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(71) Applicant: TEXAS INSTRUMENTS INCORPORATED [US/US]; P.O. Box 655474, Mail Station 3999, Dallas, TX 75265-5474 (US).

(72) Inventors: HERBSOMMER, Juan, A.; 1024 Blanco Drive, Allen, TX 75013 (US). PAYNE, Robert, F.; 1700 Briardale Drive, Lucas, TX 75002 (US). CORSI, Marco; 4304 Boulder Drive, Parker, TX 75002 (US). HAROUN, Baher, S.; 906 Pampa Dr., Allen, TX 75013 (US). ALI, Hassan; 605 Dove Cove Court, Murphy, TX 75094 (US).

(74) Agents: FRANZ, Warren L. et al.; Texas Instruments Incorporated, Deputy General Patent Counsel, P.O. Box 655474, Mail Station 3999, Dallas, TX 75265-5474 (US).

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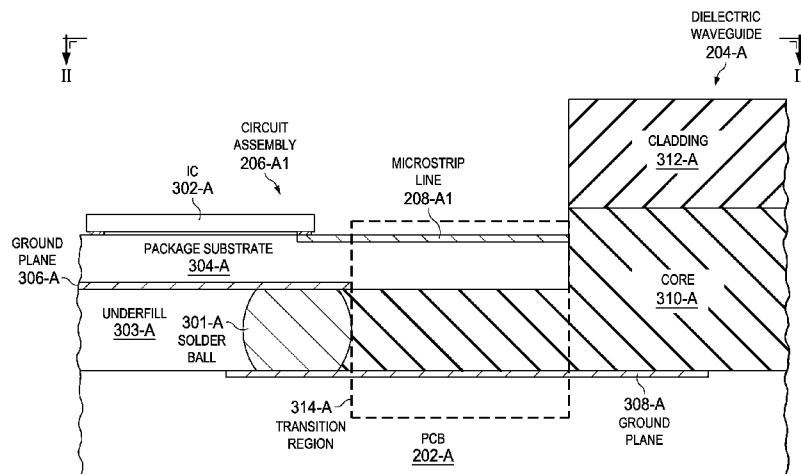


FIG. 4

(57) **Abstract:** An apparatus is provided. There is a circuit assembly (206-A1) with a package substrate (304-A) and an integrated circuit (IC) (302-A). The package substrate has a microstrip line (208-A1), and the IC is secured to the package substrate and is electrically coupled to the microstrip line. A circuit board (202-A) is also secured to the package substrate. A dielectric waveguide (204-A) is secured to the circuit board. The dielectric waveguide has a dielectric core (310-A) that extends into a transition region (314-A) located between the dielectric waveguide and the microstrip line, and the microstrip line is configured to form a communication link with the dielectric waveguide.

INTERCHIP COMMUNICATION USING A DIELECTRIC WAVEGUIDE

[0001] This relates generally to chip-to-chip communications and, more particularly, to chip-to-chip communications using a dielectric waveguide.

BACKGROUND

[0002] The most widely used interconnect system (which is employed in most electronic devices) employs metal traces that are integrated into a printed circuit board (PCB) or backplane. For this type of system, integrated circuits (ICs) are secured to the PCB so as to be electrically coupled to one or more of the traces, allowing for interchip or chip-to-chip communications. A problem with this arrangement is that the physical limit for data rates or data transmission is being reached, so, as a result, several different types of communications links have been or are being developed: optical and wireless links. Each of these developing technologies employs the use of a transmission medium, namely an optical fiber for optical links and a metal waveguide for wireless links.

[0003] Turning to FIGS. 1 and 2, an example of an interconnect system 100 using a wireless link or optical link can be seen. In this example, a transmission medium 104 (which is a metal waveguide or an optical fiber) is integrated into a PCB 102. ICs 106-1 and 106-2 are secured to the PCB 102 and located in proximity to each respective end of the transmission medium 104. Theoretically, then, the transceiver 108-1 and 108-2 (which are optical transceivers for optical links and radio frequency (RF) transceivers for wireless links) can allow for interchip communication between ICs 106-1 and 106-2. In practice, however, this interchip communication is not a simple task. Assuming, for example, that the system 100 employs an optical link, the optical transceivers 108-1 and 108-2 would have an on-die light emitting diode (LED) and/or photodiode (which is difficult with current process technologies), having an optical axis. Usually, the LED (for transmission) is a laser diode, which has a particular wavelength or frequency, and the transmission medium 104 (optical fiber for this example) is dimensioned to accommodate the wavelength of the light emitted from LED. Typically, the transmission

medium 104 (optical fiber for this example) is a monomode fiber to improve bandwidth, which has a diameter that is related to the wavelength of the light emitted from LED. For example, for near infrared (i.e., wavelength between about 0.7 μ m and about 3 μ m), a monomode optical fiber will generally have a diameter between about 8 μ m and about 10 μ m. Thus, a misalignment (of even a few microns) between the optical axis of the transmission medium 104 (optical fiber for this example) and the optical axis of the LED (or photodiode) may result in a poor interconnect or no interconnect. Therefore, precision machining or other more exotic micro-optical structures would generally be necessary. The same would also be true for metal waveguides; namely, precision machining would generally be necessary for proper alignment. Metallic waveguides for sub-millimeter waves are also quite lossy, substantially limiting the distance over which the waveguides would work.

[0004] Therefore, there is a need for an improved interconnect system.

[0005] Some other examples of conventional systems are described in U.S. Patent No. 5,754,948; U.S. Patent No. 7,768,457; U.S. Patent No. 7,379,713; U.S. Patent No. 7,330,702; U.S. Patent No. 6,967,347; and U.S. Patent Pre-Grant Publ. No. 2009/0009408.

SUMMARY

[0006] An example embodiment provides an apparatus. The apparatus comprises a circuit board having a first side, a second side, and a first ground plane, wherein the first ground plane is formed on the first side of the circuit board; a package substrate that is secured to the first side of the circuit board, wherein the package substrate includes: a second ground plane that is electrically coupled to the first ground plane; a microstrip line that is substantially parallel to the first and second ground planes, wherein the microstrip line has: a first portion that overlays at least a portion of the second ground plane and that is separated from the second ground plane by a first distance, wherein the first portion of the microstrip line is dimensioned to have an impedance to propagate radiation having a wavelength; and a second portion that overlays at least a portion of the first ground plane and that is separated from the first ground plane by a second distance, wherein the second distance is greater than the first distance, and wherein the second portion of the microstrip line is dimensioned to have the impedance to propagate the radiation having the wavelength, and wherein the second portion of the microstrip line is located within a transition region; an integrated circuit (IC) that is secured to the package substrate and that is electrically coupled to the first portion of the microstrip line; and a dielectric waveguide

that is secured to the circuit board, wherein the dielectric waveguide includes a core that overlies at least a portion of the first ground plane and extends into the transition region.

[0007] In specific implementations, the wavelength may be less than or equal to about 1mm. The dielectric waveguide may further comprise a cladding, and wherein the core has first dielectric constant, and wherein the cladding has a second dielectric constant, and wherein the first dielectric constant is greater than the second dielectric constant. The package substrate may have first and second sides, the microstrip line may be formed on the first side of the package substrate, the IC may be secured to the first side of the package substrate, and the first ground plane may be formed on the second side of the package substrate. One or more solder balls may be secured to the first and second ground planes. The impedance may be about 50Ω . Further, the first portion of the microstrip line may be generally rectangular having a width of about $25\mu\text{m}$, and the second portion of the microstrip line may be generally rectangular having a width of about $50\mu\text{m}$.

[0008] In another aspect, the described embodiment comprises a circuit board having a first side, a second side, and a plurality of circuit board ground planes, wherein each circuit board ground plane is formed on the first side of the circuit board; a plurality of package substrates, wherein each package substrate is secured to the first side of the circuit board, and wherein each is collocated with at least one of the circuit board ground planes, wherein each package substrate includes: a package substrate ground plane that is electrically coupled to its circuit board ground plane; a microstrip line that is substantially parallel to its package substrate ground plane and its circuit board ground plane, wherein the microstrip line has: a first portion that overlays at least a portion of its package substrate ground plane and that is separated from its package substrate ground plane by a first distance, wherein the first portion of the microstrip line is dimensioned to have an impedance to propagate radiation having a wavelength; and a second portion that overlays at least a portion of its circuit board ground plane and that is separated from its circuit board ground plane by a second distance, wherein the second distance is greater than the first distance, and wherein the second portion of the microstrip line is dimensioned to have the impedance to propagate the radiation having the wavelength, and wherein the second portion of the microstrip line is located within a transition region; a plurality of ICs, wherein each IC is secured to at least one of the package substrates and is electrically coupled to the first portion of its microstrip line; and a dielectric waveguide network that is secured to the circuit board,

wherein a core from dielectric waveguide network the overlies at least a portion of each circuit board ground plane and extends into its transition region.

[0009] In specific implementations, the dielectric waveguide network may further be a plurality of dielectric waveguides having a cladding, the core may have a first dielectric constant, the cladding may have a second dielectric constant, and the first dielectric constant may be greater than the second dielectric constant. Each package substrate may have first and second sides, the microstrip line may be formed on the first side of the package substrate, the IC may be secured to the first side of the package substrate, and the package substrate ground plane may be formed on the second side of the package substrate. One or more solder balls may be secured to the circuit board ground plane and the package substrate ground planes for each package substrate.

[0010] In another aspect, the embodiment is an apparatus that comprises a circuit board having a first side, a second sides, a first ground plane, and a second ground plane, wherein the first and second ground planes are formed on the first side of the circuit board, and wherein the first and second ground planes are separated from one another; a first package substrate that is secured to the first side of the circuit board, wherein the first package substrate includes: a third ground plane that is electrically coupled to the first ground plane; a first microstrip line that is substantially parallel to the first and third ground planes, wherein the first microstrip line has: a first portion that overlays at least a portion of the third ground plane and that is separated from the third ground plane by a first distance, wherein the first portion of the first microstrip line is dimensioned to have an impedance to propagate radiation having a wavelength; and a second portion that overlays at least a portion of the first ground plane and that is separated from the first ground plane by a second distance, wherein the second distance is greater than the first distance, and wherein the second portion of the first microstrip line is dimensioned to have the impedance to propagate the radiation having the wavelength, and wherein the second portion of the first microstrip line is located within a first transition region; a first IC that is secured to the package substrate and that is electrically coupled to the first portion of the first microstrip line; a second package substrate that is secured to the first side of the circuit board, wherein the second package substrate includes: a fourth ground plane that is electrically coupled to the second ground plane; a second microstrip line that is substantially parallel to the second and fourth ground planes, wherein the second microstrip line has: a first portion that overlays at least a portion of the fourth

ground plane and that is separated from the fourth ground plane by a third distance, wherein the first portion of the second microstrip line is dimensioned to have the impedance to propagate the radiation having the wavelength; and a second portion that overlays at least a portion of the second ground plane and that is separated from the second ground plane by a fourth distance, wherein the fourth distance is greater than the third distance, and wherein the second portion of the second microstrip line is dimensioned to have the impedance to propagate the radiation having the wavelength, and wherein the second portion of the second microstrip line is located within a second transition region; a second IC that is secured to the package substrate and that is electrically coupled to the first portion of the second microstrip line; and a dielectric waveguide having: a core with first and second ends, wherein the core is secured to the circuit board and overlies at least a portion of the first and second ground planes, and wherein the first end of the core extends into the first transition region, and wherein the second end of the core extends into the second transition region, and wherein the core has a first dielectric constant; and a cladding that is secured to the core, wherein the cladding has a second dielectric constant, and wherein the first dielectric constant is greater than the second dielectric constant.

[0011] In specific implementations, each of the first and second package substrates may have first and second sides, the microstrip line may be formed on the first side of the package substrate, the IC may be secured to the first side of the package substrate, and its first ground plane may be formed on the second side of the package substrate. One or more solder balls may be secured to the first and third ground planes, and one or more solder balls may be secured to the second and fourth ground planes. The first portion of each of the first and second microstrip lines may be generally rectangular, and the second portion of each of the first and second microstrip lines may be generally rectangular.

[0012] In another aspect, the apparatus comprises a circuit board having a first side, a second side, and a first ground plane; a channel formed in the first side of circuit board, wherein the first ground plane underlies at least a portion of the channel; a package substrate that is secured to the first side of the circuit board, wherein the package substrate includes: a second ground plane that is electrically coupled to the first ground plane; a microstrip line that is substantially parallel to the first and second ground planes, wherein the microstrip line has: a first portion that overlays at least a portion of the second ground plane and that is separated from the second ground plane by a first distance, wherein the first portion of the microstrip line is

dimensioned to have an impedance to propagate radiation having a wavelength; and a second portion that overlays at least a portion of the first ground plane and that is separated from the first ground plane by a second distance, wherein the second distance is greater than the first distance, and wherein the second portion of the microstrip line is dimensioned to have the impedance to propagate the radiation having the wavelength, and wherein the second portion of the microstrip line is located within a transition region; an integrated circuit (IC) that is secured to the package substrate and that is electrically coupled to the first portion of the microstrip line; and a dielectric core that overlies at least a portion of the first ground plane, that extends into the transition region, and that is secured in the channel.

[0013] In specific implementations, the apparatus may further comprise a cladding. The core may have a first dielectric constant, the cladding may have a second dielectric constant, and the first dielectric constant may be greater than the second dielectric constant. The circuit board may further comprise a via that extends from the first ground plane to the first side of the circuit board, and one or more solder balls may be secured to the second ground plane and the via. The first portion of the microstrip line may be generally rectangular.

[0014] In another aspect, the apparatus comprises a circuit board having a first side, a second side, and a plurality of circuit board ground planes; a channel network formed in the first side of circuit board, wherein each circuit board ground plane underlies at least a portion of the channel network; a plurality of package substrates, wherein each package substrate is secured to the first side of the circuit board, and wherein each is collocated with at least one of the circuit board ground planes, wherein each package substrate includes: a package substrate ground plane that is electrically coupled to its circuit board ground plane; a microstrip line that is substantially parallel to its package substrate ground plane and its circuit board ground plane, wherein the microstrip line has: a first portion that overlays at least a portion of its package substrate ground plane and that is separated from its package substrate ground plane by a first distance, wherein the first portion of the microstrip line is dimensioned to have an impedance to propagate radiation having a wavelength; and a second portion that overlays at least a portion of its circuit board ground plane and that is separated from its circuit board ground plane by a second distance, wherein the second distance is greater than the first distance, and wherein the second portion of the microstrip line is dimensioned to have the impedance to propagate the radiation having the wavelength, and wherein the second portion of the microstrip line is located within a

transition region; a plurality of ICs, wherein each IC is secured to at least one of the package substrates and is electrically coupled to the first portion of its microstrip line; and a dielectric core network that is secured in the channel network and that has a plurality of ends, wherein each end from dielectric waveguide network the overlies at least a portion of at least one of the circuit board ground planes and extends into its transition region.

[0015] In specific implementations, the dielectric waveguide network may further comprise a plurality of dielectric waveguides having a cladding. The core may have a first dielectric constant, the cladding may have a second dielectric constant, and the first dielectric constant may be greater than the second dielectric constant. The circuit board may further comprise a plurality of vias, wherein each via extends between the first side of the circuit board and at least one of the circuit board ground planes, and wherein at least one solder ball is secured to at least one via and at least one package substrate ground plane.

[0016] In another aspect, the apparatus comprises a circuit board having a first side, a second sides, a first ground plane, and a second ground plane; a channel formed in the first side of the circuit board and having a first end and a second end, wherein the first end of the channel overlies at least a portion of the first ground plane, and wherein the second end of the channel overlies at least a portion of the second ground plane; a first package substrate that is secured to the first side of the circuit board, wherein the first package substrate includes: a third ground plane that is electrically coupled to the first ground plane; a first microstrip line that is substantially parallel to the first and third ground planes, wherein the first microstrip line has: a first portion that overlays at least a portion of the third ground plane and that is separated from the third ground plane by a first distance, wherein the first portion of the first microstrip line is dimensioned to have an impedance to propagate radiation having a wavelength; and a second portion that overlays at least a portion of the first ground plane and that is separated from the first ground plane by a second distance, wherein the second distance is greater than the first distance, and wherein the second portion of the first microstrip line is dimensioned to have the impedance to propagate the radiation having the wavelength, and wherein the second portion of the first microstrip line is located within a first transition region; a first IC that is secured to the package substrate and that is electrically coupled to the first portion of the first microstrip line; a second package substrate that is secured to the first side of the circuit board, wherein the second package substrate includes: a fourth ground plane that is electrically coupled to the second ground plane;

a second microstrip line that is substantially parallel to the second and fourth ground planes, wherein the second microstrip line has: a first portion that overlays at least a portion of the fourth ground plane and that is separated from the fourth ground plane by a third distance, wherein the first portion of the second microstrip line is dimensioned to have the impedance to propagate the radiation having the wavelength; and a second portion that overlays at least a portion of the second ground plane and that is separated from the second ground plane by a fourth distance, wherein the fourth distance is greater than the third distance, and wherein the second portion of the second microstrip line is dimensioned to have the impedance to propagate the radiation having the wavelength, and wherein the second portion of the second microstrip line is located within a second transition region; a second IC that is secured to the package substrate and that is electrically coupled to the first portion of the second microstrip line; and a dielectric core with first and second ends, wherein the core is secured to in the channel, and wherein the first end of the dielectric core overlies at least a portion of the first ground plane, and wherein the send end of the dielectric core overlies at least a portion of the second ground plane, and wherein the first end of the core extends into the first transition region, and wherein the second end of the core extends into the second transition region, and wherein the dielectric core has dielectric constant that is greater than the dielectric constant of the circuit board.

[0017] In another aspect, the apparatus comprises a circuit board having a first side, a second sides, a first ground plane, and a first microstrip line, wherein the first microstrip line is generally parallel to the first ground plane; a channel formed in the first side of circuit board, wherein the first ground plane underlies a least a portion of the channel; a package substrate that is secured to the first side of the circuit board, wherein the package substrate includes: a second ground plane that is electrically coupled to the first ground plane; a second microstrip line that is substantially parallel to the first and second ground planes, wherein the second microstrip line has: a first portion that overlays at least a portion of the second ground plane and that is separated from the second ground plane by a first distance, wherein the first portion of the second microstrip line is dimensioned to have an impedance to propagate radiation having a wavelength; and a second portion that overlays at least a portion of the first ground plane and that is separated from the first ground plane by a second distance, wherein the second distance is greater than the first distance, and wherein the second portion of the second microstrip line is dimensioned to have the impedance to propagate the radiation having the wavelength, and

wherein the second portion of the microstrip line is located within a transition region, and wherein the second portion of the second microstrip line is electrically coupled to the first microstrip line; an integrated circuit (IC) that is secured to the package substrate and that is electrically coupled to the first portion of the second microstrip line; a metal waveguide that is secured in the channel, that is located in the transition region, and that is electrically coupled to the first microstrip line; and a dielectric core that overlies at least a portion of the first ground plane, that extends into the metal waveguide, and that is secured in the channel.

[0018] In specific implementations, the package substrate may have first and second sides, wherein the second microstrip line is formed on the first side of the package substrate, wherein the IC is secured to the first side of the package substrate, wherein the first ground plane is formed on the second side of the package substrate, and wherein the package substrate further comprises a via that extends from the second portion of the second microstrip line to the second side of the package substrate, and wherein at least one solder ball is secured to the via and the first microstrip line. The via may further comprise a first via, the circuit board may further comprise a second via that extends from the first ground plane to the first side of the circuit board, and one or more solder balls may be secured to the second ground plane and the second via. The metal waveguide may further comprise: a first plate that is coplanar with and electrically coupled to the first microstrip line; a second plate that is coplanar with and electrically coupled to the first plate; and a plurality of waveguide vias that extend between the second plate and the first ground plane.

[0019] In another aspect, the apparatus comprises a circuit board having a first side, second sides, a plurality of circuit board ground planes, and a plurality of circuit board microstrip lines; a channel network formed in the first side of circuit board, wherein each circuit board ground plane underlies a least a portion of the channel network; a plurality of package substrates, wherein each package substrate is secured to the first side of the circuit board, and wherein each is collocated with at least one of the circuit board ground planes and at least one of the circuit board microstrip lines, wherein each package substrate includes: a package substrate ground plane that is electrically coupled to its circuit board ground plane; a package substrate microstrip line that is substantially parallel to its package substrate ground plane and its circuit board ground plane, wherein the package substrate microstrip line has: a first portion that overlays at least a portion of its package substrate ground plane and that is separated from its package

substrate ground plane by a first distance, wherein the first portion of the package substrate microstrip line is dimensioned to have an impedance to propagate radiation having a wavelength; and a second portion that overlays at least a portion of its circuit board ground plane and that is separated from its circuit board ground plane by a second distance, wherein the second distance is greater than the first distance, and wherein the second portion of the package substrate microstrip line is dimensioned to have the impedance to propagate the radiation having the wavelength, and wherein the second portion of the package substrate microstrip line is located within a transition region; a plurality of ICs, wherein each IC is secured to at least one of the package substrates and is electrically coupled to the first portion of its microstrip line; a plurality of metal waveguides, wherein each metal waveguide is secured in the channel network, that is located in the transition region for at least one of the package substrates, and that is electrically coupled to at least one of the circuit board microstrip lines; and a dielectric core network that is secured in the channel network and that has a plurality of ends, wherein each end from dielectric waveguide network the overlies at least a portion of at least one of the circuit board ground planes and extends into its metal waveguide.

[0020] In specific implementations, the dielectric waveguide network may further comprise a plurality of dielectric waveguides having a cladding, the core may have a first dielectric constant, the cladding may have a second dielectric constant, and the first dielectric constant may be greater than the second dielectric constant. Each package substrate may have first and second sides, the microstrip line may be formed on the first side of the package substrate, the IC may be secured to the first side of the package substrate, the package substrate ground plane may be formed on the second side of the package substrate, each package substrate may further comprise a package substrate via that extends from the second portion of its package substrate microstrip line to the second side of its package substrate, and one or more solder balls may be secured to the package substrate via and its circuit board microstrip line.

[0021] In another aspect, the apparatus comprises a circuit board having a first side, second sides, a first ground plane, a second ground plane, a first microstrip line, and a second microstrip line, wherein the first and second microstrip lines are formed on the first side of the circuit board, and wherein the first microstrip line is collocated with and generally parallel to the first ground plane, and wherein second microstrip line is collocated with and generally parallel to the second ground plane; a channel formed in the first side of the circuit board and having a first

end and a second end, wherein the first end of the channel overlies at least a portion of the first ground plane, and wherein the second end of the channel overlies at least a portion of the second ground plane; a first package substrate that is secured to the first side of the circuit board, wherein the first package substrate includes: a third ground plane that is electrically coupled to the first ground plane; a third microstrip line that is substantially parallel to the first and third ground planes, wherein the third microstrip line has: a first portion that overlays at least a portion of the third ground plane and that is separated from the third ground plane by a first distance, wherein the first portion of the third microstrip line is dimensioned to have an impedance to propagate radiation having a wavelength; and a second portion that overlays at least a portion of the first ground plane and that is separated from the first ground plane by a second distance, wherein the second distance is greater than the first distance, and wherein the second portion of the third microstrip line is dimensioned to have the impedance to propagate the radiation having the wavelength, and wherein the second portion of the third microstrip line is located within a first transition region; a first IC that is secured to the package substrate and that is electrically coupled to the first portion of the third microstrip line; a second package substrate that is secured to the first side of the circuit board, wherein the second package substrate includes: a fourth ground plane that is electrically coupled to the second ground plane; a fourth microstrip line that is substantially parallel to the second and fourth ground planes, wherein the fourth microstrip line has: a first portion that overlays at least a portion of the fourth ground plane and that is separated from the fourth ground plane by a third distance, wherein the first portion of the fourth microstrip line is dimensioned to have the impedance to propagate the radiation having the wavelength; and a second portion that overlays at least a portion of the second ground plane and that is separated from the second ground plane by a fourth distance, wherein the fourth distance is greater than the third distance, and wherein the second portion of the fourth microstrip line is dimensioned to have the impedance to propagate the radiation having the wavelength, and wherein the second portion of the second microstrip line is located within a second transition region; a second IC that is secured to the package substrate and that is electrically coupled to the first portion of the fourth microstrip line; a first metal waveguide that is secured in the channel, that is located in the first transition region, and that is electrically coupled to the first microstrip line; a second metal waveguide that is secured in the channel, that is located in the second transition region, and that is electrically coupled to the second microstrip line; a dielectric core

with first and second ends, wherein the core is secured to in the channel, and wherein the first end of the dielectric core overlies at least a portion of the first ground plane, and wherein the second end of the dielectric core overlies at least a portion of the second ground plane, and wherein the first end of the core extends into the first metal waveguide, and wherein the second end of the core extends into the second metal waveguide, and wherein the dielectric core has dielectric constant that is greater than the dielectric constant of the circuit board.

[0022] In specific implementations, the package substrate may have first and second sides, the microstrip line may be formed on the first side of the package substrate, the IC may be secured to the first side of the package substrate, the first ground plane may be formed on the second side of the package substrate, the first package substrate may further comprise a first via that extends from the second portion of third substrate microstrip line to the second side of the first package substrate, one or more solder balls may be secured to the first via and the first microstrip line, the second package substrate may further comprise a second via that extends from the second portion of fourth substrate microstrip line to the second side of the second package substrate, and one or more solder balls may be secured to the second via and the second microstrip line. Further, each of the first and second metal waveguides further may comprise: a first plate that is coplanar with and electrically coupled to its microstrip line; a second plate that is coplanar with and electrically coupled to the first plate; and a plurality of waveguide vias that extend between the second plate and its circuit board ground plane.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] FIG. 1 is a diagram of an example of a conventional interconnect system.

[0024] FIG. 2 is a cross-sectional view of the interconnect system of FIG. 1 along section line I-I.

[0025] FIG. 3 is a diagram of an example of an interconnect system in accordance with the invention.

[0026] FIGS. 4 and 6 are example cross-sectional views of the interconnect system of FIG. 3 along section lines II-II and III-III, respectively.

[0027] FIG. 5 is an isometric view showing an example arrangement for the microstrip line of FIGS. 3 and 4.

[0028] FIG. 7 is a diagram of an example of an interconnect system in accordance with the invention.

[0029] FIG. 8 is example cross-sectional view of the interconnect system of FIG. 7 along section lines IV-IV.

[0030] FIG. 9 is a diagram of an example of an interconnect system in accordance with the invention.

[0031] FIG. 10 is an example cross-sectional view of the interconnect system of FIG. 9 along section lines VI-VI.

[0032] FIG. 11 is an example cross-sectional view of the interconnect system of FIGS. 7 and 9 along section lines V-V and VII-VII, respectively.

[0033] FIG. 12 is an isometric view of the metal waveguide of FIGS. 10 and 11.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

[0034] Turning to FIGS. 3-6, an example of an interconnect system 200-A in accordance with the invention can be seen. In this example system 200-A, circuit assemblies 206-A1 and 206-A2 are able to communicate with one another through a dielectric waveguide 204-A that is secured (i.e., glued) to the PCB 202-A. The circuit assemblies 206-1 and 206-2 can be formed of a IC 302-A that is secured to a package substrate 304-A (which can for example be a PCB) through a ball grid array (BGA) or solder balls (which are shown in broken lines). The package substrate 304-A can then be secured to the PCB 202-A with a BGA or solder balls (i.e., solder ball 301-A), allowing for the IC 302-A to be electrically coupled to at least one solder ball. An underfill layer 303-A may also be included between the package substrate 304-A and PCB 202-A to provide additional mechanical support for the circuit assemblies 206-1 and 206-2. The package substrate 304-A and the PCB 202-A can be separated, for example, by about 0.25mm. Other examples of dielectric waveguide systems can be found in co-pending U.S. Patent Application Ser. No. 12/887,270, entitled "HIGH SPEED DIGITAL INTERCONNECT AND METHOD," filed on September 21, 2010, and co-pending U.S. Patent Application Ser. No. 12/887,323, entitled "CHIP TO DIELECTRIC WAVEGUIDE INTERFACE FOR SUB-MILLIMETER WAVE COMMUNICATIONS LINK," filed on September 21, 2010. Each co-pending application is hereby incorporated by reference for all purposes.

[0035] In order to provide the interchip link, the package substrate 304-A and PCB 202-A include an antenna system. The antenna system for this example (which shows circuit assembly 206-A1) generally comprises a microstrip line (which is a conductive layer integrated with the package substrate 304-A), a ground plane 306-A (which is a conductive layer integrated

with the package substrate 304-A), and a ground plane 308-A (which is a conductive layer integrated with the package substrate 308-A). The ground plane 308-A, as shown and for example, is coupled to ground plane 306-A through solder ball 301-A (which can allow the ground planes 306-A and 308-A to be electrically coupled together). As shown in this example, the dielectric waveguide 204-A is secured to same side or surface as the circuits assemblies 206-A1 and 206-A2 and extends into transition region 314-A where a portion of the core 310-A is located between the ground plane 308-A and portion of the microstrip line 208-A1. Typically, the microstrip line 208-A1 (which is electrically coupled to the IC 302-A through package substrate 304-A) is dimensioned to transmit sub-millimeter (i.e., wavelengths between about 0.5mm and about 1mm or less than about 1mm) or terahertz radiation (i.e., between about 100GHz and about 1THz). For this example, the microstrip line 208-1 has two portions with a boundary at the transition region 314-A to allow for RF or wireless signals to be transmitted to the dielectric waveguide 204-A. One portion of the microstrip line 208-A1 (which is shown as extending from the IC 302-A to the transition region 314-A) is generally parallel to ground plane 306-A1, allowing an electric field to extend between the microstrip line 208-A1 and ground plane 306-A1 in the package substrate 304-A. Because there is a relatively short distance between the microstrip line 208-A1 and ground plane 306-A1, this portion of microstrip line 208-A1 can be narrow to achieve a desired impedance (i.e., about 50Ω). At the transition region, there is a step increase in the separation between the microstrip line 208-A1 and its ground plane (which is the ground plane 308-A). Because of increase, the portion of the microstrip line 208-A1 is wider so as to having a matching impedance (i.e., about 50Ω). This can then allow RF signals to be propagated directly from the circuit assemblies 206-A1 and 206-A2. While the boundary at the transition region 314-A is abrupt, most issues (i.e., reflections) can be compensated for or filtered by use of signal processing (i.e., predistortion) within IC 302-A.

[0036] The microstrip line 208-A1 can have other shapes as well. In FIG. 5, an example configuration for the microstrip line 208-A1 can be seen. For this configuration, the microstrip line 208-A1 has two portions 209 and 211. As shown, portion 209 can function as a feed line that is electrically coupled to the IC 302-A, and the portion 211 widens from the width of portion 209. This widening can be accomplished by way of a taper, but as shown, the end of portion 211 that is electrically coupled to portion 209 is rounded.

[0037] To further improve efficiency, dielectric waveguide 204-A and PCB 202-A can be appropriately configured. Typically and as shown in this example, the core 310-A (which can, for example, be formed of polyamide, polyester, RO3006TM or RO3010TM from Rogers Corporation and can, for example, can have a height of about 0.5mm) is secured to the PCB 202-A (which can, for example, be formed of RO3003TM from Rogers Corporation) with a cladding 312-A substantially surrounding the remainder the core 310-A. Both the cladding 312-A and PCB 202-A have a lower dielectric constant than the core 310-A, and the cladding 312-A may have the same or similar dielectric constant as the PCB 202-A. This allows the electric field to be confined core 310-A. Additionally, the dielectric waveguide 204-A can be dimensioned to accommodate the wavelength of radiation emitted from the antenna system (i.e., sub-millimeter wavelength).

[0038] Alternatively, as shown in FIGS. 7-12, the dielectric waveguide 312-B,C can be integrated with the PCB 202-B,C. For these examples, a channel can be routed in PCB 202-B,C, and the dielectric waveguide 204-B,C can be secured to the PCB 202-B,C in the channel. As shown and similar to core 310-A, the cores 310-B,C extend into transition regions 314-B,C. The PCB 202-B, C can also be used as the cladding 312-B,C as shown in the example of FIG. 11, but, alternatively, a cladding material may be included in the channel. Additionally, the portion of the cladding 312-B,C that extends above (which is shown in broken lines) the PCB 202-B,C can be omitted. The ends of the core 310-B,C that is secured to the channel may also be tapered (as shown, for example, in FIG. 8) or be “squared” (as shown, for example, in FIG. 10). When tapered, the steps may, for example, be incremented in depth by about 5mils.

[0039] In FIGS. 7 and 8, one example configuration (system 200-B) for an antenna system and transition region 314-B can be seen. The antenna system for circuit assembly 206-B1 (for example) is generally comprised of microstrip line 208-B1 (which is located in the package substrate 304-B and which is electrically coupled to the IC 302-B) and ground plane 306-B (which is located within package substrate 304-B and which is generally parallel to and separated from a portion of the microstrip line 208-B1). For example, the portion the microstrip line 208-B1 (which is shown as extending from the IC 302-B to the boundary with the transition region 314-B) and ground plane 306-B can be separated by about 0.2mm. The ground plane 308-B (which, as shown and for example, is located in PCB 202-B) is parallel to and separated from the portion of microstrip line 208-B1 within the transition region 314-B. The distance

between the microstrip line 208-B1 can also, for example be, separated from the ground plan 308-B by a distance of about 1mm. By having this configuration, the width of microstrip line 208-B1 and the distance between the microstrip line 208-B1 and ground plane 308-B can be dimensioned to provide a desired impedance (i.e., about 50Ω). Typically, for this example, the portions of the microstrip line 208-B1 are generally rectangular with the portion in the transition region being wider. For example, the widths can have a width to achieve a desired impedance of about 50Ω . As shown in this example, there is also a via 316 that extends from one side the ground plane 308-B to allow the ground plane 308-B to be electrically coupled to ground plane 306-B (i.e., through solder ball 301-B).

[0040] In FIGS. 9 and 10, another example configuration (system 200-C) for an antenna system and transition region 314-C can be seen. The antenna system for circuit assembly 206-C1 (for example) is generally comprised of microstrip line 208-C1 (which is located in the package substrate 304-C and which is electrically coupled to the IC 302-B), microstrip line 320-1 (which is located in the PCB 202-C), ground plane 306-C (which is located within package substrate 304-C and which is generally parallel with a portion of the microstrip line 208-C1), and via 318 (which extends between the one side of the package substrate 304-C and the microstrip line 208-C1 and which allow the microstrip line 208-C1 to be electrically coupled to the microstrip line 320-1 through solder ball 301-C’’). For example, the portion the microstrip line 208-C1 (which is shown as extending from the IC 302-C to the boundary with the transition region 314-C) and ground plane 306-C can be separated by about 0.2mm. The ground plane 308-B (which, as shown and for example, is located in PCB 202-B) is parallel to and separated from the portion of microstrip line 208-C1 within the transition region 314-C. The distance between the microstrip line 208-B1 can also, for example be, separated from the ground plan 308-B by a distance of about 1mm. By having this configuration, the width of microstrip line 208-C1 and the distance between the microstrip line 208-B1 and ground plane 306-C can be dimensioned to provide a desired impedance (i.e., about 50Ω). Typically, for this example, one portion of the microstrip line 208-C1 (which is shown as extending from the IC 302-C to the transition region 314-C) has a width (i.e., about $25\mu\text{m}$) dimensioned to provide a desired impedance (i.e., about 50Ω), and another portion (which is shown as extending from the boundary of the transition region 314-C to the edge of package substrate 304-C) is dimensioned to allow a transition to the region between microstrip line 320-1 (which is also dimensioned to

carry this radiation) and ground plane 308-B. Typically, the portion of the microstrip line 208-C1 which is shown as extending from the IC 302-C to the transition region 314-C is generally wider than portion of the microstrip line 208-C1 which is shown as extending from the boundary of the transition region 314-C to the edge of package substrate 304-C. As shown in this example, there is also a via 316 that extends from one side the ground plane 308-B to allow the ground plane 308-C to be electrically coupled to ground plane 306-C (i.e., through solder ball 301-C').

[0041] As part of the transition region 314-C, there is also a metal waveguide 322 in which the core 310-C of the dielectric waveguide 204-C extends, and an example of the metal waveguide 322 is shown in FIG. 12. To achieve the desired coupling with the dielectric waveguide 204-C (for either of the system 200-B), the metal waveguide 322 can be formed of plates 402 and 404, ground plane 308-C, and vias 408. As shown in this example, plate 404 (which, for example, can be formed of copper and which is electrically coupled to microstrip line 320-1) includes a narrow portion and a tapered portion and is generally in parallel to plate 406 (which can, for example, be formed of copper). The width of the narrow portion of plate 404 is chosen to achieve a desired impedance (i.e., so as to match the impedance from the antenna system of system 200-C). Plate 402 can also be generally coplanar with and electrically coupled to plate 404. Additionally, vias 408 are shown in this example as extended between plate 402 and ground plane 308-C so that plates 402 and 404 and ground plane 308-C are electrically coupled together. The vias 408 are also spaced apart so that the dielectric waveguide 204-C can extend into the metal waveguide 322. Moreover, the shape of the end of the dielectric waveguide 204-C can affect the properties of the transition region 314-C, and, in this example, the end of the dielectric waveguide (which extends into the metal waveguide 322 is tapered. Other shapes, however, are possible.

[0042] Those skilled in the art will appreciate that many modifications may be made, and also that many other embodiments are possible, within the scope of the claimed invention.

CLAIMS

What is claimed is:

1. An apparatus comprising:

a circuit board having a first side, a second side, and a first ground plane, wherein the first ground plane is formed on the first side of the circuit board;

a package substrate that is secured to the first side of the circuit board, wherein the package substrate includes:

a second ground plane that is electrically coupled to the first ground plane;

a microstrip line that is substantially parallel to the first and second ground planes, wherein the microstrip line has:

a first portion that overlays at least a portion of the second ground plane and that is separated from the second ground plane by a first distance, wherein the first portion of the microstrip line is dimensioned to have an impedance to propagate radiation having a wavelength; and

a second portion that overlays at least a portion of the first ground plane and that is separated from the first ground plane by a second distance, wherein the second distance is greater than the first distance, and wherein the second portion of the microstrip line is dimensioned to have the impedance to propagate the radiation having the wavelength, and wherein the second portion of the microstrip line is located within a transition region;

an integrated circuit (IC) that is secured to the package substrate and that is electrically coupled to the first portion of the microstrip line; and

a dielectric waveguide that is secured to the circuit board, wherein the dielectric waveguide includes a core that overlies at least a portion of the first ground plane and extends into the transition region.

2. The apparatus of Claim 1, wherein the wavelength is less than or equal to about 1mm.

3. The apparatus of Claim 2, wherein the dielectric waveguide further comprises a cladding, and wherein the core has first dielectric constant, and wherein the cladding has a

second dielectric constant, and wherein the first dielectric constant is greater than the second dielectric constant.

4. The apparatus of Claim 3, wherein the package substrate has first and second sides, and wherein the microstrip line is formed on the first side of the package substrate, and wherein the IC is secured to the first side of the package substrate, and wherein the first ground plane is formed on the second side of the package substrate.

5. The apparatus of Claim 4, wherein at least one solder ball is secured to the first and second ground planes.

6. The apparatus of Claim 5, wherein the impedance is about 50Ω .

7. The apparatus of Claim 6, wherein the first portion of the microstrip line is generally rectangular, and wherein the second portion of the microstrip line is generally rectangular.

8. An apparatus comprising:

a circuit board having a first side, a second sides, and a plurality of circuit board ground planes, wherein each circuit board ground plane is formed on the first side of the circuit board;

a plurality of package substrates, wherein each package substrate is secured to the first side of the circuit board, and wherein each is collocated with at least one of the circuit board ground planes, wherein each package substrate includes:

a package substrate ground plane that is electrically coupled to its circuit board ground plane;

a microstrip line that is substantially parallel to its package substrate ground plane and its circuit board ground plane, wherein the microstrip line has:

a first portion that overlays at least a portion of its package substrate ground plane and that is separated from its package substrate ground plane by a first distance, wherein the first portion of the microstrip line is dimensioned to have an impedance to propagate radiation having a wavelength; and

a second portion that overlays at least a portion of its circuit board ground plane and that is separated from its circuit board ground plane by a second distance, wherein the second distance is greater than the first distance, and wherein the second portion of the microstrip line is dimensioned to have the impedance to propagate the radiation having the wavelength, and wherein the second portion of the microstrip line is located within a transition region;

a plurality of ICs, wherein each IC is secured to at least one of the package substrates and is electrically coupled to the first portion of its microstrip line; and

a dielectric waveguide network that is secured to the circuit board, wherein a core from dielectric waveguide network the overlies at least a portion of each circuit board ground plane and extends into its transition region.

9. The apparatus of Claim 8, wherein the wavelength is less than or equal to about 1mm.

10. The apparatus of Claim 9, wherein the dielectric waveguide network further a plurality of dielectric waveguides having a cladding, and wherein the core has first dielectric constant, and wherein the cladding has a second dielectric constant, and wherein the first dielectric constant is greater than the second dielectric constant.

11. The apparatus of Claim 10, wherein each package substrate has first and second sides, and wherein the microstrip line is formed on the first side of the package substrate, and wherein the IC is secured to the first side of the package substrate, and wherein the package substrate ground plane is formed on the second side of the package substrate.

12. The apparatus of Claim 11, wherein at least one solder ball is secured to the circuit board ground plane and the package substrate ground planes for each package substrate.

13. The apparatus of Claim 12, wherein the impedance is about 50Ω .

14. The apparatus of Claim 13, wherein the first portion of the microstrip line is generally rectangular, and wherein the second portion of the microstrip line is generally rectangular.

15. An apparatus comprising:

a circuit board having a first side, a second side, a first ground plane, and a second ground plane, wherein the first and second ground planes are formed on the first side of the circuit board, and wherein the first and second ground planes are separated from one another;

a first package substrate that is secured to the first side of the circuit board, wherein the first package substrate includes:

a third ground plane that is electrically coupled to the first ground plane;

a first microstrip line that is substantially parallel to the first and third ground planes, wherein the first microstrip line has:

a first portion that overlays at least a portion of the third ground plane and that is separated from the third ground plane by a first distance, wherein the first portion of the first microstrip line is dimensioned to have an impedance to propagate radiation having a wavelength; and

a second portion that overlays at least a portion of the first ground plane and that is separated from the first ground plane by a second distance, wherein the second distance is greater than the first distance, and wherein the second portion of the first microstrip line is dimensioned to have the impedance to propagate the radiation having the wavelength, and wherein the second portion of the first microstrip line is located within a first transition region;

a first IC that is secured to the package substrate and that is electrically coupled to the first portion of the first microstrip line;

a second package substrate that is secured to the first side of the circuit board, wherein the second package substrate includes:

a fourth ground plane that is electrically coupled to the second ground plane;

a second microstrip line that is substantially parallel to the second and fourth ground planes, wherein the second microstrip line has:

a first portion that overlays at least a portion of the fourth ground plane and that is separated from the fourth ground plane by a third distance, wherein the first portion of the

second microstrip line is dimensioned to have the impedance to propagate the radiation having the wavelength; and

a second portion that overlays at least a portion of the second ground plane and that is separated from the second ground plane by a fourth distance, wherein the fourth distance is greater than the third distance, and wherein the second portion of the second microstrip line is dimensioned to have the impedance to propagate the radiation having the wavelength, and wherein the second portion of the second microstrip line is located within a second transition region;

a second IC that is secured to the package substrate and that is electrically coupled to the first portion of the second microstrip line; and

a dielectric waveguide having:

a core with first and second ends, wherein the core is secured to the circuit board and overlies at least a portion of the first and second ground planes, and wherein the first end of the core extends into the first transition region, and wherein the second end of the core extends into the second transition region, and wherein the core has a first dielectric constant; and

a cladding that is secured to the core, wherein the cladding has a second dielectric constant, and wherein the first dielectric constant is greater than the second dielectric constant.

16. The apparatus of Claim 15, wherein the wavelength is less than or equal to about 1mm.

17. The apparatus of Claim 16, wherein each of the first and second package substrates has first and second sides, and wherein its microstrip line is formed on the first side of the package substrate, and wherein its IC is secured to the first side of the package substrate, and wherein its first ground plane is formed on the second side of the package substrate.

18. The apparatus of Claim 17, wherein at least one solder ball is secured to the first and third ground planes, and at least one solder ball is secured to the second and fourth ground planes.

19. The apparatus of Claim 18, wherein the impedance is about 50Ω .
20. The apparatus of Claim 19, wherein the first portion of each of the first and second microstrip lines is generally rectangular, and wherein the second portion of each of the first and second microstrip lines is generally rectangular.

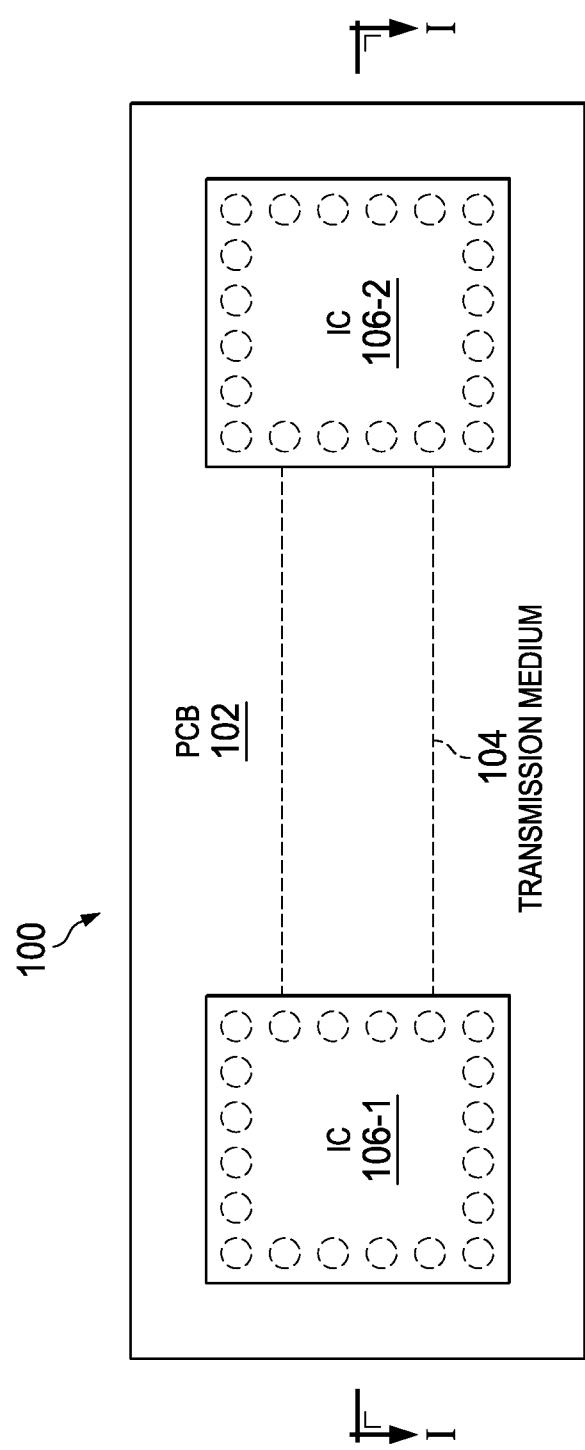


FIG. 1
(PRIOR ART)

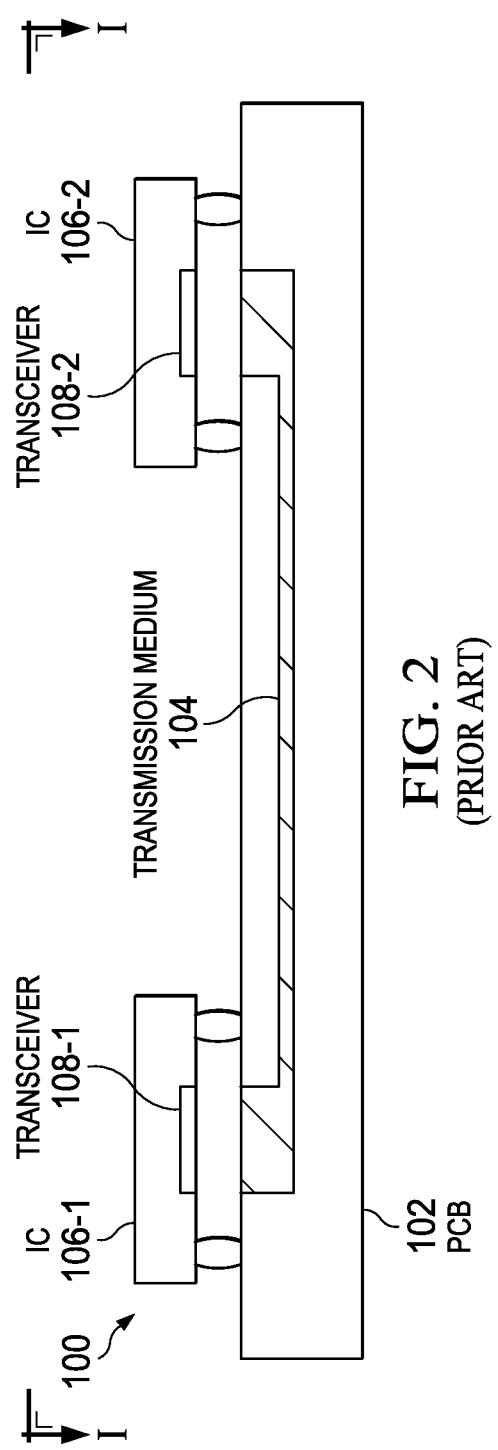


FIG. 2
(PRIOR ART)

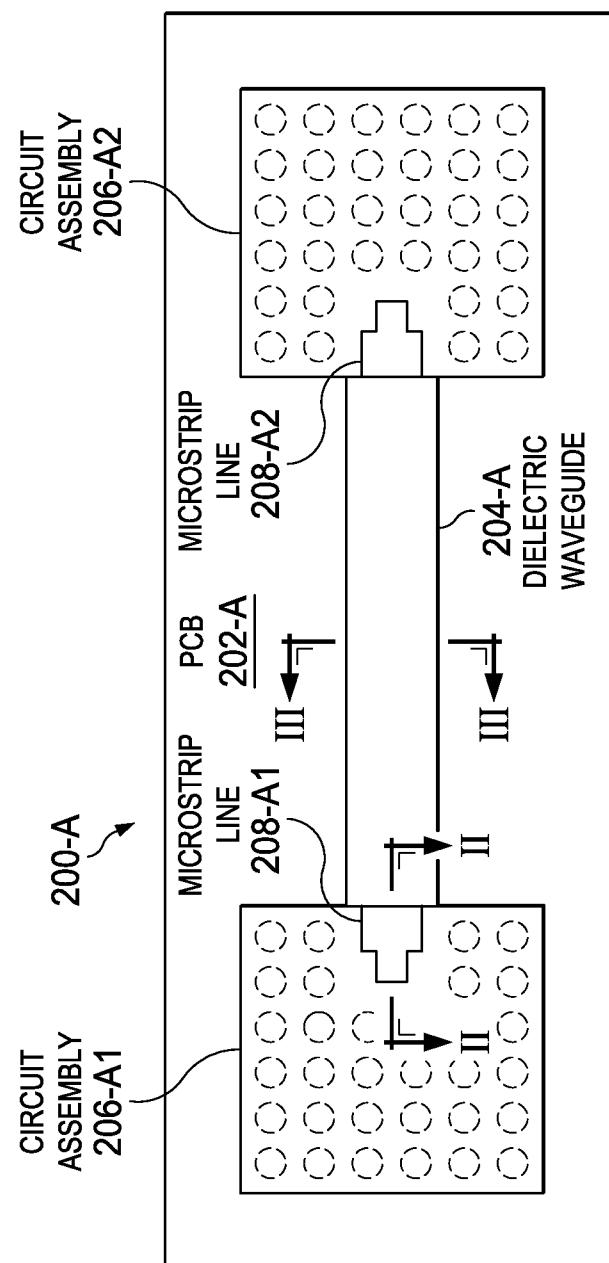


FIG. 3

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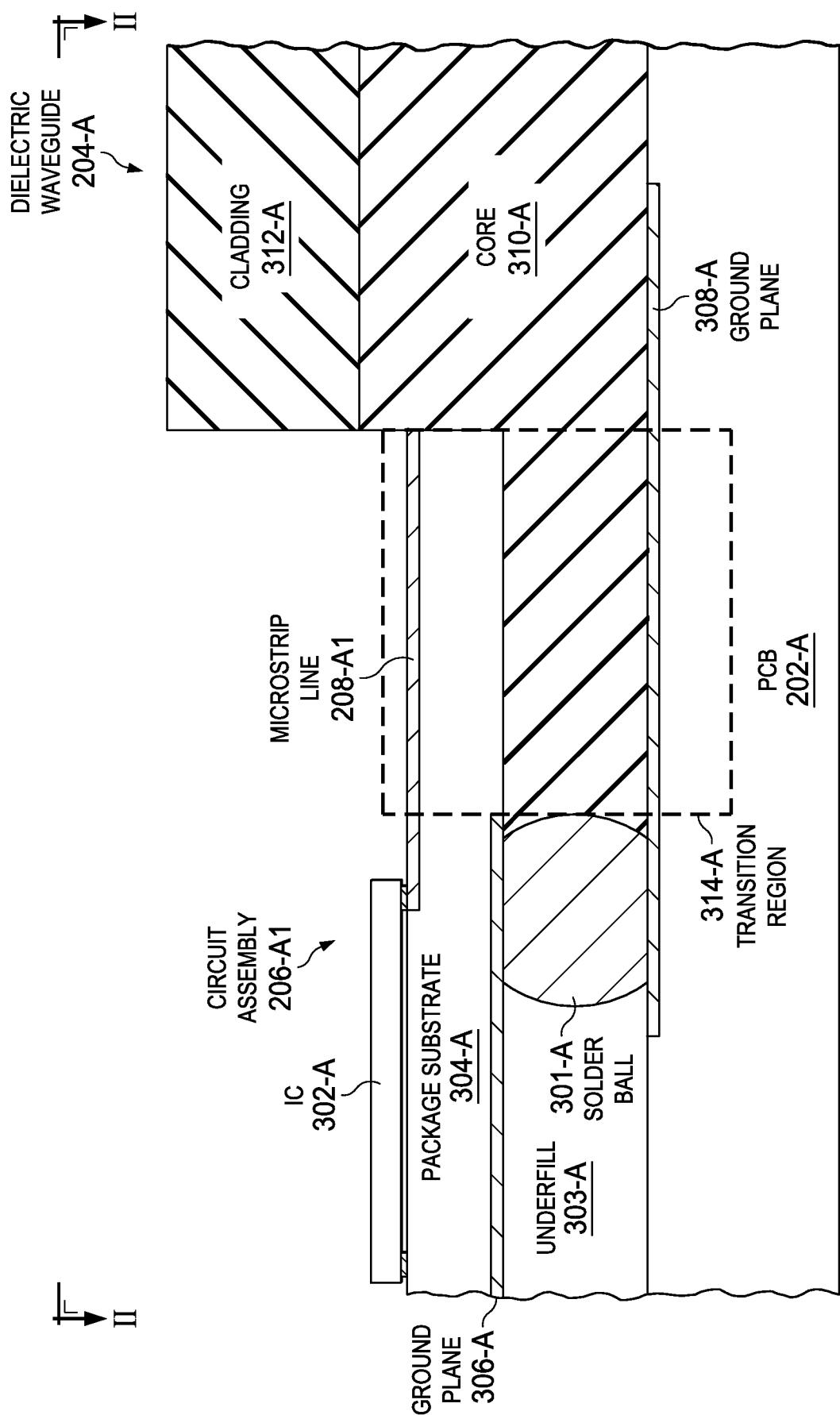


FIG. 4

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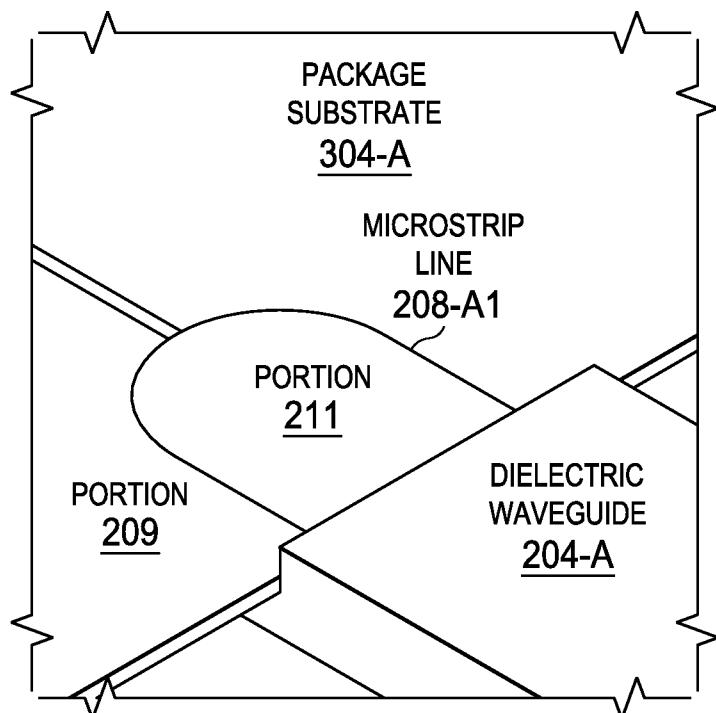


FIG. 5

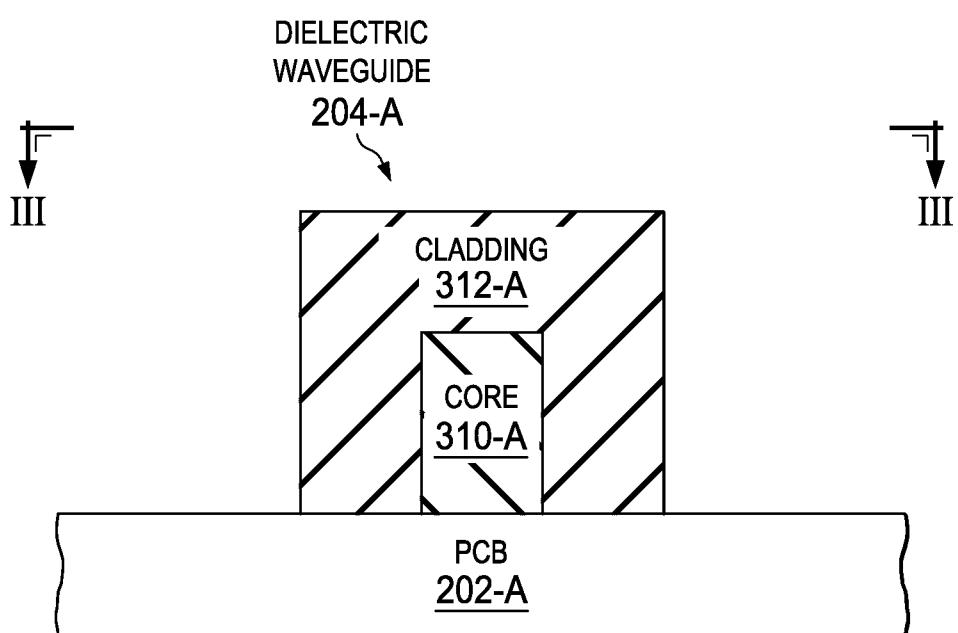


FIG. 6

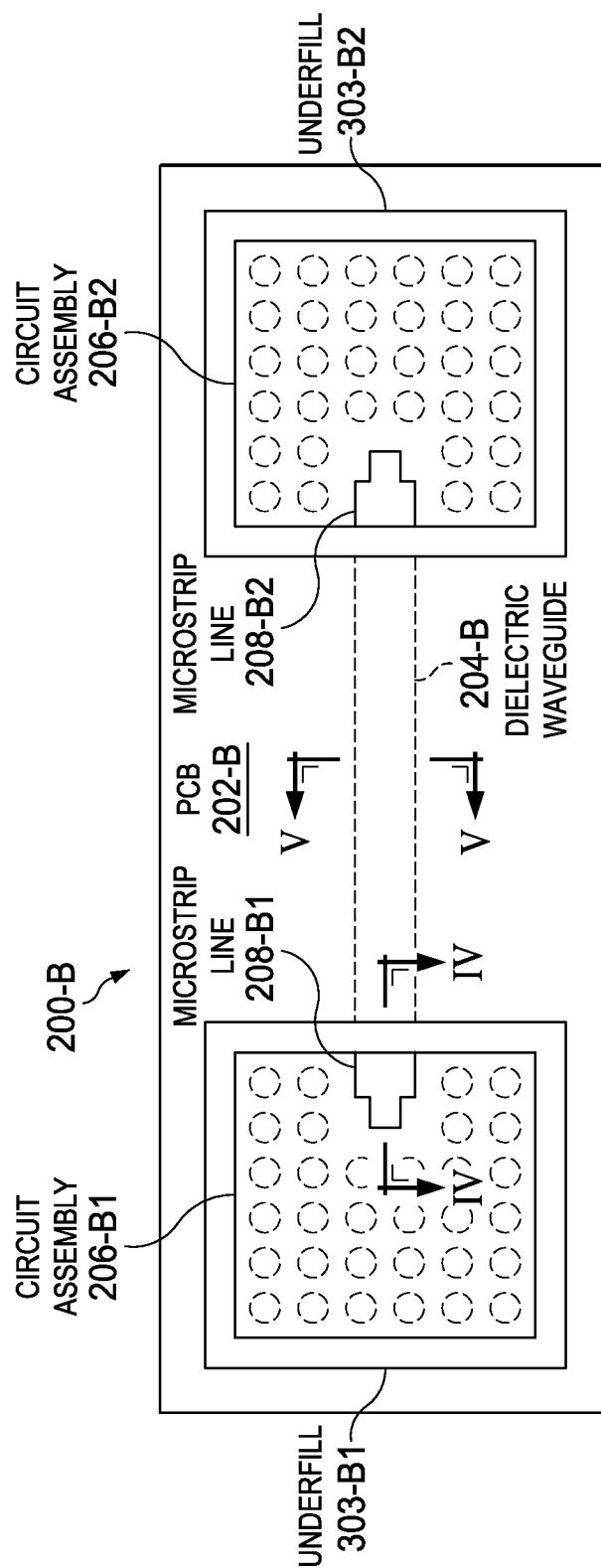


FIG. 7

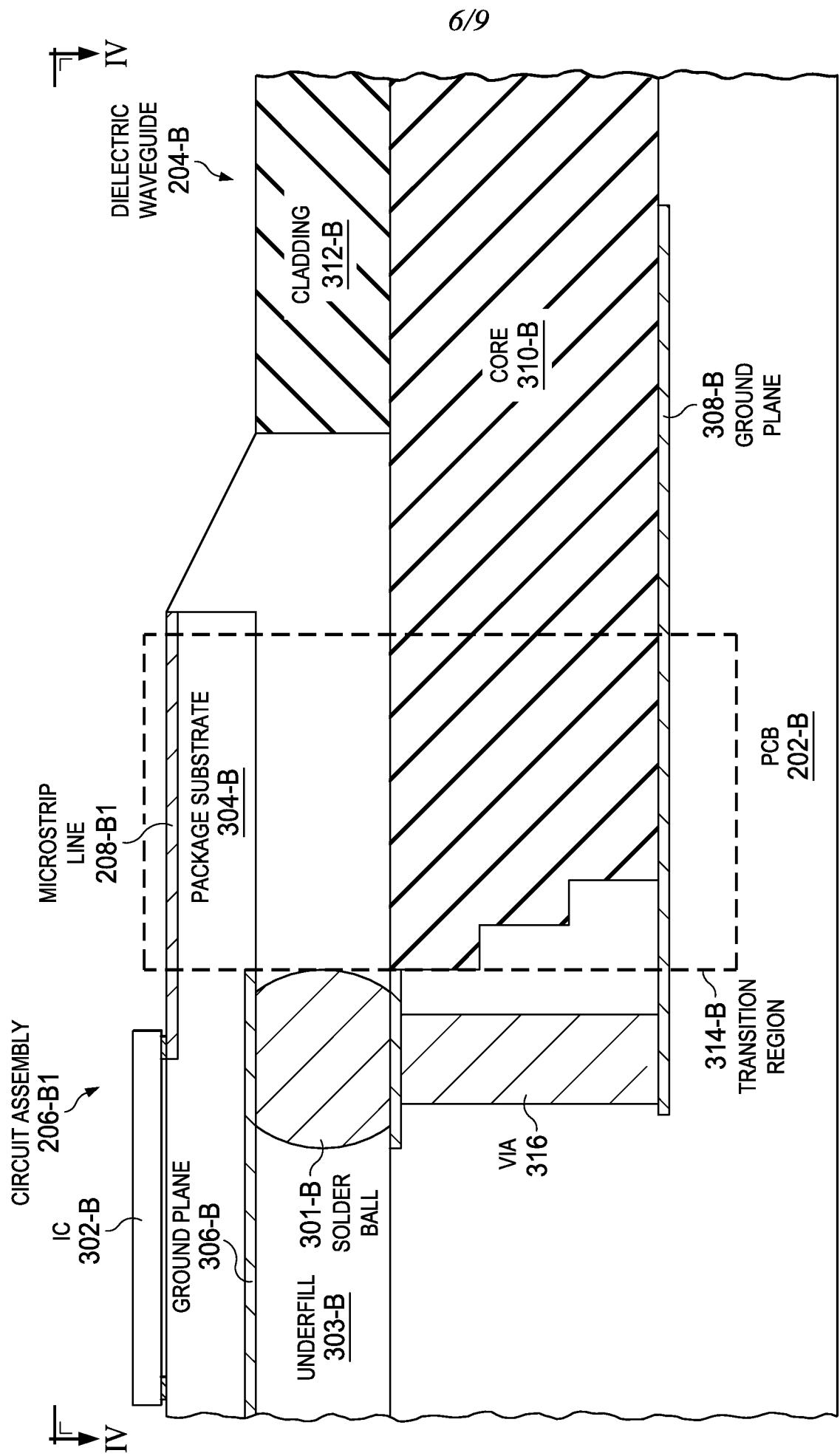


FIG. 8

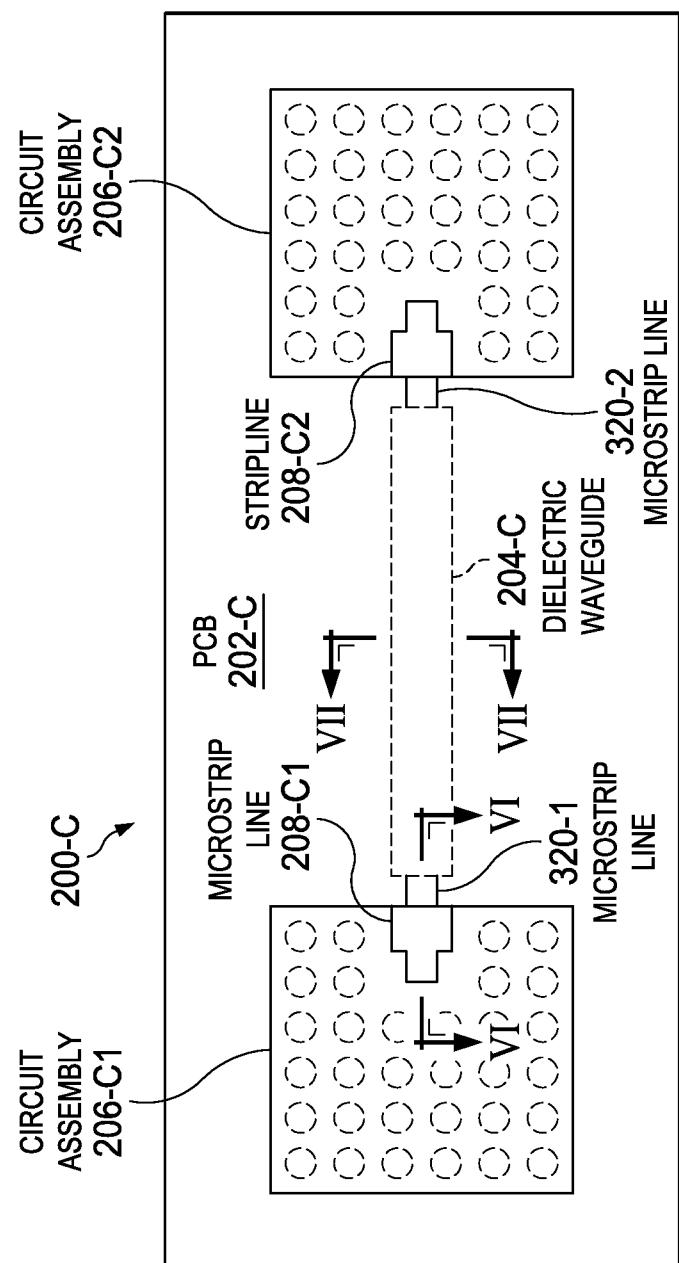


FIG. 9

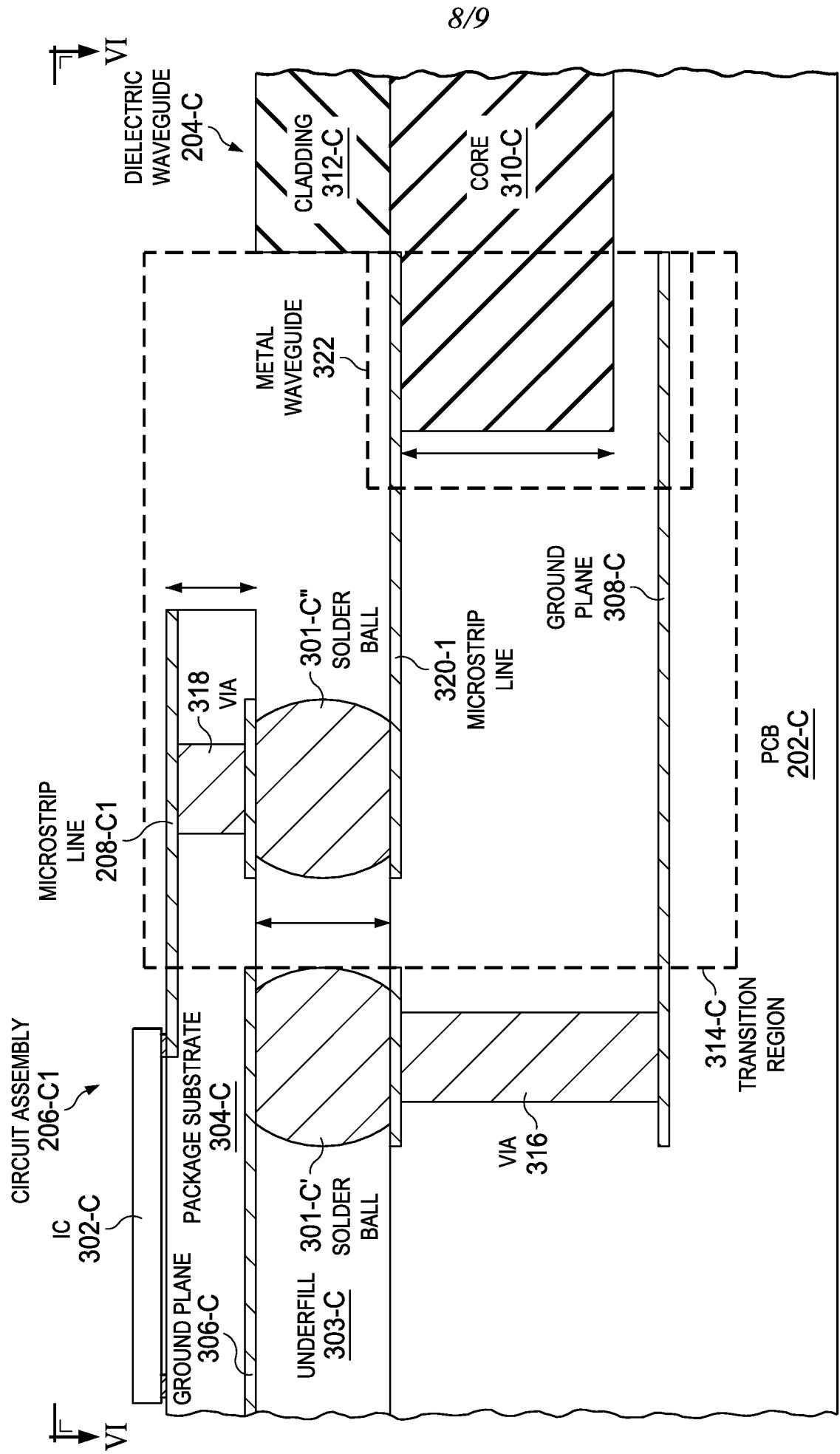


FIG. 10

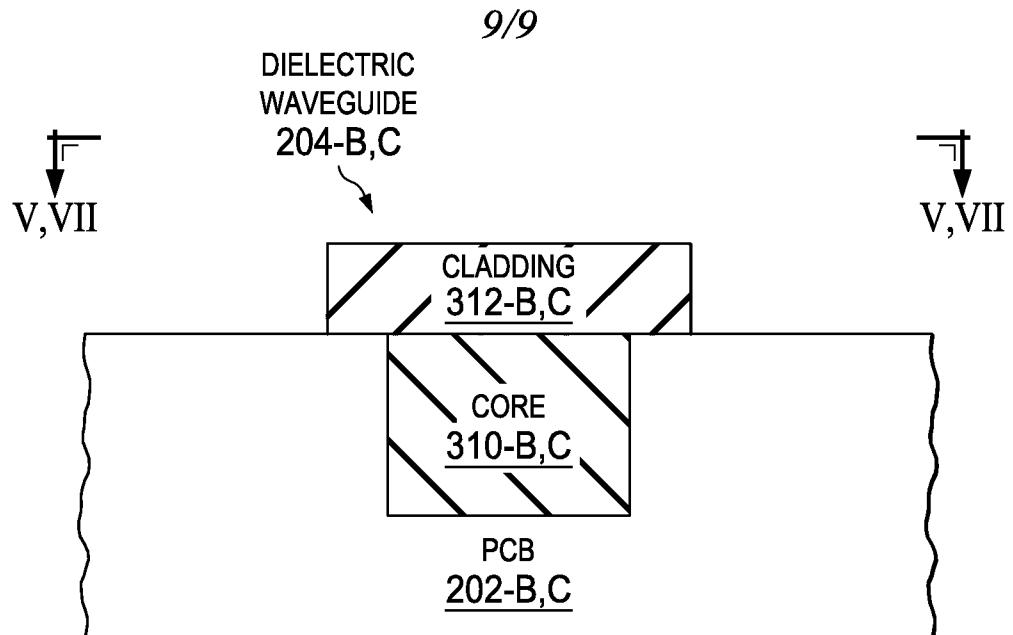


FIG. 11

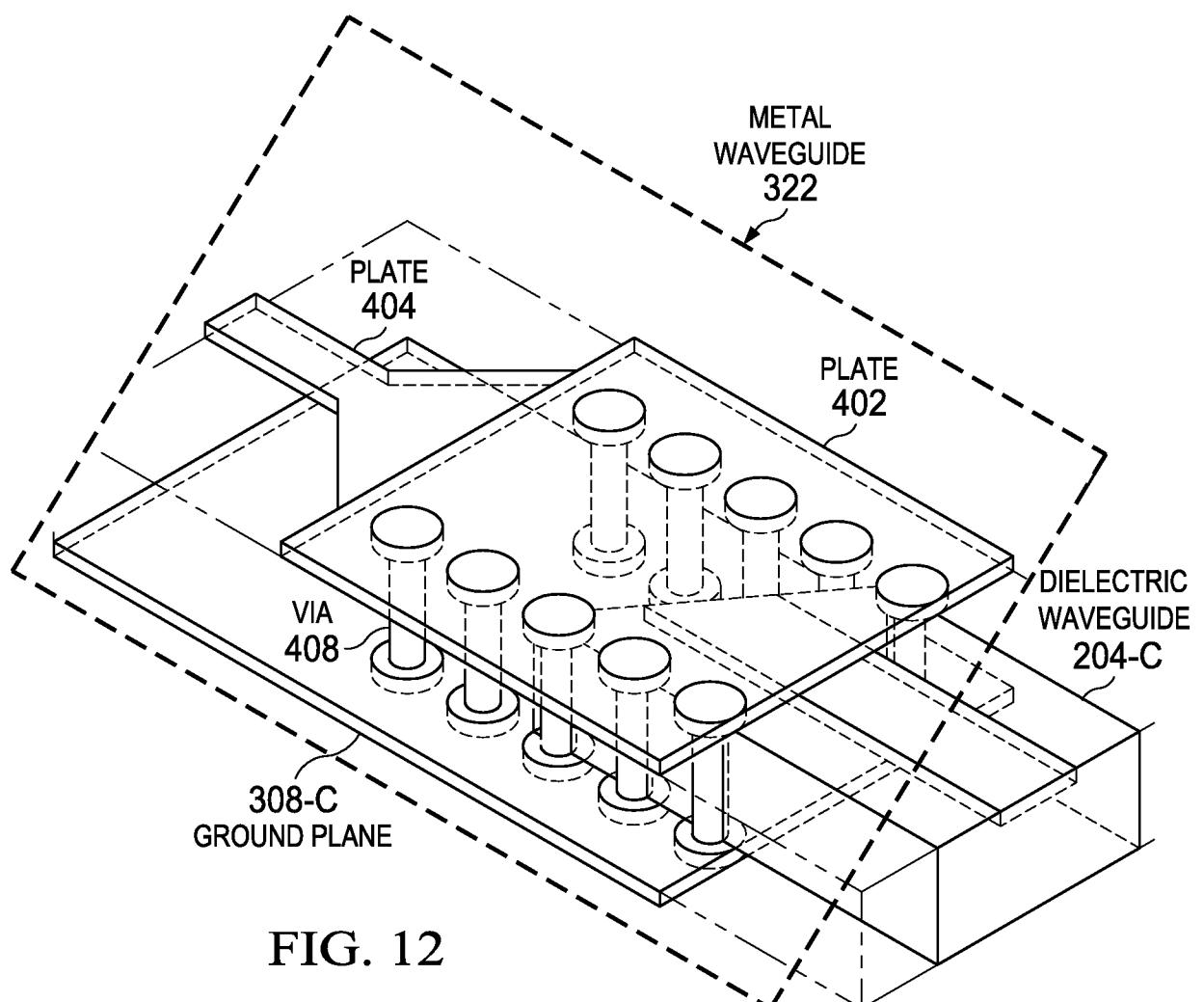


FIG. 12

A. CLASSIFICATION OF SUBJECT MATTER**G02B 6/10(2006.01)i, G02B 6/02(2006.01)i**

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)

G02B 6/10; H01P 1/00; G02B 6/43; H01L 23/12; G02B 6/42; G02B 6/12; G02B 6/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility modelsElectronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: interconnect, microstrip, waveguide**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2008-0118200 A1 (KIM et al.) 22 May 2008 See abstract, paragraph [0036] and figures 1-2.	1-20
A	US 2007-0262836 A1 (VOSS) 15 November 2007 See paragraphs [0054], [0064] and figures 1-2.	1-20
A	US 2004-0173880 A1 (ACHYUT) 09 September 2004 See abstract, paragraph [0101] and figure 15.	1-20
A	US 2010-0316335 A1 (FURUYAMA) 16 December 2010 See paragraphs [0062]-[0065], claim 1 and figure 6.	1-20
A	KR 10-2010-0071668 A (ELECTRONICS AND TELECOMMUNICATIONS RESEARCH INSTITUTE) 29 June 2010 See abstract, claim 1 and figure 13.	1-20

 Further documents are listed in the continuation of Box C. See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E" earlier application or patent but published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search
26 June 2013 (26.06.2013)

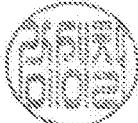
Date of mailing of the international search report

28 June 2013 (28.06.2013)Name and mailing address of the ISA/KR
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Authorized officer

KANG, Sung Chul

Telephone No. 82-42-481-8405



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2013/035273

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