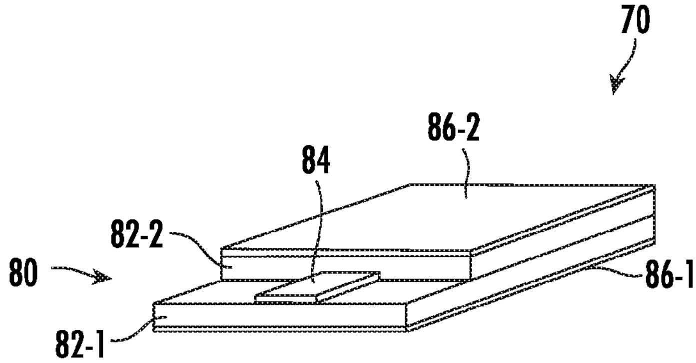


FIG. 1D

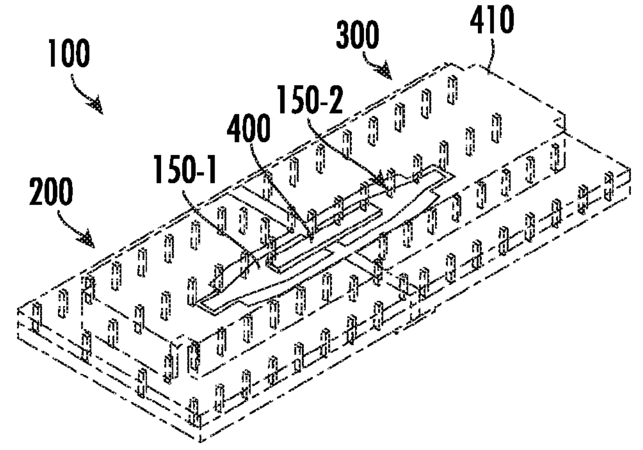


FIG. 2A

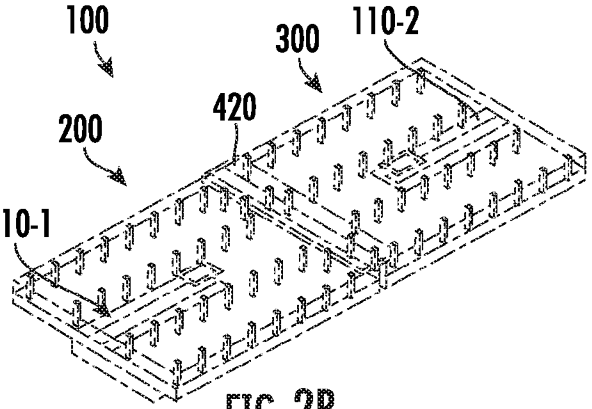


FIG. 2B

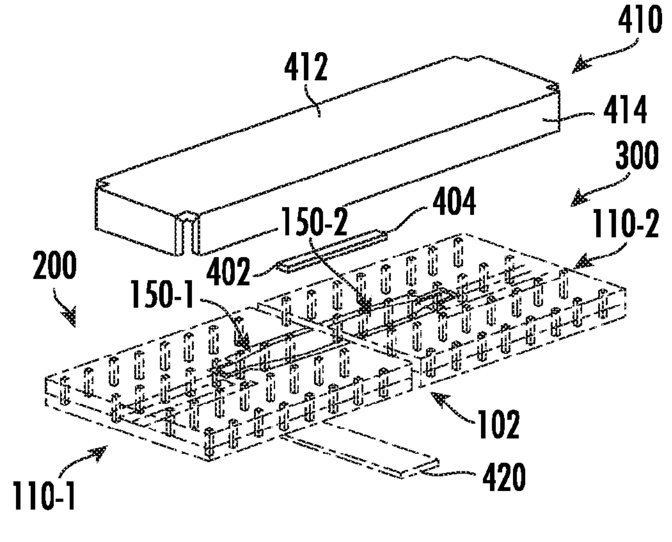


FIG. 2C

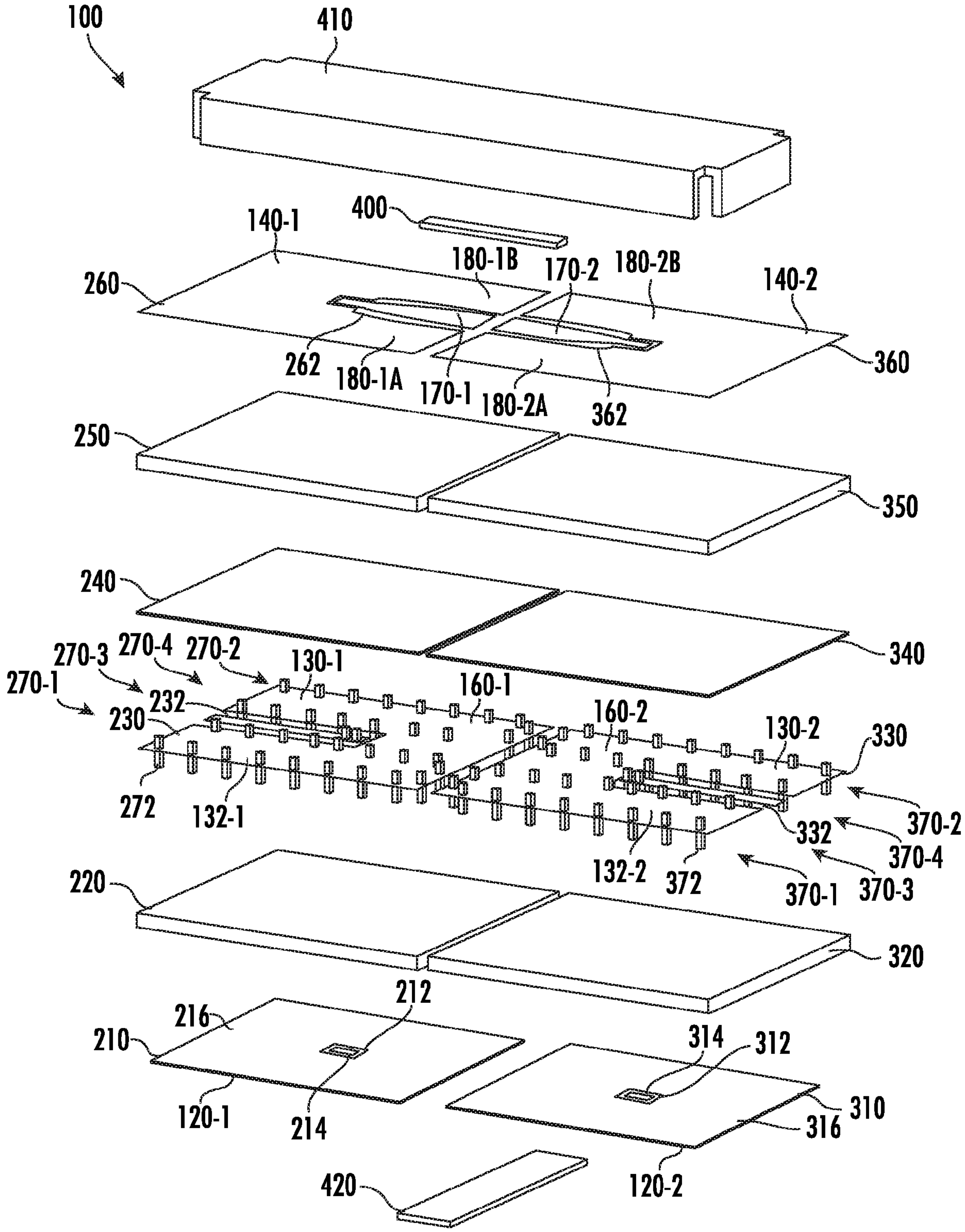
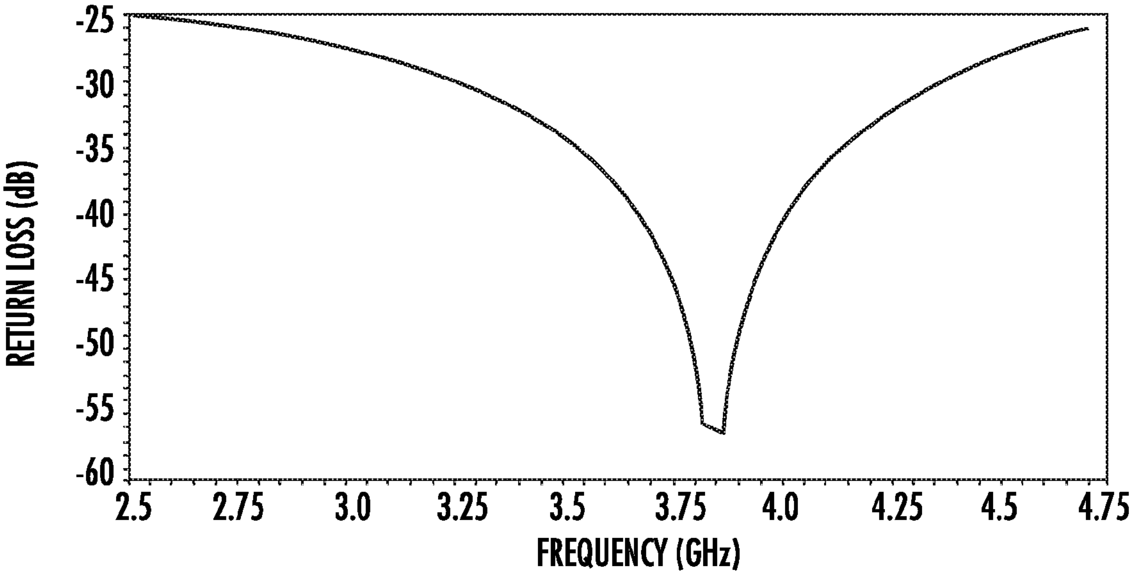
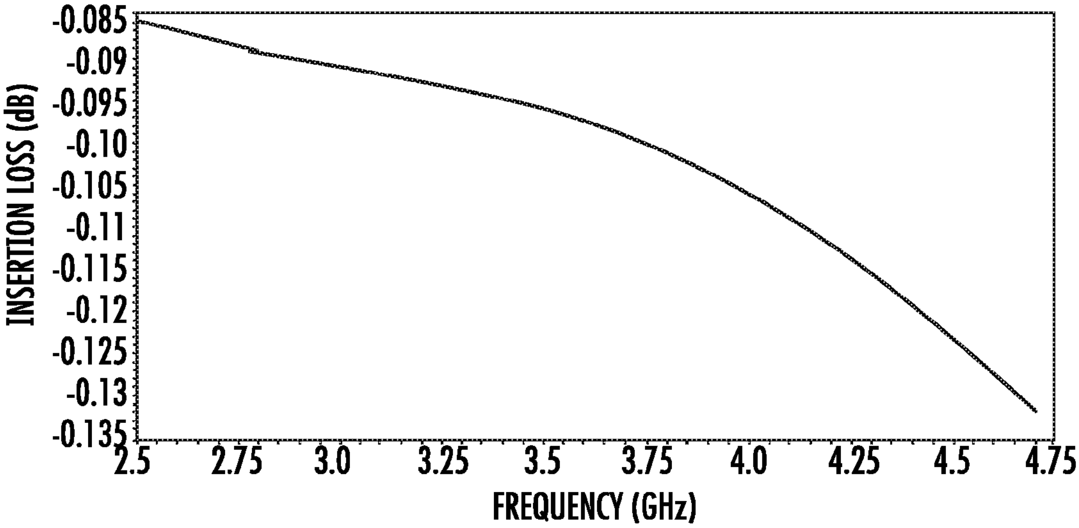

100
410
400
140-1
260
180-1B
170-2
180-2B
140-2
360
262
180-1A
170-1
180-2A
362
250
350
240
340
270-3
270-4
270-2
130-1
270-1
232
230
160-1
160-2
130-2
330
272
132-1
332
370-2
370-4
132-2
372
370-1
370-3
220
320
212
216
210
314
312
310
316
120-1
214
420
120-2

FIG. 2D



-25
-30
-35
-40
-45
-50
-55
-60
RETURN LOSS (dB)
2.5
2.75
3.0
3.25
3.5
3.75
4.0
4.25
4.5
4.75
FREQUENCY (GHz)

FIG. 3A



-0.085
-0.09
-0.095
-0.10
-0.105
-0.11
-0.115
-0.12
-0.125
-0.13
-0.135
INSERTION LOSS (dB)
2.5
2.75
3.0
3.25
3.5
3.75
4.0
4.25
4.5
4.75
FREQUENCY (GHz)

FIG. 3B

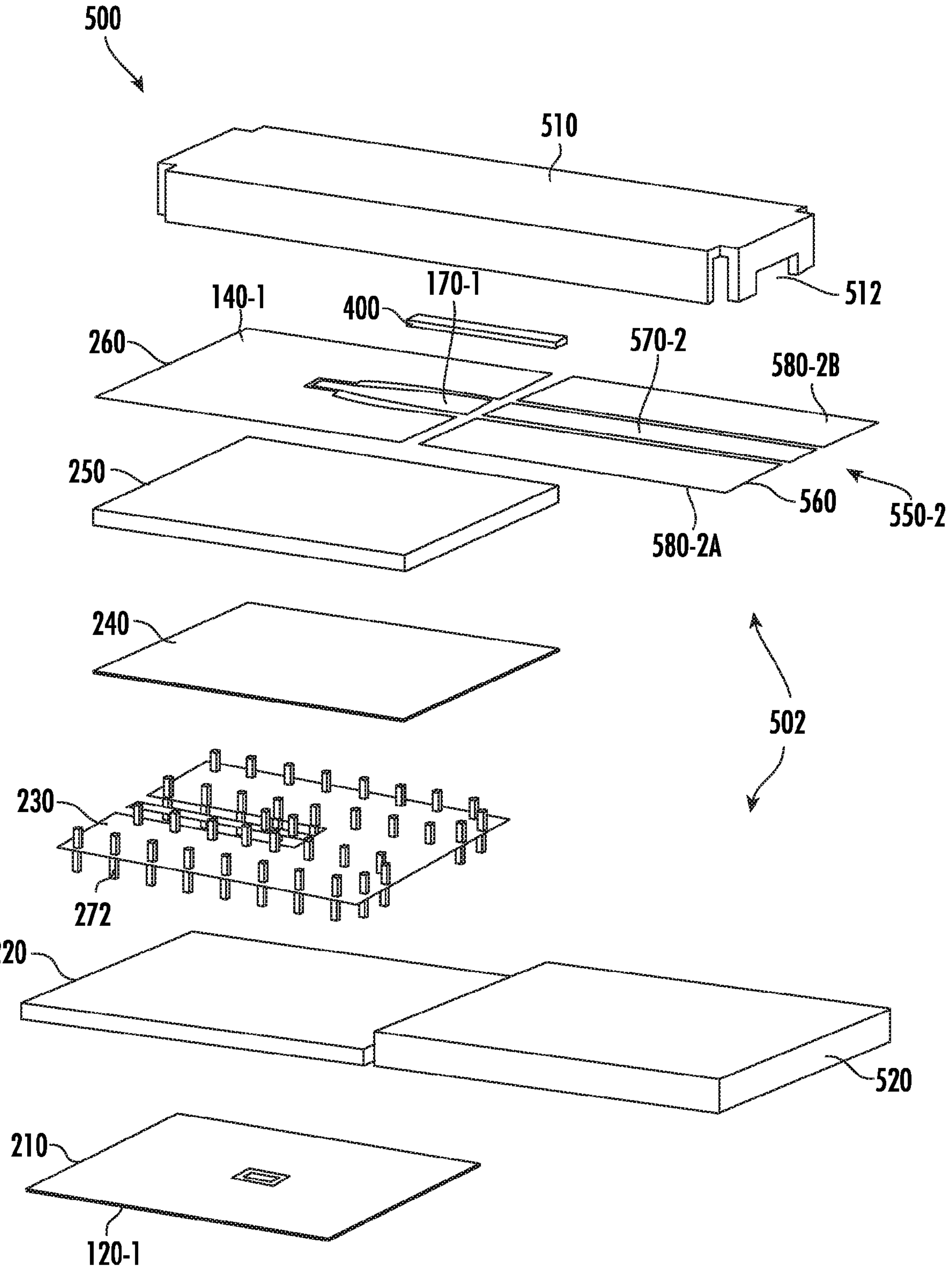

500
510
512
140-1
400
170-1
260
570-2
580-2B
250
560
550-2
580-2A
240
502
230
272
220
520
210
120-1

FIG. 4A

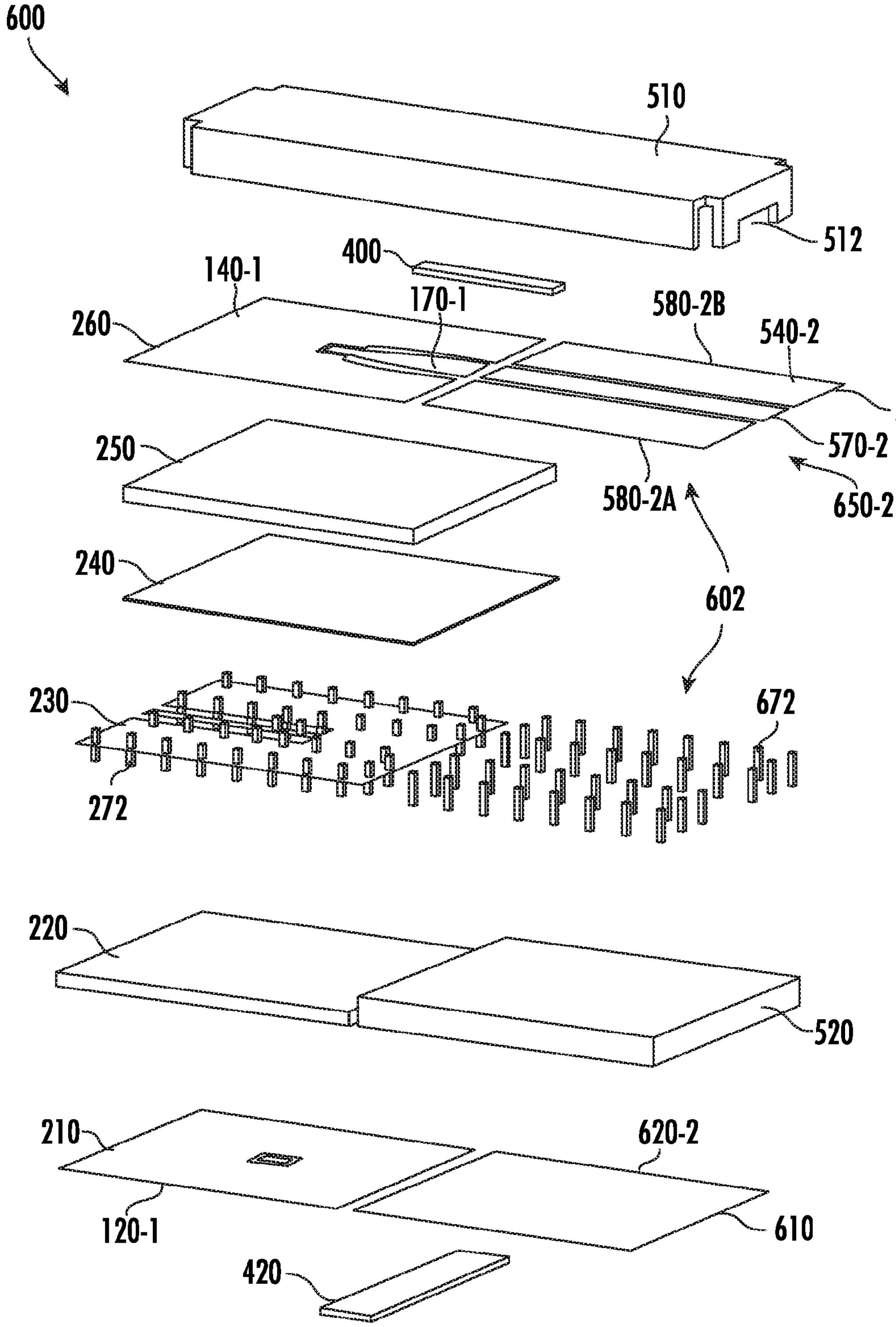

600
510
512
400
140-1
170-1
580-2B
540-2
260
560
570-2
250
580-2A
650-2
240
602
230
672
272
220
520
210
620-2
120-1
610
420

FIG. 4B

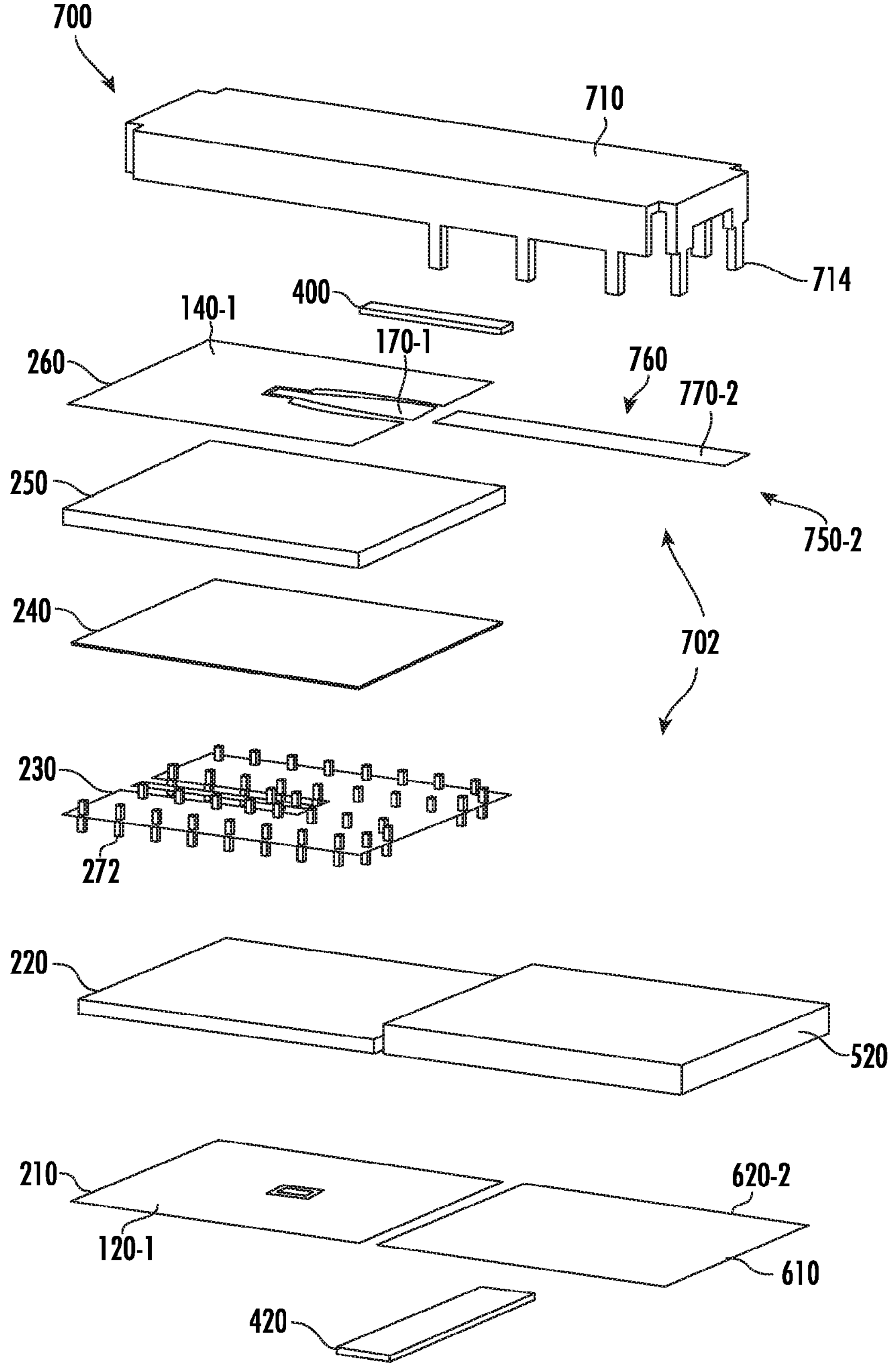

700
710
714
400
140-1
170-1
260
760
770-2
250
750-2
240
702
230
272
220
520
210
620-2
120-1
610
420

FIG. 4C

INTERNATIONAL SEARCH REPORT

International application No
PCT/CN2022/071729

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01P1/04 H01P5/08
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01P

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	YANG SHILIN ET AL: "A Low-Loss Broadband Planar Transition From Ground Coplanar Waveguide to Substrate-Integrated Coaxial Line", IEEE MICROWAVE AND WIRELESS COMPONENTS LETTERS, IEEE SERVICE CENTER, NEW YORK, NY, US, vol. 31, no. 11, 12 May 2021 (2021-05-12), pages 1191-1194, XP011886883, ISSN: 1531-1309, DOI: 10.1109/LMWC.2021.3079439 [retrieved on 2021-11-04]	1-13,16, 17,21-38
A	section II.; page 1192; figures 1, 2(a)	14,15, 18-20

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[x] Further documents are listed in the continuation of Box C.

[x] See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 June 2022	05/07/2022

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Blech, Marcel

2

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	US 2010/254094 A1 (OHHIRA RISATO [JP]) 7 October 2010 (2010-10-07) page 3, paragraph 50 - page 4, paragraph 60; figures 2A-2H	1-13,16, 17,21-38 14,15, 18-20
Y A	JP H11 346106 A (NEC CORP) 14 December 1999 (1999-12-14) page 3, paragraph 25 - page 4, paragraph 36; figures 1, 2	1-13,16, 17,21-38 14,15, 18-20
A	EP 3 229 311 A1 (HUAWEI TECH CO LTD [CN]) 11 October 2017 (2017-10-11) column 6, paragraph 50 - column 6, paragraph 53; figure 1A page 7, paragraph 60 - page 7, paragraph 61; figure 2	7,32
A	JIANG C ET AL: "Packaging of photodetector modules for 100 Gbit/s applications using electromagnetic simulations", MICROWAVE CONFERENCE, 2009. EUMC 2009. EUROPEAN, IEEE, PISCATAWAY, NJ, USA, 29 September 2009 (2009-09-29), pages 1369-1372, XP031669925, ISBN: 978-1-4244-4748-0 section II.A.; page 1370; figures 2-4	19,20

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/CN2022/071729

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		US 2010254094 A1	07-10-2010
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EP 3229311 A1	11-10-2017	NONE	