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Description

[0001] The present invention relates to a device for coupling an electromagnetic signal from an input to at least two outputs.

[0002] In many situations, it can be necessary to divide an input signal to two or more outputs. This can be useful in applications such as signal mixing, phase delay networks and power distribution, to name a few examples. Signal couplers are used to split a signal provided at an input port. Each portion of the signal is provided at a separate output port of the coupler, where it can be provided for further use. Signal couplers can also be used to combine multiple signals onto the same output path.

[0003] Signal couplers (or beam splitters) are often used to process microwave, millimetre, and sub-millimetre wavelength signals. Much of the signal processing for this is carried out on planar circuits.

[0004] Wire grid splitters and free-standing thin dielectric film splitters are two examples of signal couplers. These signal couplers are not planar devices that can be integrated onto planar circuits. These are free-space devices, which are bulky, and take up considerable space. The signal processing sometimes needs to take place at cryogenic temperatures, and so the use of bulky splitters increases the cryogenic requirements.

[0005] In many applications, it can be necessary to create an array of signal couplers. At each coupler, a portion of the signal is divided off for use, and the remainder of the signal is provided to the next coupler. Where free-space devices are used, the problems of space and cryogenic requirements are made worse. Furthermore, it is preferable that each coupler provides the same power level for use. However, at least some of the couplers in an array use an input signal that has been through one or more previous couplers. Therefore, if the couplers are identical, each coupler provides different amounts of signal power. A separate signal input could be used for each coupler, but this increases electrical, cooling and space costs.

[0006] One example where a signal coupler is required is heterodyne detection. Heterodyning is a method of combining two electromagnetic signals through a non-linear medium to generate new signals at different frequencies. Heterodyne detection combines and mixes an input signal to be detected with a strong local oscillator signal. The signals undergo frequency conversion through either up-conversion and/or harmonic generation and/or down conversion to generate new signals (often called the intermediate frequency (IF) signal). The new signals can be used to interpret the detected input signal. Both the amplitude and phase of the input signal are preserved in the new signals, compared to direct signal detection schemes, where only amplitude of the signal is detected. Therefore, heterodyne detection is particularly useful where both the amplitude and phase of the incoming signal is important, such as astronomical interferometer.

[0007] Typically, a heterodyne detection system uses a beam splitter and a mixer or non-linear medium. The beam splitter divides the strong local oscillator power such that a proportion of the signal is directed down the same optical path as, and merged with, the input signal. The mixer/non-linear medium then mixes the signals.

[0008] It is often desirable to create an array of heterodyne detectors, so that a large number of signals can be detected simultaneously, reducing the observation time. In one example, each detected signal corresponds to a pixel of a resultant image. Each pixel has a separate receiver chain, having a beam splitter, a mixer and other ancillary components. Therefore, even small arrays of pixels take up considerable space and require considerable cooling.

[0009] In a heterodyne detector, only a small portion of the local oscillator power is used at each pixel. This is because the local oscillator signal adds noise to the receiver chain. Furthermore, a portion of the input signal power, proportional to the amount of local oscillator power used, will be lost through the wave combining process. Therefore, in large array detectors, the unused portion of the local oscillator can be provided to a subsequent pixel for use.

[0010] Another example of a device which makes use of signal coupling is a multi-beam phased array. A multi-beam phased array can be used in a variety of applications, such as 4G/5G wireless telecommunications, remote sensing, radar imaging system, and astronomical receivers. A multi-beam phased array receives detected signals from a number of antenna elements. The detected signal from each antenna element is split, prior to being passed through a phase shifter network. The phase-shifted signals from each antenna element are then recombined to reconstruct the input signals. The input signals correspond to beams that are pointed in different directions with reference to the antenna array.

[0011] US 9,300,027 B2 discloses a directional coupler that has a first line capable of transmitting a high-frequency signal therethrough and a second line arranged for electromagnetic coupling with the first line in a laminated board. The first line and the second line are routed on a first conductor layer to extend in close proximity to and in parallel with each other, to form an intra-layer coupling zone for developing electromagnetic coupling between the first line and the second line. The second line is routed on a second conductor layer such that the second line partially overlaps with the first line disposed on the first conductor layer with respect to a length-wise direction, when viewed in plan, to form an inter-layer coupling space for developing electromagnetic coupling between the second line on the second conductor layer and the first line on the first conductor layer.

[0012] According to a first aspect of the invention, there is provided a device for coupling and/or splitting signals, the device including: a first transmission line configured to carry at least one first signal; a second transmission line configured to carry at least one second signal; and

an overlap region in which the first transmission line crosses the second transmission line such that it overlies the second transmission line, and in which the first transmission line and second transmission line extend parallel or substantially parallel to each other where the first transmission line overlies the second transmission line, such that a predetermined portion of the power of a signal provided on either the first transmission line or the second transmission line is transferred to an output optical path of the other transmission line. One of the first transmission line and the second transmission line is a coplanar waveguide, and the other of the first transmission line and the second transmission line is a microstrip. The device provides a coupler that can control how power is distributed from one or more input ports to one or more output ports. The device can be integrated as part of a planar circuit, rather than a separate free-space device. This means it can be easily integrated with other circuitry, such as detectors, mixers and the like. The device is also compact, and can be a few square millimetres in size, providing an order of magnitude saving for space and cooling requirements, power usage and weight considerations.

[0013] A length that the first transmission line and second transmission line extend parallel or substantially parallel to each other for may be configured to control the predetermined portion. This provides for controllable coupling of the signals, so that a desired proportion of each signal can be merged onto the same path.

[0014] The overlap region may be configured such that a second portion of the power of the signal provided on either the first transmission line or the second transmission line remains on an output path of the transmission line it is provided on. This means that the signal can be provided for further use.

[0015] A one of the first transmission line and second transmission line may be straight or substantially straight, extending in a first direction, and the other of the first transmission line and second transmission line includes a deformation away from straight, where the first transmission line overlies the second transmission line.

[0016] The other of the first transmission line and second transmission line may include a first portion and a second portion, both extending in a second direction, different to the first, and, an intermediate portion between the first portion and second portion. The intermediate portion may be arranged parallel or substantially parallel to the first direction, and may be formed where the first transmission line overlies the second transmission line. The first direction may be perpendicular to the second direction. The first portion may be an input portion and the second portion may be an output portion.

[0017] The overlap region may be configured such that at least a portion of the power of a signal carried on the first transmission line is combined with a portion of the power of a signal on the second transmission line, on the output optical path of the first or second transmission line. Substantially all of the power of the signal carried

on the straight or substantially straight transmission line may be combined with a portion of the power of a signal carried on the other transmission line.

[0018] The length of the co-planar waveguide may be approximately half the wavelength of a central frequency of the operating bandwidth of the device.

[0019] Each transmission line may include a first port and a second port, and wherein the coupling may be directional, such that signals are only coupled from the first ports to the second ports. Where the first transmission line overlies the second transmission line, the arrangement of one of the first transmission line and second transmission line may be asymmetric about an axis defined by the direction between the first port and the second port of the one of the first transmission line and second transmission line. The device may comprise a directional coupler.

[0020] Alternatively, each transmission line may include a first port and a second port, and wherein the coupling may be non-directional, such that signals are coupled from the first ports to the first ports and second ports. Where the first transmission line overlies the second transmission line, the arrangement of the first transmission line may be symmetric about an axis defined by the direction between the first port and the second port of the first transmission line. The arrangement the second transmission line may be symmetric about an axis defined by the direction between the first port and second port of the second transmission line. The device may comprise a non-directional coupler.

[0021] The device may comprise: a first conducting layer; a second conducting layer; and a dielectric layer between the first conducting layer and the second conducting layer, wherein the conducting layers are arranged to form the transmission lines. A one of the first transmission line and the second transmission line may be wholly formed in a one of the first conducting layer and second conducting layer, such that the highest concentration of the field lines of a signal in the one of the first transmission line and the second transmission line extend parallel to a plane of the layers. The other of the first transmission line and the second transmission line may be formed by the first conducting layer and the second conducting layer, such that the highest concentration of the field lines of a signal carried in the other of the first transmission line and the second transmission line extend perpendicular to the plane of the layers. The device is planar, and so relative straight forward to fabricate.

[0022] The one of the first transmission line and the second transmission line may include feeds for providing a signal to and from the one of the first transmission line and the second transmission line, wherein the feeds are formed in the other of the first conducting layer and second conducting layer.

[0023] The device may include one or more electrical connection extending through the dielectric layer, between at least a region of the first conducting layer and at least a region of the second conducting layer, such

that the first conducting layer and second conducting layer are contactable from the same side of the device.

[0024] According to a second aspect of the invention, there is provided a device for coupling and/or splitting a plurality of signals, the device comprising: one or more first transmission lines, each configured to carry one or more first signal; and a plurality of second transmission lines, each configured to carry one or more second signal; wherein each of the one or more first transmission lines crosses each of the plurality second transmission lines, in turn, in a respective overlap region, where one of the transmission lines overlies the other. The one or more first transmission lines are coplanar waveguides, and the one or more second transmission lines are a microstrips, or the one or more first transmission lines are microstrips, and the one or more second transmission lines are a coplanar waveguides. In each overlap region the first transmission line and the second transmission line extend parallel or substantially parallel to each other as they cross, such that a first portion of the power of a first signal carried on the first transmission line is transferred to an output optical path of each second transmission line and a second portion of the power of the first signal carried on the first transmission line is provided to an adjacent overlap region on the first transmission line.

[0025] As with the first aspect, the device provides a compact and broadband circuit element for combining signals onto the same path that can be provided in a planar circuit. Because the device is compact, it takes up less space, and reduces cooling requirements, if necessary. The device is also easily scalable to provide an array of devices.

[0026] The length of subsequent overlap regions may increase along each first transmission line, such that the amount of power transferred to each second transmission line is the same at each overlap region.

[0027] The overlap region may be configured such that the portion of the power of the first signal transferred to each second transmission line may be combined with at least a portion of the power of a second signal carried on each second transmission line, on an output path of each second transmission line.

[0028] An example of a further device for coupling signals is also disclosed, the further device including: a first transmission line for carrying at least one first signal; a second transmission line for carrying at least one second signal; and an overlap region in which the first transmission line crosses the second transmission line such that it overlies the second transmission line, and in which the first transmission line and second transmission line extend parallel or substantially parallel to each other where the first transmission line overlies the second transmission line, such that field lines from the first and second signals interact, and the at least one first signal and the at least one second signal are combined onto an output optical path in a predetermined ratio of the power of the at least one first signal and the at least one second signal.

[0029] Another example of a second further device for

coupling a plurality of first signals with one or more second signal is disclosed, the second further device comprising: a plurality of first transmission lines, each carrying one or more first signal; a second transmission line for carrying one or more second signal; and for each first transmission line, an overlap region in which the second transmission line crosses the first transmission line such that it overlies the first transmission line, and in which the first transmission line and the second transmission line extend parallel or substantially parallel to each other where the first transmission line overlies the second transmission line, such that field lines from the at least one first signal and the at least one second signal interact, and the at least one first signal and the at least second signal are combined onto a first output optical path in a predetermined ratio of the power of the at least one first signal and the at least one second signal, and a second portion of the at least one second signal is provided on a second output path, wherein the second output optical path provides an input of the one or more second signal at an adjacent overlap region.

[0030] It will be appreciated that features discussed in relation to particular aspects of the invention can also be applied to other aspects.

[0031] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1A illustrates a plan view of directional coupler for combining a pair of electromagnetic signals onto an output optical path;

Figure 1B illustrates the directional coupler of Figure 1A, in exploded view;

Figure 2A illustrates an example of the coupling coefficient for the directional coupler of Figure 1A, with an input signal of 650 GHz;

Figure 2B illustrates an example of the response of a signal provided at a first input port of the directional coupler of Figure 1A, with an overlap length chosen to provide -13dB coupling at 650GHz;

Figure 2C illustrates an example of the response of a signal provided at a second input port of the directional coupler of Figure 1A, with an overlap length chosen to provide -13dB coupling at 650GHz;

Figure 3A illustrates an example of the coupling coefficient for the directional coupler of Figure 1A, with an input signal of 7GHz;

Figure 3B illustrates an example of the response of a signal provided at a first input port of the directional coupler of Figure 1A, with an overlap length chosen to provide -13dB coupling at 7GHz;

Figure 3C illustrates an example of the response of a signal provided at a second input port of the directional coupler of Figure 1A, with an overlap length chosen to provide -13dB coupling at 7GHz;

Figure 4A illustrates an example of the coupling coefficient for the directional coupler of Figure 1A, with an input signal of 13 GHz;

Figure 4B illustrates an example of the response of a signal provided at a first input port of the directional coupler of Figure 1A, with an overlap length chosen to provide -13dB coupling at 13GHz;

Figure 4C illustrates an example of the response of a signal provided at a second input port of the directional coupler of Figure 1A, with an overlap length chosen to provide -13dB coupling at 13GHz;

Figure 5 illustrates an example of a heterodyne detector including the directional coupler of Figure 1A;

Figure 6A illustrates an array of directional couplers;

Figure 6B illustrates an example of the response of a first signal provided at an input port of an array of directional couplers;

Figure 7A illustrates a plan view of a non-directional cross-coupler;

Figure 7B illustrates a perspective view of the overlap region of the non-directional cross-coupler of Figure 7A; and

Figure 8A illustrates a plan view of a first example of a circuit including connection pads for connecting a co-axial connection;

Figure 8B illustrates the upper and lower conducting layers of the circuit of

Figure 8A;

Figure 8C illustrates a cross-section of the circuit shown in Figure 8A and 8B;

Figure 9A illustrates the response of the first input measured on a circuit constructed as shown in Figures 8A and 8B;

Figure 9B illustrates the response of the second input measured on a circuit constructed as shown in Figures 8A and 8B;

Figure 10 illustrates a plan view of a second example of a circuit including connection pads for connecting a co-axial connection;

Figure 11A illustrates an exploded view of a third example of a circuit including connection pads for connecting a co-axial connection;

Figure 11B illustrates a plan view of the circuit of Figure 11A;

Figure 12A illustrates the response of the first input measured on a circuit constructed as shown in Figure 11, for a first frequency range;

Figure 12B illustrates the response of the second input measured on a circuit constructed as shown in Figure 11, for the first frequency range;

Figure 12C illustrates the response of the first input measured on a circuit constructed as shown in Figure 11, for a second frequency range;

Figure 12D illustrates the response of the second input measured on a circuit constructed as shown in Figure 11, for the second frequency range; and **Figure 13** illustrates a schematic example of a phased array system.

that can carry electromagnetic signals.

[0033] In a microstrip, a track of conducting material is spaced above or below a ground plane by a dielectric layer. The ground plane is formed by a layer of conducting material. For a signal transmitted along the microstrip, the majority of the field is directed vertically from the strip to the ground plane.

[0034] A stripline is formed in a single layer of conducting material. Three parallel conducting tracks are formed in the conducting layer, with the outer tracks forming the ground plane. For a signal transmitted along the stripline, the majority of the field is directed horizontally.

[0035] A coplanar waveguide is similar to a stripline, however, the outer conducting tracks are extended out, and provided by the body of the conducting layer. Therefore, the ground plane is formed by the body of the conducting layer, rather than tracks. An alternative version of a coplanar waveguide is a grounded coplanar waveguide. In this, the conducting layer of the coplanar waveguide is provided on a non-conducting substrate, and a conducting ground plane is provided on the opposite side of the substrate.

[0036] In the below description, it will be appreciated that reference to a beam splitter is also reference to a directional cross-coupler, and reference to a power coupler is also reference to a non-directional cross coupler.

[0037] Figures 1A and 1B schematically illustrate a beam splitter 1 for combining a pair of electromagnetic signals onto a single optical path. Figure 1A shows the beam splitter 1 in plan view, and Figure 1B shows an exploded view of the beam splitter 1.

[0038] As shown in Figure 1B, the beam splitter 1 is formed from a layered structure provided on a non-conducting substrate 3. The layered structure is formed of a lower conducting layer 5, provided on the substrate 3, a dielectric layer 7, provided on the lower conducting layer 5, and an upper conducting layer 9 provided on the dielectric layer 7.

[0039] The lower conducting layer 5 includes a conducting material that extends over the extent of the beam splitter 1, forming a ground plane. The upper conducting layer 9 includes a number of separate conducting regions 11, 35a,b, 37a,b that are electrically isolated from each other. The space between the conducting regions 11, 35a,b, 37a,b may be an air gap, or a dielectric.

[0040] The lower conducting layer 5 includes a narrow non-conducting track 19 that extends in a closed loop, forming a gap between the body of the lower conducting layer 5 and a central conducting region 23a,b, 25 electrically isolated from the body of the lower conducting layer 5. The non-conducting track 19 may be formed by an air gap or a dielectric, the substrate, or other insulating material.

[0041] The non-conducting track 19 includes a pair of end portions 21a,b. At each end portion 21a,b the track 19 defines a perimeter around a rectangular region 21a,b of the lower conducting layer 5. The non-conducting track 19 also includes two straight sections 27a,b extending

[0032] Coplanar waveguides, striplines and microstrips are examples of different types of transmission lines

between the end portions 21a,b. The straight sections 27a,b define a narrow conducting track 25 extending between, and electrically coupled to, the rectangular regions 23a,b. Therefore the central conducting region 23a,b, 25 can be said to be dumbbell shaped.

[0042] The narrow conducting track 25 in the lower conducting layer 5 and the body of the lower conducting layer 5 either side of the conducting track 25 forms a coplanar waveguide 29 for carrying an electromagnetic signal.

[0043] In the upper conducting layer 9, a first narrow conducting track 11 is formed, extending from a first side of the device to a second side, opposite the first. The first and second sides extend parallel to the direction of the coplanar waveguide 29.

[0044] The first conducting track 11 and lower conducting layer 5 combine to form a first microstrip 13 for carrying an electromagnetic signal. The first microstrip 13 crosses the coplanar waveguide 29 at the centre of the beam splitter 1, in an overlap region 43.

[0045] A second narrow conducting track 35a extends in from a third side of the device 1, extending between the first side and second side. The second conducting track 35a ends in an enlarged rectangular region 37a that overlies a first rectangular region 23a defined in the lower conducting layer 5.

[0046] The second conducting track 35a and the lower conducting layer 5 define a second microstrip 33a for carrying an electromagnetic wave. The overlap of the rectangular regions 37a, 23a in the upper conducting layer 9 and lower conducting layer 5 forms a broadside coupler 37a for coupling the electromagnetic signal from the second microstrip 33a to the coplanar waveguide 29.

[0047] A third narrow conducting track 35b extends in from a fourth side of the device 1, opposite the third side. The third conducting track 35b ends in an enlarged rectangular region 37b that overlies a second rectangular region 23b defined in the lower conducting layer 5.

[0048] The third conducting track 35b and the lower conducting layer 5 define a third microstrip 33b for carrying an electromagnetic wave. The overlap of the rectangular regions 37b, 23b in the upper conducting layer 9 and lower conducting layer 5 forms a second broadside coupler 37b for coupling the electromagnetic signal from the coplanar waveguide 29 to the third microstrip 33b.

[0049] The first microstrip 13 provides a first input port 15 of the beam splitter 1, and a first output port 17 of the beam splitter 1. A first electromagnetic wave can be transmitted on the first microstrip 13, from the first input 15 to the first output 17.

[0050] The second microstrip 33a provides a second input port 31 of the beam splitter 1, and the third microstrip 33b provides a second output port 41. A second electromagnetic signal can be transmitted from the second input port 31, through the second microstrip 33a, and into the coplanar waveguide 29 through the first broadside coupler 39a. The second signal is then transmitted along the coplanar waveguide 29, and into the third microstrip 33b

through the second broadside coupler 39b. The signal is then provided to the second output port 41 along the third microstrip 33b. The second and third microstrips 33a,b and the broadside couplers 39a,b can be considered feeds for the coplanar waveguide 29.

[0051] In the beam splitter 1 of Figures 1A and 1B, the coplanar waveguide 29 is straight. However, the conducting track 11 that forms the first microstrip 13 is not. The conducting track 11 includes an input portion 11a that extends from the input port 15 into the overlap region 43, and an output portion 11c that extends from the overlap region 43 to the output port 17. An intermediate portion 11b extends between the input portion 11a and the output portion 11c.

[0052] The intermediate portion 11b is parallel to the coplanar waveguide 29, and overlies the conducting track 25 in the lower conducting layer 5 that forms the coplanar waveguide 29. The input portion 11a couples to a first end of the intermediate portion 11b, and extends perpendicular to the coplanar waveguide 29. The output portion 11c couples to a second end of the intermediate portion 11b, and also extends perpendicular to the coplanar waveguide 29. In this way, the microstrip 13 can be said to follow a "Z-bend" configuration, with the intermediate portion 11b defining an overlap portion in the beam splitter 1.

[0053] At the overlap portion, the field lines of the first electromagnetic signal interact with the field lines of the second electromagnetic signal, such that a portion of the first electromagnetic signal is coupled to the second output port 41. At the same time, the second electromagnetic signal is transmitted along the length of the coplanar waveguide 29. Therefore, a portion of the first electromagnetic signal and the second electromagnetic signal are provided on the same optical path - the coplanar waveguide 29.

[0054] The length of the overlap portion controls the proportion of the power of the first electromagnetic signal that is provided on the coplanar waveguide 29.

[0055] Figure 2A illustrates an example of the coupling coefficient calculated for the beam splitter of Figure 1A and 1B, for a first electromagnetic signal provided on the microstrip 13 having frequency 650GHz. The coupling is shown as a function of the length of the overlap portion.

[0056] For the calculation shown in Figure 2A, the two conducting layers 5, 9 are Niobium with 400 nm thickness. The dielectric layer 7 is 475 nm thick, and formed of silicon monoxide. The substrate 3 is a 15 microns thick silicon. The track 11 forming first microstrip 13 is 2 microns wide, and the central conducting track 25 of the coplanar waveguide 29 is 2.05 microns thick. The non-conducting track 19 is also 2.05 microns wide. The width of the second and third microstrips 33a,b is 2.05 microns.

[0057] The first electromagnetic signal is provided at the first input port 15. As can be seen, as the length of the overlap portion increases, the coupling coefficient increases. This in turn means a greater proportion of the power of the first electromagnetic signal is provided onto

the coplanar waveguide 29.

[0058] The length of the overlap portion determines the amount of power from the first signal provided onto the coplanar waveguide 29. In many applications, it can be useful to control this amount. For example, selecting the length of the overlap portion so that the coupling coefficient is approximately -13dB corresponds to approximately 5% of the power provided on the microstrip 13 coupling to the output 41 of the coplanar waveguide 29. In the example shown in Figure 2A, -13dB coupling can be achieved when the length of the overlap portion is approximately 3.8 microns.

[0059] Figure 2B illustrates the response of a signal provided at the first input port 15, as a function of the frequency of the signal, for the beam splitter 1 modelled for Figure 2A. The length of the overlap portion is chosen to provide -13dB coupling at 650GHz. The four curves 102a, 104a, 106a, 108a represent the amount of the signal detected at each of the ports 17, 41, 15, 31 of the beam splitter 1.

[0060] A first curve 102a in Figure 2B shows the transmission of the first signal from the first input port 15 to the first output port 17. This is the upper most curve on the plot. As can be seen, this is relatively flat across the whole range of frequencies shown, and shows a large portion of the first signal is transmitted along this path.

[0061] A second curve 104a in Figure 2B shows transmission of the first signal from the first input 15 to the second output 41. Therefore this is the coupling of the microstrip 13 and the coplanar waveguide 29. As can be seen, this is -13dB at 650GHz, and, as with the transmission, is relatively stable over the range of frequencies considered.

[0062] A third curve 106a in Figure 2B shows the reflection of the first signal from the first input 15 back to the first input 15. The response is low (approximately -27dB) around 650GHz, showing that a low proportion of the signal is reflected at this frequency. The reflection 106a increases as the frequency of the signal increases or decreases, meaning more of the signal is reflected. For frequencies below approximately 550GHz or above 750GHz, the response is greater than -10dB, meaning a larger portion of the signal (over 10%) is reflected.

[0063] A fourth curve 108a in Figure 2B shows the leakage of the first signal from the first input 15 to the second input 31. As can be seen, this remains below -20dB over the range of frequencies considered. There is a minimum at around 600GHz, and the response gradually increases as the frequency increases or decreases, with a maximum at the higher frequencies.

[0064] Figure 2C illustrates the response of a second signal provided at the second input port 31, as a function of the frequency of the signal, for the beam splitter 1 modelled for Figure 2A. Again, the length of the overlap portion is chosen to provide -13dB coupling at 650GHz. The four curves 110a, 112a, 114a, 116a represent the amount of the second signal detected at each of the ports 41, 17, 31, 15 of the beam splitter 1.

[0065] A first curve 110a in Figure 2C shows the transmission of the second signal from the second input port 31 to the second output port 41. This is the upper most curve on the plot. As can be seen, this is relatively flat across the whole range of frequencies shown, and shows a large portion of the signal is transmitted along this path.

[0066] A second curve 112a in Figure 2C shows transmission of the second signal from the second input 31 to the first output 17. As can be seen, this is relatively stable between -12dB and -14dB over the range of frequencies.

[0067] A third curve 114a in Figure 2C shows the reflection of the second signal from the second input 31 back to the second input 31. The response is low between 600GHz and 725GHz, with a local maximum of -22dB at approximately 660GHz, showing that a low proportion of the signal is reflected at these frequencies. The reflection 114a increases as the frequency of the signal increases from 725GHz or decreases from 600GHz, meaning more of the signal is reflected. For frequencies below approximately 540GHz or above approximately 770GHz, the response is greater than -15dB, meaning a larger portion of the signal (over 3%) is reflected.

[0068] A fourth curve 116a in Figure 2C shows the leakage of the second signal from the second input 31 to the first input 15. As can be seen, this remains below -15dB over the range of frequencies considered. There is a minimum at around 600GHz, and the response gradually increases as the frequency increases or decreases, with a maximum at the higher frequencies.

[0069] Typically, a beam splitter requires a controllable amount of each of the input signals to be provided on the same optical path. In some examples, it is desirable to combine a relatively low, but controlled, proportion of one signal with as much of another signal as possible. For example, in heterodyne detection, the first signal may be a local oscillator, and the second signal a weak input signal to be detected. In such an example, the unused portion of the local oscillator may be provided for further use.

[0070] Referring to Figures 2B and 2C, the transmission of the second signal from the second input 31 to the second output 41 is higher than the transmission of the first signal from the first input 15 to the first output 17. Therefore, the second input 31 should be used for the input signal and the first input 15 for the local oscillator, as a greater portion of the signal to be detected is transmitted.

[0071] It is desired to provide a controlled amount of the local oscillator (first signal) at the second output 41, such that it is on the same optical path as the input signal (second signal). The proportion of the signals combined should be relatively stable with frequency, to provide a controllable outcome over the operational bandwidth of the splitter 1.

[0072] Therefore, the losses through reflection of the first signal 106a or the coupling of the first signal to the second input port 31 should be minimised. This reduces loss of the first signal, and interference with the second

signal. Similarly, losses through coupling of the second signal to any port other than the second output port 41 (including reflection) should also be minimised, to avoid loss of signal or interference.

[0073] As shown by the highlighted range in Figures 2B and 2C, when providing 5% of the power of the local oscillator onto the path of the input signal, between frequencies of approximately 600GHz and 700GHz, the coupling 104a of the first signal to the second output 41 is relatively stable, and the losses of the first signal are below -15dB. Similarly, the losses of the second signal are also low over this range.

[0074] Therefore, the beam splitter 1 with the length of overlap portion selected to provide - 13dB coupling for a signal of 650GHz has an operational bandwidth of 600GHz to 700GHz for either the local oscillator or input signal.

[0075] Furthermore, since the coupling of the first input 15 to the second input 31 is low over the operational bandwidth, compared to the coupling of the first input 15 to the second output 41, the coupling can be seen to be directional. It is believed that a portion the signal fields travelling along the microstrip 13 interact with the signal fields travelling along the coplanar waveguide 29 at the Z-bend, and the signal travelling along the microstrip 13 is reflected at the bend between the overlap portion and output portion 11c of the conducting track 13, such that the first electromagnetic signal is either transmitted to the first output port 17 or the second output port 41. Therefore, the asymmetry of the conducting track 11, about an axis defined by the direction between the input port 15 and output port 17, can be seen to provide the directional splitting.

[0076] As shown by Figures 2B and 2C, the first and second signals are also combined at the first output 17. Therefore, the first and second signals are also provided on a second output optical path - the first microstrip 13. As with the signal at the second output 41, the proportion of the first and second signal is controllable by varying the length of the overlap portion. In the example of heterodyning, transmission of the second signal (the input signal) to anything other than the second output 41 is considered to be losses. However, in other applications, the coupling may be controlled to provide combined signals at both outputs 17, 41, with controlled proportions of each signal at each output 17, 41.

[0077] Figure 3A show the coupling coefficient calculated when the signal provided at the first input 15 has a frequency of 7GHz.

[0078] For the calculation shown in Figure 3A, the two conducting layers 5, 9 are Copper with 18 micron thickness. The insulation layer 7 is 50.8 microns thick of Dupont Pyralux AP8525. The supporting substrate 3 is a 1.27 mm thick Roger Duroid 6010 bare PCB. The track 11 forming first microstrip 13 is 150 microns wide, and the conducting track 25 of the coplanar waveguide is 150 microns wide, with the gap between the signal track 25 and the body of the lower conducting layer 5 191.5 mi-

crons wide. The width of the second and third microstrips 33a,b is 150 microns.

[0079] Figures 3B and 3C shows the response from the two input ports 15, 31 based on the splitter modelled in Figure 3A, when the length of the overlap portion is selected to provide -13dB coupling for a signal of 7GHz. In this case, the length of the overlap portion is approximately 0.7 microns.

[0080] As with Figure 2B, Figure 3B shows the transmission 102b from the first input port 15 to the first output port 17, the transmission 104b from the first input port 15 to the second output port 41, the reflection 106b back to the first input port 15 and the leakage 108b to the second input port 31.

[0081] As with Figure 2C, Figure 3C shows the transmission 110b from the second input port 31 to the second output port 41, the leakage 112b to the first output port 17, the reflection 114b to the second input port 31, and the leakage 116b to the first input port 15.

[0082] The responses 102b, 104b, 106b, 108b, 110b, 112b, 114b, 116b for the 7GHz case follow a similar pattern to the 650GHz case. In this case, the operational bandwidth, when used with a local oscillator, is 6GHz to 8GHz.

[0083] Figures 4A show the coupling coefficient calculated when the signal provided at the first input 15 has a frequency of 13GHz. In this example, the beam splitter 1 is the same as for Figure 3A, although the non-conducting track 19 in the lower conducting layer is 195 microns wide.

[0084] Figures 4B and 4C shows the response from the two input ports 15, 31 based on the splitter modelled in Figure 4A, when the length of the overlap portion is selected to provide -13dB coupling for a signal of 13GHz. In this case, the length of the overlap portion is approximately 270 microns.

[0085] As with Figure 2B and 3B, Figure 4B shows the transmission 102c from the first input port 15 to the first output port 17, the transmission 104c from the first input port 15 to the second output port 41, the reflection 106c back to the first input port 15 and the leakage 108c to the second input port 31.

[0086] As with Figure 2C and 3C, Figure 4C shows the transmission 110c from the second input port 31 to the second output port 41, the leakage 112c to the first output port 17, the reflection 114c to the second input port 31, and the leakage 116c to the first input port 15.

[0087] The responses 102c, 104c, 106c, 108c, 110c, 112c, 114c, 116c for the 13GHz case follow a similar pattern to the 650GHz and 7 GHz cases. In this case, the operational bandwidth, when used with a local oscillator, is 12GHz to 14GHz.

[0088] It will be appreciated that the parameters discussed above are given by way of example only, and the principles discussed above can be applied to provide a beam splitter that operates over a range of different frequencies, by correct choice of the length of the overlap portion. For example, depending on the physical param-

eters of the device (materials and sizes of the layers 5, 7, 9 and conducting tracks 11, 25, 31a,b), the length of the overlap may provide coupling of signals from kilohertz up to terahertz, or higher or lower. Depending on the physical parameters of the device, the device can provide coupling of any proportion of the first and second signals.

[0089] In some examples, the length of the co-planar waveguide 29 (measured as the spacing between the broadside couplers 39a,b) is set at approximately half the wavelength of the central frequency of the operating bandwidth of the device. In some examples, the length of each broadside coupler 39a,b is half of the length of the co-planar waveguide 29 (i.e. approximately quarter of the wavelength of the central frequency of the operating bandwidth of the device).

[0090] The operational bandwidth over which the splitter 1 works will also depend on the structural parameters of the beam splitter 1, including the width of the conducting tracks 11, 25, 35, the spacing of the conducting layers 5, 9, the material of the conducting layers and the length for which the microstrip 13 overlies the coplanar waveguide 29.

[0091] The operational bandwidth is selected based on desired levels for power coupling and losses. Any suitable coupling and losses may be chosen, depending on the application, and so the operating bandwidth is given by way of example only.

[0092] Figure 5 illustrates an example of the beam splitter discussed in relation to Figures 1 to 4C incorporated into a heterodyne detector 51. A local oscillator signal is provided through the first input port 15 of the beam splitter 1. An input signal is detected by an antenna, and coupled to the detector through an input port 45, and fed to the second input port 31 of the beam splitter 1.

[0093] At the overlap region 43, a portion of the local oscillator signal is coupled onto the same optical path as the input signal. This is then fed to a mixer 47, which mixes the signal, and then to further circuitry through a wire bonding pad 49.

[0094] As discussed above, the signal provided at the first output 17 can be provided for further use. In the examples discussed above, the signal at the first output 17 contains approximately 90 to 95% of the local oscillator signal (after a portion has been coupled onto the coplanar waveguide 29, and losses). Therefore, in one example, the signal at the first output port 17 could be fed into a beam splitter 1 of a second heterodyne detector 51.

[0095] Figure 6A illustrates an example of an array 53 of four beam splitters 1a-d, that can be used to provide a 4×1 array of pixels using a single local oscillator signal.

[0096] The input signal is fed from an antenna (not shown) into the second input port 31a-d of each beam splitter 1a-d. The local oscillator signal is provided at the first input port 15a of a first beam splitter 1a. As discussed above, a portion of the local oscillator is coupled to the second output port 41a of the first beam splitter 1a, with the first input signal.

[0097] The remainder of the local oscillator signal is

then provided at the first output port 17a of the first beam splitter 1a. The output from the first output port 17a of the first beam splitter 1a is provided to the first input port 15b of the second beam splitter 1b. The local oscillator signal is coupled to the second input signal at the second beam splitter 1b. As discussed above, a portion of the local oscillator is coupled to the second output port 41b of the second beam splitter 1b, with the second input signal.

[0098] Again, the remainder of the local oscillator signal is then provided at the first output port 17b of the second beam splitter 1b. The output from the first output port 17b of the second beam splitter 1b is provided to the first input port 15c of the third beam splitter 1c. The local oscillator signal is coupled to the third input signal at the third beam splitter 1c. As discussed above, a portion of the local oscillator is coupled to the second output port 41c of the third beam splitter 1c, with the third input signal.

[0099] Once again, the remainder of the local oscillator signal is then provided at the first output port 17c of the third beam splitter 1c. The output from the first output port 17c at the third beam splitter 1c is provided to the first input port 15d of the fourth beam splitter 1d. The local oscillator signal is coupled to the fourth input signal at the fourth beam splitter 1d. As discussed above, a portion of the local oscillator is coupled to the second output port 41d of the fourth beam splitter 1d, with the fourth input signal.

[0100] In this way, the local oscillator signal can be used to detect a number of input signals.

[0101] Figure 6B illustrates the response calculated for an example array 53, with a signal provided at the first input 15a of the first splitter 1a of the 4×1 array 53. The length of the overlap portion for each splitter 1a-d is chosen to provide 5% of the power of the local oscillator signal measured at the first input 15a of the first splitter 1a to each of the second outputs 41a-d, at 650GHz. The structure is calculated based on the same calculation used in Figure 2A.

[0102] A first curve 118, with a plateau formed at approximately -4dB, shows the coupling of the first input port 15a of the first splitter 1a to the first output port 17d of the last splitter 1d.

[0103] A second curve 120, with a peak at 500GHz shows the reflection back to the first input port 15a of the first splitter 1a.

[0104] The set of four lowest curves 122a,b,c,d show the coupling to each of the second input ports 31a-d respectively. As can be seen, at high frequency, the further to second input 31a-d from the first input 15a of the first splitter 1a, the lower the coupling. The curves with a plateau formed around -13dB shows the coupling to each of the second output ports 41a-d respectively.

[0105] As can be seen, in the range 600GHz to 700GHz, the coupling to each of the second output ports 41a-d is substantially identical, the reflection back to the first input port 15a of the first splitter 1a is below -15dB and the coupling to the second input ports 31a-d is below

-20dB.

[0106] It will be appreciated that the input power of the local oscillator at the first input port 15a-d is lower in the fourth beam splitter 1d than the third 1c, and lower in the third beam splitter 1c than the second beam splitter 1b, and lower in the second beam splitter 1b than the first beam splitter 1a.

[0107] In order to provide a useful output over the array 53, each of the signals at the second output 41a-d should include an equal amount of the local oscillator signal. To achieve this, the overlap portion gradually increases in length up the array 53. This increases the coupling power for each beam splitter 1a-d. However, since the input power is lower, the increased coupling coefficient ensures that the same power of the local oscillator signal is provided onto the same optical path as the input signals.

[0108] Between each of the beam splitters 1a-d a further Z-bend 55a-c is provided in the microstrip 13 carrying the local oscillator signal. This Z-bend does not coincide with a coplanar waveguide. This ensures that the beam splitters 1a-d are aligned in the array, and saves on space taken up by the array 53. It will be appreciated that this is optional, and the beam splitters 1a-d may be unaligned.

[0109] The array 53 shown in Figure 6A is a 4×1 array, having four beam splitters 1a-d provided in a single column. It will be appreciated that the column may include any number of beam splitters 1a-d, provided the attenuation of the local oscillator signal is such that sufficient power can still be provided. In the example shown above, the array includes only a single column, and so is one dimensional. In other examples, the array may include two or more columns, and be two dimensional.

[0110] Figure 13 illustrates an example of a device 300 using a two dimensional array 302 of beam splitters 1. The device 300 shown in Figure 13 is a phased array system, but this is by way of example only. Any device requiring an array 302 of beam splitters 1 may be provided.

[0111] The phased array system 300 includes a number of antenna elements 304. A signal from a first antenna element 304a is provided on a first antenna transmission line 306a. A portion of the signal from the first antenna element 304a is split onto a first beam transmission line 308a at a first beam splitter 1a,a. The remaining power on the first antenna transmission line 306a is then provided to a second beam splitter 1a,b, where a portion of the remaining power is split onto the second beam transmission line 308b. Further portions of the power of the signal from the first antenna element 304a are split on to further beam transmission lines 306c-h at further beam splitters 1a,c-h, along the first antenna transmission line 306a.

[0112] Similarly, the signal from a second antenna element 304b is provided on a second antenna transmission line 306b, and split onto the same beam transmission lines 308ah at beam splitters 1b,a-h provided along the second antenna transmission line 306b. The signals

from the further antenna elements 304c-h are also split onto the beam transmission line 308a-h at yet further beam splitters 1.

[0113] Each beam splitter 1 has an input and an output along the antenna transmission lines 304 and an input and an output along the beam transmission lines 308. Along each antenna transmission line 304, the first beam splitter 1a-h,a takes the input from the antenna 304a-h as the antenna transmission line input. Each subsequent beam splitter 1 takes the antenna transmission line output from the previous beam splitter 1 as its input. Similarly, along each beam transmission line 308a-b, each beam splitter 1 takes the output from the previous beam splitter 1 as its input.

[0114] Therefore, the beam splitters 1 form an array. Each antenna transmission line 306a-h forms a row of the array 302, whilst each beam transmission line 308a-h forms a column. The incoming signal is split along the rows, and recombined along the columns.

[0115] By way of example, in the first column of the array 302, a portion of the signal from the first antenna element 304a is coupled onto the first beam transmission line 308a at a first coupler in the beam splitter 1a,a, a portion of the signal from the second antenna element 304b is coupled onto the first beam transmission line 308a, and combined with the portion from the first antenna element 304a, at a second coupler in the beam splitter 1b,a and so forth.

[0116] Appropriate phase shifting can be achieved by providing phase shifters 310 between the columns (i.e. between each beam splitter 1 along an antenna transmission line 306). Furthermore, the inputs of the beam transmission lines 308 before the first row of the array, and the outputs of the antenna transmission lines 306 after the last column are terminated without connections (or not present), because no input signal is required before the first row of beam splitters, and no output is required after the last column. The lines should be terminated such that no power is reflected along the transmission lines, such that the final beam splitters 1 in the rows (and the first beam splitters in the columns 1 are three port splitters 3). In other examples, the remaining power in the antenna transmission lines may be provided for other uses.

[0117] The beam splitters 1 and transmission lines 306, 308 are the same as discussed above. Furthermore, across the array 302, the length for which the transmission lines overlap each other in each beam splitter 1 is varied to ensure equal amounts of power from each signal in each beam.

[0118] The phased array system (or any other 2D system) implemented in this way can be formed of a simple planar structure, that can be integrated with other circuit elements. The example given above is an 8 by 8 array, but any size array is possible.

[0119] The devices discussed above use a single beam splitter, a 1D array of beam splitters 1, or a 2D array. In yet further examples, the array may be stacked

vertically, so that a second array of beam splitters is provided above or below a first array.

[0120] As discussed in the examples above, each set of beam splitters 1 is formed of a layered structure including at least a first conducting layer 5, a dielectric layer 7 and a second conducting layer 9. In the example with vertically stacked beam splitters 1, the layered structure of the stacked sets of beam splitters 1 are separated by a non-conducting spacer layer (not shown). The spacer layer is provided on top of the second conducting layer 9 of the lower set of beam splitters 1, and the first conducting layer 5 of the upper set of beam splitters 1 is then provided on the spacer layer. The spacer layer is a material (e.g., thick layer of vacuum or air, plus a metal layer) that can separate the interaction between the two sets of beam splitters 1.

[0121] In this way, two or more sets and/or arrays of beam splitters 1 (or single beam splitters 1) can be stacked vertically.

[0122] In the example discussed above, the conducting track 11 forming the microstrip 13 carrying the first signal is provided in the upper conducting layer 9, and the coplanar waveguide 29 carrying the second signal (and the ground plane for the microstrip 13) is provided in the lower conducting layer 5. It will be appreciated that this is by way of example only. In some examples, the microstrip 13 may be formed in the lower conducting layer 5, and the upper conducting layer 9 may form the coplanar waveguide 29 (and the ground plane for the microstrip 13).

[0123] Furthermore, in the above examples, the coplanar waveguide 29 is straight, whilst the microstrip 11 includes the bend. It will be appreciated that this is by way of example only, and it may be that the microstrip extends substantially straight, whilst the coplanar waveguide 29 includes the Z-bend. Whichever of the lines shows the higher response from the input to the output should be chosen for the input signal. The local oscillator should be provided on the other line. The overlap portion is defined by the length for which one of the transmission lines overlaps the other.

[0124] Furthermore, the arrangement of one of the transmission lines 13, 29 crossing the other at right angles is by way of example. The lines 13, 29, may follow any path, provided one of the lines includes a deformation such that it there is an overlap portion formed. For example, one the lines 13, 29 may be at any angle to the other, away from the overlap region 43. Alternatively, one or both of the lines 13, 29 may follow a curved path or any other path that results in a section of one line lying over and parallel to the other.

[0125] In the examples discussed above, the microstrip 13 extends parallel to the coplanar waveguide 29 at the overlap portion. It will be appreciated that in some examples, there may be a small angle formed. The overlap section will still be substantially parallel, but not exactly. As the angle increases, the degree of coupling will decrease, and so this can be used to tune to coupling

required.

[0126] Figures 7A and 7B illustrate an alternative device 70 according to an embodiment of the invention. The device of Figures 7A and 7B is similar to the device of Figures 1A and 1B and based on the same layered structure. However, in this example, the microstrip 13 extends straight between the first input 15 and the first output 17, without a Z-bend.

[0127] Within the overlap region 43, the conducting track 25 forming the central conductor of the coplanar waveguide 29 is widened. The widened part 72 of the conducting track 25 extends parallel to and underneath the conducting track 11 forming the microstrip 13, forming an overlap portion. The widened part 72 is extended towards both ports 15, 17 of the microstrip 13, so that the coplanar waveguide 29 is symmetric about an axis defined between the input port 31 and output port 41. The non-conducting track 19 follows the widened section 72.

[0128] Where the coplanar waveguide 29 extends parallel to the microstrip 13, the field lines of the first electromagnetic signal interact with the field lines of the second electromagnetic signal, such that a portion of the first electromagnetic signal is coupled to the first output port 17. At the same time, the second electromagnetic signal is transmitted along the length of the microstrip 13. Therefore, a portion of the first electromagnetic signal and the second electromagnetic signal are provided on the same optical path - the microstrip 13.

[0129] The length of the overlap portion of the coplanar waveguide 29 controls the amount that the signals interact. This therefore in turn controls the proportion of the power of the second electromagnetic signal that is provided on the microstrip 13.

[0130] In this example, the response of the straight microstrip 13 will be such that the majority of the power is transmitted from the first input 15 to the first output 17. A proportion of the power transmitted from the second input 31, through the coplanar waveguide 29, is also transmitted to the first output 17 and the first input 15. As discussed in relation to the beam splitter 1, there will be some reflection and losses, but the remaining signal will be transmitted to the second output 41.

[0131] Since the arrangement of the widened section 72 is symmetric, the second signal will be coupled in both directions along the microstrip 13, to both ports 15, 17. Therefore, the device 70 of Figure 7A and 7B can be considered a non-directional cross-coupler.

[0132] It will be appreciated that an array of non-directional cross couplers 70 may be formed in a similar manner to the array of beam splitters 1. The length of the overlap portion may again be varied, to provide even power at each splitter 70.

[0133] In the beam splitter 1, the waves propagate around a 90 degree corner in the Z-bend. In the non-directional cross coupler 70, the waves do not turn, they simply propagate down the lines. The widened section 72 simply enhance the interaction between the two transmission lines 13, 29.

[0134] As with the beam splitter 1, in the example of the cross-coupler 70 discussed above, the conducting track 11 forming the microstrip 13 carrying the first signal is provided in the upper conducting layer 9, and the coplanar waveguide 29 carrying the second signal (and the ground plane for the microstrip 13) is provided in the lower conducting layer 5. It will be appreciated that this is by way of example only. In some examples, the microstrip 13 may be formed in the lower conducting layer 5, and the upper conducting layer 9 may form the coplanar waveguide 29 (and the ground plane for the microstrip 13).

[0135] Furthermore, in the above examples, the microstrip 13 is straight, whilst the coplanar waveguide 29 includes a widened section 72. It will be appreciated that this is by way of example only, and it may be that the coplanar waveguide 29 extends substantially straight, whilst the microstrip 13 includes a widened section. The overlap portion is defined by the length for which one of the lines overlies the other.

[0136] In some examples, the coplanar waveguide 29 may only be widened in one direction, towards one of the first input port 15 and the first output port 17. In this case, the coupling from the coplanar waveguide 29 to the microstrip 13 is directional - the signal carried on the coplanar waveguide coupler in the direction of the widening is less than the opposite direction. However, the coupling of the microstrip 13 to the coplanar waveguide 29 is non-directional - so the signal carried on the microstrip 13 is coupled to the input 31 and output 41 of the waveguide.

[0137] It will be appreciated that the arrangement of one of the transmission lines 13, 29 crossing the other at right angles is by way of example. The lines 13, 29, may follow any path provided that the overlap portion is symmetric. For example, one the lines 13, 29 may be at an angle to the other, away from the overlap region 43. Alternatively, one or both of the lines 13, 29 may follow a curved path or any other path that results in a section of one line lying over and parallel to the other.

[0138] In the above description, a number of examples of conducting and dielectric materials have been given. However, it will be appreciated that the conducting layers 5, 9 may be formed of any suitable conducting material and may have any suitable dimensions. For example, for microwave applications, the conducting layers 5, 9 may be Copper, Silver or Gold, or the conducting layers 5, 9 may be superconducting materials, such as Niobium, Aluminium, Niobium Nitride. The conducting layers 5, 9 may be the same material as each other, or different. The conducting layers may be, for example, between 10 nanometres and 200 microns thick depending on the materials used, although any suitable thickness may be used.

[0139] The dielectric layer may be any suitable dielectric material, such as silicon monoxide or silicon dioxide, Dupont Pyralux 9121R, Dupont Pyralux AP8525, or Roger Duroid RO4350. The dielectric layer may be between, for example, 20 microns and 5 mm thick, although any

suitable thickness may be used.

[0140] The layered structure discussed above is given by way of example only. Any suitable layered structure may be used, with or without intermediate layers between the substrate 3, lower conducting layer 5, dielectric layer 7 and upper conducting layer 9. Furthermore, additional conducting and dielectric layers may be provided. In some cases, the substrate 3 is not needed. For example, the device can be fabricated on standard printed circuit board or flexible standard printed circuit board. It will also be appreciated that the dimension given above are by way of example only, and any suitable dimensions could be applied to the devices 1, 70 discussed.

[0141] The use of one microstrip 13 and one coplanar waveguide 29 is by way of example only. Any suitable combination of different transmission lines, including microstrips, slotlines, coplanar waveguide and grounded coplanar waveguides may be used. The choice of transmission line can be used to further control the amount of coupling. For example, using two transmission lines where the fields extend in the same direction reduces coupling, whilst having orthogonal fields increases coupling.

[0142] The use of microstrips 33a,b as feeds for the coplanar waveguide 29 is also by way of example only, feeds may be provided in any suitable manner. Similarly, the use of broadside couplers 39a,b is by way of example only, any suitable coupling may be used. Alternatively, the input and output may be provided directly in the coplanar waveguide 29 or transmission line used.

[0143] In the above, the beam splitter 1 and cross coupler 70 are described as having input and output ports 15, 17, 31, 41. It will be appreciated that this may simply refer to any point on the microstrips 13, 33a,b feeding the overlap region 43, and may not refer to specific features at which an input or output is connected.

[0144] The devices discussed above are four port devices, having two input ports 15, 31 and two output ports 17, 41. It will be appreciated that in some examples, as discussed in the example of the phased array system 300, not all of the ports may be required. For example, one of the input ports 15, 31 may be absent (simply no input signal here), or terminated, so a signal at the other input port is simply divided into different portions on each transmission line. One of the output ports may also be absent or terminated.

[0145] In use, the beam splitter 1 or cross coupler 70 are connected out to a wider system. In the example discussed above, this is through an input port 45 and a wire bonding pad 49. In order to provide a connection to the wider system, the electrical contact must also be provided to the lower conducting layer 5 in order to provide a connection to the ground plane.

[0146] In some examples, the beam splitter 1 or cross coupler 70 is integrated into a larger planar circuit. In these examples, the lower conducting layer 5 may form the ground plane for the whole system, and connection of the input and output ports 15, 17, 31, 41 to the wider

system may simply be by continuation of the conducting tracks 11, 35a,b.

[0147] In other examples, the beam splitter 1 or cross coupler 70 may be connected out to a wider system. In the example discussed above, this is through an input port 45 and a wire bonding pad 49. In order to provide a connection to the wider system, the electrical contact must also be provided to the lower conducting layer 5 in order to provide a connection to the ground plane.

[0148] An RF or co-axial connector, such as a SubMiniature version A (SMA) connector can be used to connect the device to a wider system or test rig. RF or co-axial connectors include a signal conductor for carrying the signal and ground conductor (for example, the signal conductor may be provided in a core and the ground conductor in a shield surrounding the core).

[0149] Figures 8A and 8B illustrate a first example circuit used to provide connections from a beam splitter 1 to SMA connectors (not shown). The circuit is formed in the same layered structure as the beam splitter 1. Figure 8A illustrates the circuit in plan view, showing the regions of the upper conducting layer 9 and lower conducting layer 5.

[0150] The connection to each microstrip 13, 33a,b is formed by co-planar waveguides 80a-d formed in the upper conducting layer 9 at the edge of the circuit. Each co-planar waveguide 80a-d is connected to one of the microstrips 13, 33a,b of the beam splitter 1.

[0151] Figure 8B shows the lower conducting layer 5 and upper conducting layer 9 of the circuit shown in Figure 8A. As discussed above, in the upper conducting layer a number of conducting tracks 11, 35a,b are formed. Similarly, a track 25 is formed in the central region of the lower conducting layer 5.

[0152] In a central region 82a of the circuit, the upper conducting layer 9 is removed, apart from the tracks 11, 35a,b. Therefore, in the central region 82a, the tracks 11, 35a,b, 25 in both conducting layers 5,9 form the microstrips 11, 33a,b and the co-planar waveguide 29 of the beam splitter 1.

[0153] Away from the central region 82a, the tracks 11, 35a,b include a step change to a wider intermediate portion 84a-d. From the intermediate portion 84a-d, the tracks 84a-d then taper outwards to outer portions 86a-d, wider than the intermediate portions 84a-d.

[0154] Adjacent the intermediate portions 84a-d and outer portions 86a-d of the tracks 11, 35a,d, the upper conducting layer 9 includes a body 82b spaced from the conducting tracks by a non-conducting gap.

[0155] No material in the lower conducting layer 5 is provided around the outer edge of the circuit. The border of the lower conducting layer 5 is aligned with the point at which the intermediate portions 84a-d of the tracks 11, 35a,d start to widen to the outer portions 86a-d. This is shown by the dashed lines in Figure 8B. Furthermore, the conducting material is removed in the lower conducting layer 5 in the region of the intermediate portion 84a-d of the tracks.

[0156] The regions where there are no conducting material and the non-conducting tracks can be formed by air gaps, dielectric material or any other suitable manner,

[0157] Figure 8C shows a cut through of the circuit at (a) the central region 82a of the circuit, (b) the transition between the central region 82a and the intermediate portion 84a-d of the tracks 11 35a,b, (c) the intermediate portions 84a-d of the tracks 11, 35a,b and (d) the outer portions 86a-d of the tracks 11 35a,b.

[0158] As can be seen, at the central region, the conducting tracks 11, 35a,b form a microstrip with the ground plane in the lower conducting layer 5. At the outer portions 86a-d, the tracks 11,35a,b form the central conductor of a co-planar waveguide 80a-d formed in the upper conducting layer 9, with the ground plane provided by the body 82b. The intermediate portion allows for a transition between the microstrip 13, 31a,b and the co-planar waveguide 80a-d. The transition maintains electrical continuity.

[0159] Capacitive coupling couples the ground plane in the lower conducting layer 5 and the ground plane in the upper conducting layer 9. In general, the field lines in a microstrip extend vertically, between the conducting track 11,35 and the ground plane (formed in the lower conducting layer 5). As the body 82a-d of the upper conducting layer 9 approaches the conducting tracks 11,35a,b then a proportion of the field extends horizontally. As the lower conducting layer 5 is removed, this increases, until the field extends fully horizontally, as in a co-planar waveguide.

[0160] The wider central conductor of the co-planar waveguide 80a-d in the outer portion 86a-d gives a large region to contact the signal conductor of the SMA connector. This widening is optional, and the signal conductor may simply connect to the conducting track 82a-d. The body 82b of the upper conducting layer 9 provides a large connection for the ground conductor of the SMA connector, on the upper face of the circuit.

[0161] Figures 9A and 9B illustrate the measured response for a beam splitter 1 constructed as shown in Figure 8A and 8B. The overall size of the device is 45mm by 45mm. The copper conducting layers were fabricated on both side of a 50 micron thin flexible substrate (Dupont PyraluxAP 9121R, $\epsilon_R = 3.4$). The flexible printed circuit board was then supported by a Roger Duroid RO6010 bare substrate (1.27mm , $\epsilon_R = 10.9$). The conducting layers were both 18 microns thick.

[0162] Figure 9A shows the measured response for a signal provided at the first input 15. The response was measured at the first input 15 (i.e. reflection), at the second input 31 (i.e. leakage), at the first output 17 (i.e. transmission) and at the second output 41 (i.e. coupling). Figure 9A shows the reflection 202a, leakage 202c, transmission 202b and coupling 202d of the first input 15 of a beam splitter 1 where the overlap between the coplanar waveguide 29 and microstrip 13 extends for 348 microns, as a function of the frequency of the signal. Figure 9A also shows the coupling of the first input 15 to the second

output 41 for a beam splitter 1 with overlap of 288 microns 204a, the coupling of the first input 15 to the second output 41 for a beam splitter 1 with overlap of 427 microns 204b, the coupling of the first input 15 to the second output 41 for a beam splitter 1 with overlap of 510 microns 204c, and the coupling of the first input 15 to the second output 41 for a beam splitter 1 with overlap of 610 microns 204d.

[0163] For the beam splitter 1 with an overlap of 348 microns, Figure 9B shows the reflection 206a of a signal provided at the second input 31, the leakage 206b of the signal provided at the second input 31 to the first input 15, the transmission 206c from the second input 31 to the second output 41 and the coupling 206d of the second input 31 to the first output 17, as a function of frequency of the signal. Figure 9B also shows the coupling of the second input 31 to the first output 17 for a beam splitter 1 with overlap of 288 microns 208a, for a beam splitter 1 with overlap of 427 microns 208b, for a beam splitter 1 with overlap of 510 microns 208c, and for a beam splitter 1 with overlap of 610 microns 208d.

[0164] The measured responses in Figures 9A and 9B are similar to the calculated responses shown in Figure 4B and 4C.

[0165] Figure 10 illustrates a second circuit that may be used to provide connections from a beam splitter 1 to SMA connectors (not shown). In this example, the conducting tracks 11 35a,b, that form the microstrips 13, 33a,b is widened at the edge of the circuit, to form first connection pads 88a-d in the upper conducting layer 9. The first connection pads are for coupling to the signal conductors of the SMA connectors.

[0166] Second connection pads 90 are also provided in the upper conducting layer 9. Each second connection pad 90 includes one or more conducting through channels 92 (also known as vias) between the conducting layers 5,9, through the insulating layer 7. The channels are made conducting by plating the surface of through holes with a conducting material.

[0167] The vias 92 connect the second connection pads 90 to the ground plane, so that the second connection pads provide a connection for the ground conductor of the SMA connector on the upper face of the circuit.

[0168] Through holes 98 are formed in each of the conducting layers 5, 9 and the dielectric layer 7. The through holes 98 are provided for SMA alignment pins and screws, and may also, in some examples, be plated so that they provide additional vias. Alternatively, the through holes 98 may not be plated.

[0169] It will be appreciated that, as with the first example, the widening of the conducting strips 11, 35a,b is optional, and the SMA signal conductor may be connected to the narrow section of the strip 11 35a,b.

[0170] Figures 11A and 11B show a further example of a circuit for connecting a beam splitter 1 to SMA connectors. Figure 11A shows an exploded view, and Figure 11B shows a plan view. As with the first and second example circuits, this is formed in the same layered struc-

ture as the beam splitter 1.

[0171] In this third example, the substrate 3 is 1.27 mm thick, and includes a central non-conducting region 94, for example formed of the same substrate used above, and a copper rim 96. The central non-conducting region 94 is formed in the area of the coplanar waveguide 29, and the rim 96 is formed away from the co-planar waveguide 29.

[0172] L-shaped contacts 91 are formed in the upper conducting layer 9, at each corner of the device, away from the conducting tracks 11, 35a,b. The L-shaped contacts include one or more conducting vias 92 through to the lower conducting layer 5. Therefore, the L-shaped contacts provided connections for the ground plane on the top of the device.

[0173] Additional z-bends 93 are provided in the track 11 that runs across the whole circuit, to ensure the circuit is symmetrical.

[0174] Through holes 98 are formed in each of the conducting layers 5, 9, the copper rim 96 and the dielectric layer 7. The through holes 98 are provided for SMA alignment pins and screws, and may also, in some examples, be plated so that they provide additional vias. Alternatively, the through holes 98 may not be plated. The conducting strips 11, 35a,b can be connected to the signal conductor of the SMA connector in any suitable manner. It will be appreciated that similar through holes 98 for SMA connectors may be provided in any of the circuits.

[0175] Figures 12A-D show the measured response for a beam splitter 1 constructed as shown in Figure 11. In this example, the conducting layers 5, 9 are 35 micron thick copper, and the dielectric layer is 254 micron thick Roger RO4350. The top three layers 5, 7, 9 are formed by a Roger RO4350 Printed Circuit Board. The non-conducting region of the substrate is Roger 6010.

[0176] Figures 12A and 12B show the measured response of the first input port 15 as function of input signal between 10GHz and 15GHz. Figure 12A shows the reflection 210a, leakage 210b, transmission 210c and coupling 210d of the first input port 15 for a beam splitter 1 with overlap of 1100 microns, Figure 12A also shows the coupling 212a-e of the first input port 15 to the second output port 41 for a beam splitter 1 with overlap of 850 microns 212a, for a beam splitter 1 with overlap of 660 microns 212b, for a beam splitter 1 with overlap of 500 microns 212c, for a beam splitter 1 with overlap of 360 microns 212d, and for a beam splitter 1 with overlap of 240 microns 212e.

[0177] Figure 12B shows the reflection 214a, leakage 214b, transmission 214c and coupling 214d of the second input port 31 for a beam splitter 1 with overlap of 1100 microns, as a function of input signal between 10GHz and 15GHz. Figure 12B also shows the coupling 216a-e of the second input port 31 to the first output port 17 for a beam splitter 1 with overlap of 850 microns 216a, for a beam splitter 1 with overlap of 660 microns 216b, for a beam splitter 1 with overlap of 500 microns 216c, for a beam splitter 1 with overlap of 360 microns 216d,

and for a beam splitter 1 with overlap of 240 microns 216e.

[0178] Figures 12C and D show the measured response of the first input port 15, as a function of input signal between 6 and 11GHz. Figure 12C shows the reflection 218a, leakage 218b, transmission 218c and coupling 218d of the first input port 15 for a beam splitter 1 with overlap of 500 microns. Figure 12C also shows the coupling 220a-e of the first input port 15 to the second output port 41 for a beam splitter 1 with overlap of 645 microns 220a, for a beam splitter 1 with overlap of 815 microns 220b, for a beam splitter 1 with overlap of 1012 microns 220c, for a beam splitter 1 with overlap of 1238 microns 220d, and for a beam splitter 1 with overlap of 1515 microns 220e,

[0179] Figure 12D shows the reflection 222a, leakage 222b, transmission 222c and coupling 222d of the second input port 31 for a beam splitter 1 with overlap of 500 microns. Figure 12D also shows the coupling 224a-e of the second input port 31 to the first output port 17 for beam splitter 1 with overlap of 645 microns 224a, for a beam splitter 1 with overlap of 815 microns 224b, for a beam splitter 1 with overlap of 1012 microns 224c, for a beam splitter 1 with overlap of 1238 microns 224d, and for a beam splitter 1 with overlap of 1515 microns 224e.

[0180] The measured responses in Figures 12A to D are approximately similar to the calculated responses shown in Figure 4B and 4C, and 3B and 3C.

[0181] The examples shown in relation to Figures 8 to 12 are discussed in relation to a single beam splitter 1. However, it will be appreciated that these circuits are also applicable to cross-couplers 70, and arrays of beam splitters 1 or cross-couplers 70.

[0182] Furthermore, although these techniques have been described in relation to SMA connectors, they may be used to provide any desired connection.

[0183] In the above examples, the connection to the ground plane and signal are both provided on the same (upper) face of the device. Any suitable arrangement of vias, through holes or other through connections may be used. It will also be appreciated that in some examples, a back connector may be used to connect to the ground plane, as is known in the art. In further examples, all connections may be provided on the back (lower) face.

[0184] The physical parameters of any connection should be controlled to achieve suitable impedance matching with the wider system. For example, for SMA connectors, the connections are set to 50 Ohm.

[0185] The devices shown in Figures 8 to 12 are given by way of example only. The person skilled in the art will appreciate that there are a variety of different ways in which to connect the beam splitter 1 or cross-coupler 70 to the wider system.

[0186] It will be appreciated that the device 1, 70 discussed above may be operated at cryogenic temperatures or any other suitable temperature.

[0187] In the above examples, a single signal is carried on each transmission line. However, it will be appreciated

that each line may carry two signals or more.

Claims

1. A device (1) for coupling and/or splitting signals, the device (1) including:

a first transmission line (29) configured to carry at least one first signal;
a second transmission line (13) configured to carry at least one second signal; and
an overlap region (43) in which the first transmission line (29) crosses the second transmission line (13) such that it overlies the second transmission line (13), and in which the first transmission line (29) and second transmission line (13) extend parallel or substantially parallel to each other where the first transmission line (29) overlies the second transmission line (13), such that a predetermined portion of the power of a signal provided on either the first transmission line (29) or the second transmission line (13) is transferred to an output optical path of the other transmission line,

wherein one of the first transmission line (29) and the second transmission line (13) is a coplanar waveguide, and the other of the first transmission line (29) and the second transmission line (13) is a microstrip.

2. The device (1) of claim 1, wherein a length that the first transmission line (29) and second transmission line (13) extend parallel or substantially parallel to each other for is configured to control the predetermined portion.
3. The device (1) of claim 1 or claim 2, wherein the overlap region (43) is configured such that a second portion of the power of the signal provided on either the first transmission line (29) or the second transmission line (13) remains on an output optical path of the transmission line it is provided on.
4. The device (1) of any preceding claim, wherein a one of the first transmission line (29) and second transmission line (13) is straight or substantially straight, extending in a first direction, and the other of the first transmission line (29) and second transmission line (13) includes a deformation away from straight where the first transmission line (29) overlies the second transmission line (13).
5. The device (1) of claim 4, wherein the other of the first transmission line (29) and second transmission line (13) includes a first portion and a second portion,

both extending in a second direction, different to the first, and an intermediate portion between the first portion and the second portion, the intermediate portion being arranged parallel or substantially parallel to the first direction, and being formed where the first transmission line (29) overlies the second transmission line (13), optionally wherein the first direction is perpendicular to the second direction.

6. The device (1) of any preceding claim, wherein the overlap region (43) is configured such that at least a portion of the power of a signal carried on the first transmission line (29) is combined with a portion of the power of a signal on the second transmission line (13), on the output optical path of the first (29) or second transmission line (13).
7. The device (1) of any preceding claim, wherein the length of the co-planar waveguide (29) is approximately half the wavelength of a central frequency of the operating bandwidth of the device (1).
8. The device (1) of any preceding claim, wherein each transmission line (29, 13) includes a first port (15, 31) and a second port (17, 41), and wherein the coupling is directional, such that signals are only coupled from the first ports (15, 31) to the second ports (17, 41), optionally wherein, where the first transmission line (29) overlies the second transmission line (13), the arrangement of one of the first transmission line (29) and second transmission line (13) is asymmetric about an axis defined by the direction between the first port (15, 31) and the second port (17, 41) of the one of the first transmission line (29) and second transmission line (13), and/or optionally wherein the device (1) comprises a directional coupler.
9. The device (1) of any of claims 1 to 8, wherein each transmission line (29, 13) includes a first port (15, 31) and a second port (17, 41), and wherein the coupling is non-directional, such that signals are coupled from the first ports (15, 31) to the first ports (15, 31) and second ports (17, 41), optionally wherein, where the first transmission line (29) overlies the second transmission line (13), the arrangement of the first transmission line (29) is symmetric about an axis defined by the direction between the first port (15) and the second port (17) of the first transmission line (29), and wherein the arrangement the second transmission line (13) is symmetric about an axis defined by the direction between the first port (17) and the second port (41) of the second transmission line (13), and/or optionally wherein the device (1) comprises a non-directional coupler.
10. The device (1) of any preceding claim, wherein the device (1) comprises at least:

a first conducting layer (5);
a second conducting layer (9); and
a dielectric layer (7) between the first conducting layer (5) and the second conducting layer (9),

wherein the conducting layers (5, 9) are arranged to form the transmission lines (29, 13).

11. The device (1) of claim 10, wherein a one of the first transmission line (29) and the second transmission line (13) is wholly formed in a one of the first conducting layer (5) and second conducting layer (9) such that the field lines of a signal in the one of the first transmission line (29) and the second transmission line (13) extend parallel to a plane of the layers (5, 9), optionally wherein the other of the first transmission line (29) and the second transmission line (13) is formed by the first conducting layer (5) and second conducting layer (9), such that the field lines of a signal carried in the other of the first transmission line (29) and the second transmission line (13) extend perpendicular to the plane of the layers (5, 9), and optionally wherein the one of the first transmission line (29) and the second transmission line (13) includes feeds (33, 39) for providing a signal to and from the one of the first transmission line (29) and the second transmission line (13), wherein the feeds (33, 39) are formed in the other of the first conducting layer (5) and second conducting layer (9).
12. The device (1) of claim 11, wherein the device (1) includes one or more electrical connection extending through the dielectric layer (7) between at least a region of the first conducting layer (5) and at least a region of the second conducting layer (9), such that the first conducting layer (5) and second conducting layer (9) are contactable from the same side of the device (1).
13. A device (1) for coupling and/or splitting a plurality of signals, the device (1) comprising:

one or more first transmission lines (29), each configured to carry one or more first signal; and
a plurality of second transmission lines (13), each configured to carry one or more second signal;
wherein each of the one or more first transmission lines (29) crosses each of the plurality second transmission lines (13), in turn, in a respective overlap region (43), where one of the transmission lines (29, 13) overlies the other;
wherein the one or more first transmission lines (29) are coplanar waveguides, and the one or more second transmission lines (13) are a microstrips, or the one or more first transmission lines (29) are microstrips, and the one or more second transmission lines (13) are a coplanar

waveguides; and
 wherein in each overlap region (43), the first transmission line (29) and the second transmission line (13) extend parallel or substantially parallel to each other as they cross, such that a first portion of the power of a first signal carried on the first transmission line (29) is transferred to an output optical path of each second transmission line (13) and a second portion of the power of the first signal carried on the first transmission line (29) is provided to an adjacent overlap region (43) on the first transmission line (29).

14. The device (1) of claim 13, wherein a length that the first transmission line (29) and second transmission line (13) extend parallel or substantially parallel to each other for is configured to control the predetermined portion, optionally wherein the length of subsequent overlap regions (43) increases along each first transmission line (29), such that the amount of power transferred to each second transmission line (13) is the same at each overlap region (43).
15. The device (1) of claim 13 or claim 14, wherein each overlap region (43) is configured such that the portion of the power of the first signal transferred to each second transmission line (13) is combined with at least a portion of the power of a second signal carried on each second transmission line (13), on an output optical path of each second transmission line (13)

Patentansprüche

1. Vorrichtung (1) zum Koppeln und/oder Teilen von Signalen, wobei die Vorrichtung (1) Folgendes umfasst:

eine erste Übertragungsleitung (29), die konfiguriert ist, um mindestens ein erstes Signal zu führen;
 eine zweite Übertragungsleitung (13), die konfiguriert ist, um mindestens ein zweites Signal zu führen; und
 einen Überlappungsbereich (43), in dem die erste Übertragungsleitung (29) die zweite Übertragungsleitung (13) derart kreuzt, dass sie über der zweiten Übertragungsleitung (13) liegt, und in dem sich die erste Übertragungsleitung (29) und die zweite Übertragungsleitung (13) parallel oder im Wesentlichen parallel zueinander erstrecken, wo die erste Übertragungsleitung (29) über der zweiten Übertragungsleitung (13) liegt, so dass ein vorbestimmter Teil der Leistung eines Signals, das entweder auf der ersten Übertragungsleitung (29) oder auf der zweiten Über-

tragungsleitung (13) bereitgestellt ist, an einen optischen Ausgangspfad der anderen Übertragungsleitung übertragen wird, wobei eine der ersten Übertragungsleitung (29) und der zweiten Übertragungsleitung (13) ein koplanarer Wellenleiter ist und die andere der ersten Übertragungsleitung (29) und der zweiten Übertragungsleitung (13) ein Mikrostreifen ist.

2. Vorrichtung (1) nach Anspruch 1, wobei eine Länge, über die sich die erste Übertragungsleitung (29) und die zweite Übertragungsleitung (13) parallel oder im Wesentlichen parallel zueinander erstrecken, konfiguriert ist, um den vorbestimmten Teil zu steuern.
3. Vorrichtung (1) nach Anspruch 1 oder 2, wobei der Überlappungsbereich (43) derart konfiguriert ist, dass ein zweiter Teil der Leistung des Signals, das entweder auf der ersten Übertragungsleitung (29) oder auf der zweiten Übertragungsleitung (13) bereitgestellt ist, auf einem optischen Ausgangspfad der Übertragungsleitung verbleibt, auf dem er bereitgestellt ist.
4. Vorrichtung (1) nach einem der vorhergehenden Ansprüche, wobei eine der ersten Übertragungsleitung (29) und der zweiten Übertragungsleitung (13) gerade oder im Wesentlichen gerade ist, wobei sie sich in einer ersten Richtung erstreckt, und die andere der ersten Übertragungsleitung (29) und der zweiten Übertragungsleitung (13) eine Verformung weg von der Geraden aufweist, wo die erste Übertragungsleitung (29) über der zweiten Übertragungsleitung (13) liegt.
5. Vorrichtung (1) nach Anspruch 4, wobei die andere der ersten Übertragungsleitung (29) und der zweiten Übertragungsleitung (13) einen ersten Abschnitt und einen zweiten Abschnitt, die sich beide in einer zweiten, von der ersten Richtung verschiedenen Richtung erstrecken, und einen Zwischenabschnitt zwischen dem ersten Abschnitt und dem zweiten Abschnitt umfasst, wobei der Zwischenabschnitt parallel oder im Wesentlichen parallel zu der ersten Richtung angeordnet und dort ausgebildet ist, wo die erste Übertragungsleitung (29) über der zweiten Übertragungsleitung (13) liegt, optional wobei die erste Richtung senkrecht zur zweiten Richtung ist.
6. Vorrichtung (1) nach einem der vorhergehenden Ansprüche, wobei der Überlappungsbereich (43) derart konfiguriert ist, dass mindestens ein Teil der Leistung eines Signals, das auf der ersten Übertragungsleitung (29) geführt ist, mit einem Teil der Leistung eines Signals auf der zweiten Übertragungsleitung (13) kombiniert wird, und zwar auf dem optischen Ausgangspfad der ersten (29) oder zweiten Über-

gungsleitung (13).

7. Vorrichtung (1) nach einem der vorhergehenden Ansprüche, wobei die Länge des koplanaren Wellenleiters (29) ungefähr die Hälfte der Wellenlänge einer Mittenfrequenz der Betriebsbandbreite der Vorrichtung (1) beträgt. 5
8. Vorrichtung (1) nach einem der vorhergehenden Ansprüche, wobei jede Übertragungsleitung (29, 13) einen ersten Anschluss (15, 31) und einen zweiten Anschluss (17, 41) umfasst und wobei die Kopplung gerichtet ist, so dass Signale nur von den ersten Anschlüssen (15, 31) zu den zweiten Anschlüssen (17, 41) gekoppelt werden, wobei optional dort, wo die erste Übertragungsleitung (29) über der zweiten Übertragungsleitung (13) liegt, die Anordnung der ersten Übertragungsleitung (29) oder der zweiten Übertragungsleitung (13) um eine Achse asymmetrisch ist, die durch die Richtung zwischen dem ersten Anschluss (15, 31) und dem zweiten Anschluss (17, 41) der ersten Übertragungsleitung (29) oder der zweiten Übertragungsleitung (13) definiert ist, und/oder optional wobei die Vorrichtung (1) einen Richtungskoppler umfasst. 10 15 20 25
9. Vorrichtung (1) nach einem der Ansprüche 1 bis 8, wobei jede Übertragungsleitung (29, 13) einen ersten Anschluss (15, 31) und einen zweiten Anschluss (17, 41) umfasst und wobei die Kopplung derart ungerichtet ist, dass Signale von den ersten Anschlüssen (15, 31) zu den ersten Anschlüssen (15, 31) und zweiten Anschlüssen (17, 41) gekoppelt werden, wobei optional die erste Übertragungsleitung (29) über der zweiten Übertragungsleitung (13) liegt, die Anordnung der ersten Übertragungsleitung (29) symmetrisch um eine Achse ist, die durch die Richtung zwischen dem ersten Anschluss (15) und dem zweiten Anschluss (17) der ersten Übertragungsleitung (29) definiert ist, und wobei die Anordnung der zweiten Übertragungsleitung (13) symmetrisch um eine Achse ist, die durch die Richtung zwischen dem ersten Anschluss (17) und dem zweiten Anschluss (41) der zweiten Übertragungsleitung (13) definiert ist, und/oder optional wobei die Vorrichtung (1) einen ungerichteten Koppler umfasst. 30 35 40 45
10. Vorrichtung (1) nach einem der vorhergehenden Ansprüche, wobei die Vorrichtung (1) mindestens Folgendes umfasst: 50
 - eine erste leitende Schicht (5);
 - eine zweite leitende Schicht (9); und
 - eine dielektrische Schicht (7) zwischen der ersten leitenden Schicht (5) und der zweiten leitenden Schicht (9),
 - wobei die leitenden Schichten (5, 9) angeordnet sind, um die Übertragungsleitungen (29, 13)

auszubilden.

11. Vorrichtung (1) nach Anspruch 10, wobei die erste Übertragungsleitung (29) oder die zweite Übertragungsleitung (13) vollständig derart in der ersten leitenden Schicht (5) oder der zweiten leitenden Schicht (9) ausgebildet ist, dass sich die Feldlinien eines Signals in der ersten Übertragungsleitung (29) oder der zweiten Übertragungsleitung (13) parallel zu einer Ebene der Schichten (5, 9) erstrecken, optional wobei die andere der ersten Übertragungsleitung (29) und der zweiten Übertragungsleitung (13) derart durch die erste leitende Schicht (5) und die zweite leitende Schicht (9) gebildet ist, dass sich die Feldlinien eines Signals, das in der anderen der ersten Übertragungsleitung (29) und der zweiten Übertragungsleitung (13) geführt wird, senkrecht zu der Ebene der Schichten (5, 9) erstrecken, und optional wobei die erste Übertragungsleitung (29) oder die zweite Übertragungsleitung (13) Zuführungen (33, 39) umfasst, um ein Signal zu und von der ersten Übertragungsleitung (29) oder der zweiten Übertragungsleitung (13) bereitzustellen, wobei die Zuführungen (33, 39) in der anderen der ersten leitenden Schicht (5) und der zweiten leitenden Schicht (9) ausgebildet sind.
12. Vorrichtung (1) nach Anspruch 11, wobei die Vorrichtung (1) eine oder mehrere elektrische Verbindungen umfasst, die sich derart durch die dielektrische Schicht (7) zwischen mindestens einem Bereich der ersten leitenden Schicht (5) und mindestens einem Bereich der zweiten leitenden Schicht (9) erstrecken, dass die erste leitende Schicht (5) und die zweite leitende Schicht (9) von derselben Seite der Vorrichtung (1) aus kontaktierbar sind.
13. Vorrichtung (1) zum Koppeln und/oder Teilen mehrerer Signale, wobei die Vorrichtung (1) Folgendes umfasst:
 - eine oder mehrere erste Übertragungsleitungen (29), die jeweils konfiguriert sind, um ein oder mehrere erste Signale zu führen; und
 - mehrere zweite Übertragungsleitungen (13), die jeweils konfiguriert sind, um ein oder mehrere zweite Signale zu führen;
 - wobei jede der einen oder mehreren ersten Übertragungsleitungen (29) jede der mehreren zweiten Übertragungsleitungen (13) wiederum in einem jeweiligen Überlappungsbereich (43) kreuzt, wo eine der Übertragungsleitungen (29, 13) über der anderen liegt;
 - wobei die eine oder mehreren ersten Übertragungsleitungen (29) koplanare Wellenleiter sind und die eine oder mehreren zweiten Übertragungsleitungen (13) Mikrostreifen sind, oder die eine oder mehreren ersten Übertragungsleitun-

gen (29) Mikrostreifen sind, und die eine oder mehreren zweiten Übertragungsleitungen (13) koplanare Wellenleiter sind; und wobei sich in jedem Überlappungsbereich (43) die erste Übertragungsleitung (29) und die zweite Übertragungsleitung (13) derart parallel oder im Wesentlichen parallel zueinander erstrecken, wenn sie sich kreuzen, dass ein erster Teil der Leistung eines ersten Signals, das auf der ersten Übertragungsleitung (29) geführt wird, an einen optischen Ausgangspfad jeder zweiten Übertragungsleitung (13) übertragen wird und ein zweiter Teil der Leistung des ersten Signals, das auf der ersten Übertragungsleitung (29) geführt wird, einem benachbarten Überlappungsbereich (43) auf der ersten Übertragungsleitung (29) bereitgestellt wird.

14. Vorrichtung (1) nach Anspruch 13, wobei eine Länge, über die sich die erste Übertragungsleitung (29) und die zweite Übertragungsleitung (13) parallel oder im Wesentlichen parallel zueinander erstrecken, konfiguriert ist, um den vorbestimmten Teil zu steuern, optional wobei die Länge der nachfolgenden Überlappungsbereiche (43) entlang jeder ersten Übertragungsleitung (29) derart zunimmt, dass der Leistungsbetrag, der an jede zweite Übertragungsleitung (13) übertragen wird, an jedem Überlappungsbereich (43) gleich ist.
15. Vorrichtung (1) nach Anspruch 13 oder 14, wobei jeder Überlappungsbereich (43) derart konfiguriert ist, dass der Teil der Leistung des ersten Signals, das an jede zweite Übertragungsleitung (13) übertragen wird, mit mindestens einem Teil der Leistung eines zweiten Signals kombiniert wird, das auf jeder zweiten Übertragungsleitung (13) geführt wird, und zwar auf einem optischen Ausgangspfad jeder zweiten Übertragungsleitung (13).

Revendications

1. Dispositif (1) permettant de coupler et/ou diviser des signaux, le dispositif (1) comportant :
- une première ligne de transmission (29) conçue pour transporter au moins un premier signal ;
une seconde ligne de transmission (13) conçue pour transporter au moins un second signal ; et
une région de chevauchement (43) dans laquelle la première ligne de transmission (29) croise la seconde ligne de transmission (13) de telle sorte qu'elle recouvre la seconde ligne de transmission (13), et dans laquelle la première ligne de transmission (29) et la seconde ligne de transmission (13) s'étendent parallèlement ou sensiblement parallèlement l'une à l'autre où la

première ligne de transmission (29) recouvre la seconde ligne de transmission (13), de telle sorte qu'une partie prédéterminée de la puissance d'un signal fournie sur la première ligne de transmission (29) ou sur la seconde ligne de transmission (13) est transférée à un chemin optique de sortie de l'autre ligne de transmission, dans lequel l'une de la première ligne de transmission (29) et de la seconde ligne de transmission (13) est un guide d'ondes coplanaire, et l'autre de la première ligne de transmission (29) et de la seconde ligne de transmission (13) est un microruban.

2. Dispositif (1) selon la revendication 1, dans lequel une longueur sur laquelle la première ligne de transmission (29) et la seconde ligne de transmission (13) s'étendent parallèlement ou sensiblement parallèlement l'une à l'autre est conçue pour commander la partie prédéterminée.
3. Dispositif (1) selon la revendication 1 ou la revendication 2, dans lequel la région de chevauchement (43) est conçue de telle sorte qu'une seconde partie de la puissance du signal fournie sur la première ligne de transmission (29) ou sur la seconde ligne de transmission (13) reste sur un chemin optique de sortie de la ligne de transmission sur laquelle il est fourni.
4. Dispositif (1) selon l'une quelconque des revendications précédentes, dans lequel l'une de la première ligne de transmission (29) et de la seconde ligne de transmission (13) est droite ou sensiblement droite, s'étendant dans une première direction, et l'autre de la première ligne de transmission (29) et de la seconde ligne de transmission (13) comporte une déformation s'éloignant de la droite où la première ligne de transmission (29) recouvre la seconde ligne de transmission (13).
5. Dispositif (1) selon la revendication 4, dans lequel l'autre de la première ligne de transmission (29) et de la seconde ligne de transmission (13) comporte une première partie et une seconde partie, toutes deux s'étendant dans une seconde direction, différente de la première, et une partie intermédiaire entre la première partie et la seconde partie, la partie intermédiaire étant disposée parallèlement ou sensiblement parallèlement à la première direction, et étant formée là où la première ligne de transmission (29) recouvre la seconde ligne de transmission (13), éventuellement dans laquelle la première direction est perpendiculaire à la seconde direction.
6. Dispositif (1) selon l'une quelconque des revendications précédentes, dans lequel la région de chevauchement (43) est conçue de telle sorte qu'au moins

une partie de la puissance d'un signal transporté sur la première ligne de transmission (29) est combinée avec une partie de la puissance d'un signal sur la seconde ligne de transmission (13), sur le chemin optique de sortie de la première (29) ou de la seconde ligne de transmission (13).

7. Dispositif (1) selon l'une quelconque des revendications précédentes, dans lequel la longueur du guide d'ondes coplanaire (29) est approximativement la moitié de la longueur d'onde d'une fréquence centrale de la largeur de bande de fonctionnement du dispositif (1).

8. Dispositif (1) selon l'une quelconque des revendications précédentes, dans lequel chaque ligne de transmission (29, 13) comporte un premier port (15, 31) et un second port (17, 41), et dans lequel le couplage est directionnel, de telle sorte que les signaux sont uniquement couplés des premiers ports (15, 31) aux seconds ports (17, 41), éventuellement dans lequel, lorsque la première ligne de transmission (29) recouvre la seconde ligne de transmission (13), l'agencement de l'une de la première ligne de transmission (29) et de la seconde ligne de transmission (13) est asymétrique autour d'un axe défini par la direction entre le premier port (15, 31) et le second port (17, 41) de l'une de la première ligne de transmission (29) et de la seconde ligne de transmission (13), et/ou éventuellement dans lequel le dispositif (1) comprend un coupleur directionnel.

9. Dispositif (1) selon l'une quelconque des revendications 1 à 8, dans lequel chaque ligne de transmission (29, 13) comporte un premier port (15, 31) et un second port (17, 41), et dans lequel le couplage est non directionnel, de telle sorte que les signaux sont couplés des premiers ports (15, 31) aux premiers ports (15, 31) et aux seconds ports (17, 41), éventuellement dans lequel, où la première ligne de transmission (29) recouvre la seconde ligne de transmission (13), l'agencement de la première ligne de transmission (29) est symétrique autour d'un axe défini par la direction entre le premier port (15) et le second port (17) de la première ligne de transmission (29), et dans lequel l'agencement de la seconde ligne de transmission (13) est symétrique autour d'un axe défini par la direction entre le premier port (17) et le second port (41) de la seconde ligne de transmission (13), et/ou éventuellement dans lequel le dispositif (1) comprend un coupleur non directionnel.

10. Dispositif (1) selon l'une quelconque des revendications précédentes, dans lequel le dispositif (1) comprend au moins :

une première couche conductrice (5) ;
une seconde couche conductrice (9) ; et

une couche diélectrique (7) entre la première couche conductrice (5) et la seconde couche conductrice (9),
dans lequel les couches conductrices (5, 9) sont agencées pour former les lignes de transmission (29, 13).

11. Dispositif (1) selon la revendication 10, dans lequel l'une de la première ligne de transmission (29) et de la seconde ligne de transmission (13) est entièrement formée dans l'une de la première couche conductrice (5) et de la seconde couche conductrice (9) de telle sorte que les lignes de champ d'un signal dans l'une de la première ligne de transmission (29) et de la seconde ligne de transmission (13) s'étendent parallèlement à un plan des couches (5, 9), éventuellement dans lequel l'autre de la première ligne de transmission (29) et de la seconde ligne de transmission (13) est formée par la première couche conductrice (5) et la seconde couche conductrice (9), de telle sorte que les lignes de champ d'un signal transporté dans l'autre de la première ligne de transmission (29) et de la seconde ligne de transmission (13) s'étendent perpendiculairement au plan des couches (5, 9), et éventuellement dans laquelle l'une de la première ligne de transmission (29) et de la seconde ligne de transmission (13) comporte des alimentations (33, 39) pour fournir un signal vers et depuis l'une de la première ligne de transmission (29) et de la seconde ligne de transmission (13), dans lequel les alimentations (33, 39) sont formées dans l'autre de la première couche conductrice (5) et de la seconde couche conductrice (9).

12. Dispositif (1) selon la revendication 11, dans lequel le dispositif (1) comporte une ou plusieurs connexions électriques s'étendant à travers la couche diélectrique (7) entre au moins une région de la première couche conductrice (5) et au moins une région de la seconde couche conductrice (9), de telle sorte que la première couche conductrice (5) et la seconde couche conductrice (9) peuvent être contactées depuis le même côté du dispositif (1).

13. Dispositif (1) pour coupler et/ou diviser une pluralité de signaux, le dispositif (1) comprenant :

une ou plusieurs premières lignes de transmission (29), chacune étant conçue pour transporter un ou plusieurs premiers signaux ; et
une pluralité de secondes lignes de transmission (13), chacune étant conçue pour transporter un ou plusieurs seconds signaux ;
dans lequel chacune de la ou des premières lignes de transmission (29) croise chacune de la pluralité de secondes lignes de transmission (13), à son tour, dans une région de chevauchement respective (43), où l'une des lignes de

transmission (29, 13) recouvre l'autre ;
 dans lequel la ou les premières lignes de transmission (29) sont des guides d'ondes coplanaires, et la ou les secondes lignes de transmission (13) sont des microrubans, ou la ou les premières lignes de transmission (29) sont des microrubans, et la ou les secondes lignes de transmission (13) sont des guides d'ondes coplanaires ; et
 dans lequel dans chaque région de chevauchement (43), la première ligne de transmission (29) et la seconde ligne de transmission (13) s'étendent parallèlement ou sensiblement parallèlement l'une à l'autre lorsqu'elles se croisent, de telle sorte qu'une première partie de la puissance d'un premier signal transporté sur la première ligne de transmission (29) est transférée à un chemin optique de sortie de chaque seconde ligne de transmission (13) et une seconde partie de la puissance du premier signal transporté sur la première ligne de transmission (29) est fournie à une région de chevauchement adjacente (43) sur la première ligne de transmission (29).

14. Dispositif (1) selon la revendication 13, dans lequel une longueur sur laquelle la première ligne de transmission (29) et la seconde ligne de transmission (13) s'étendent parallèlement ou sensiblement parallèlement l'une à l'autre est conçue pour commander la partie prédéterminée, éventuellement dans lequel la longueur des régions de chevauchement ultérieures (43) augmente le long de chaque première ligne de transmission (29), de telle sorte que la quantité de puissance transférée à chaque seconde ligne de transmission (13) est la même au niveau de chaque région de chevauchement (43).
15. Dispositif (1) selon la revendication 13 ou la revendication 14, dans lequel chaque région de chevauchement (43) est conçue de telle sorte que la partie de la puissance du premier signal transférée à chaque seconde ligne de transmission (13) est combinée avec au moins une partie de la puissance d'un second signal transporté sur chaque seconde ligne de transmission (13), sur un chemin optique de sortie de chaque seconde ligne de transmission (13).

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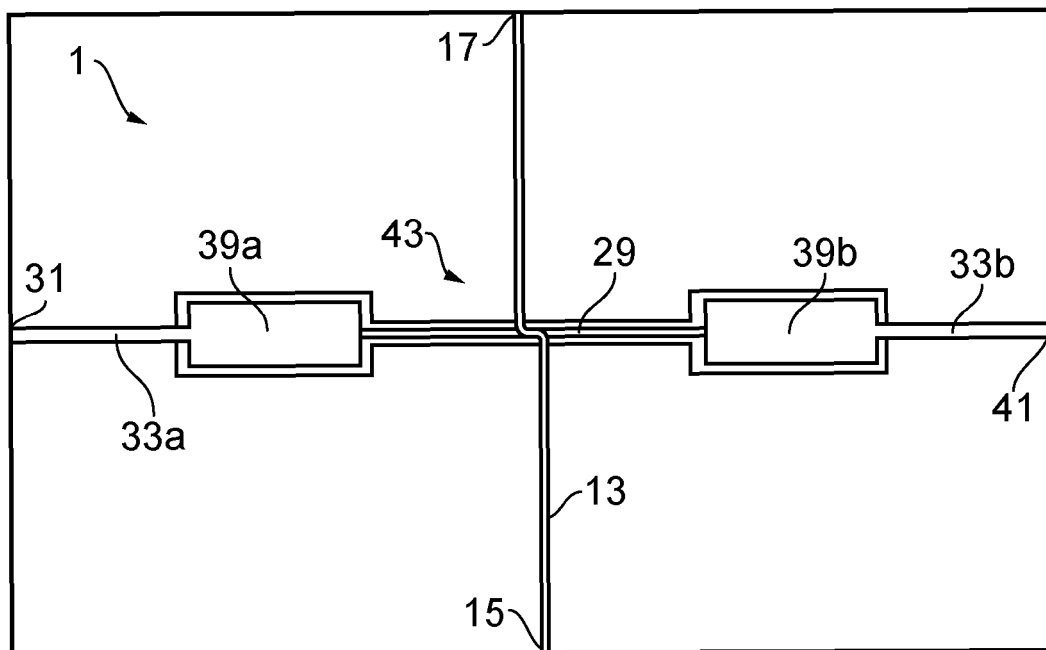


FIG. 1A

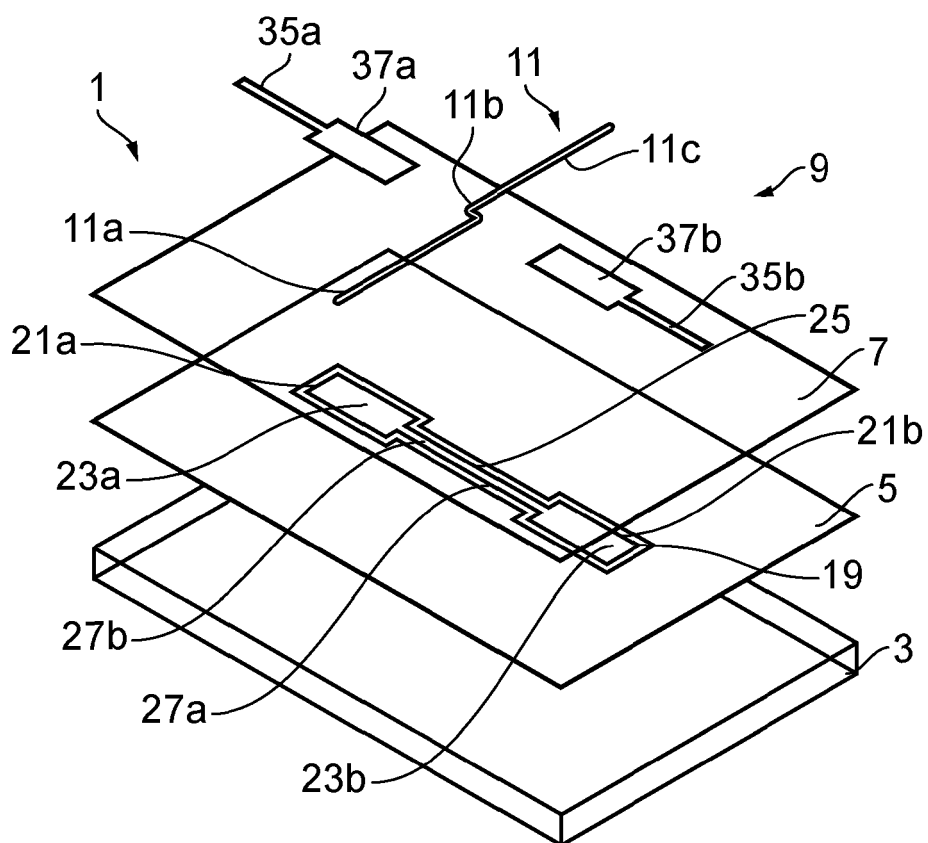


FIG. 1B

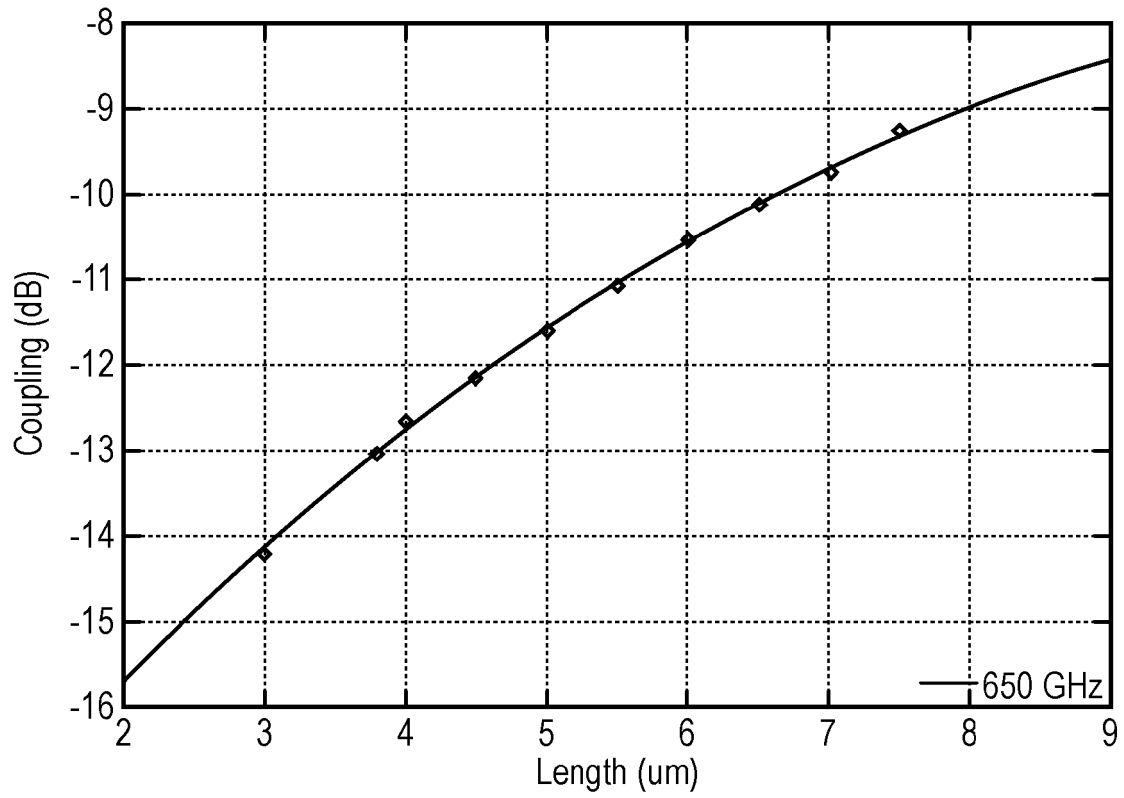


FIG. 2A

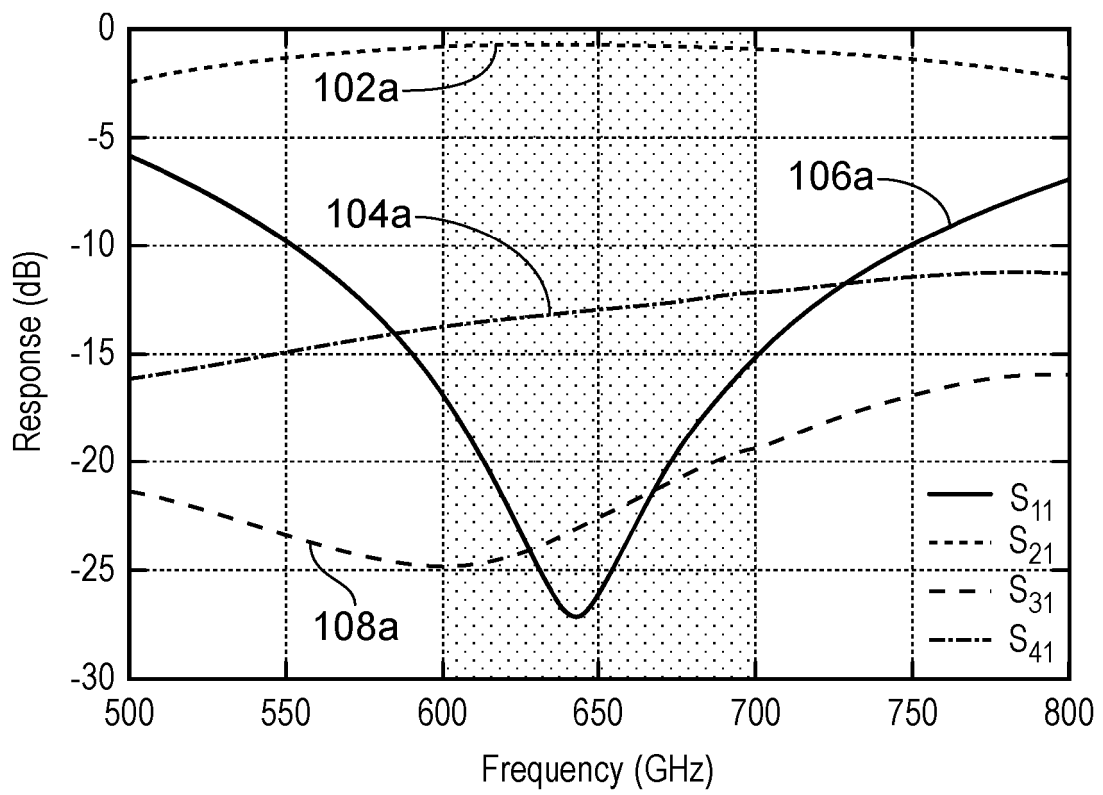


FIG. 2B

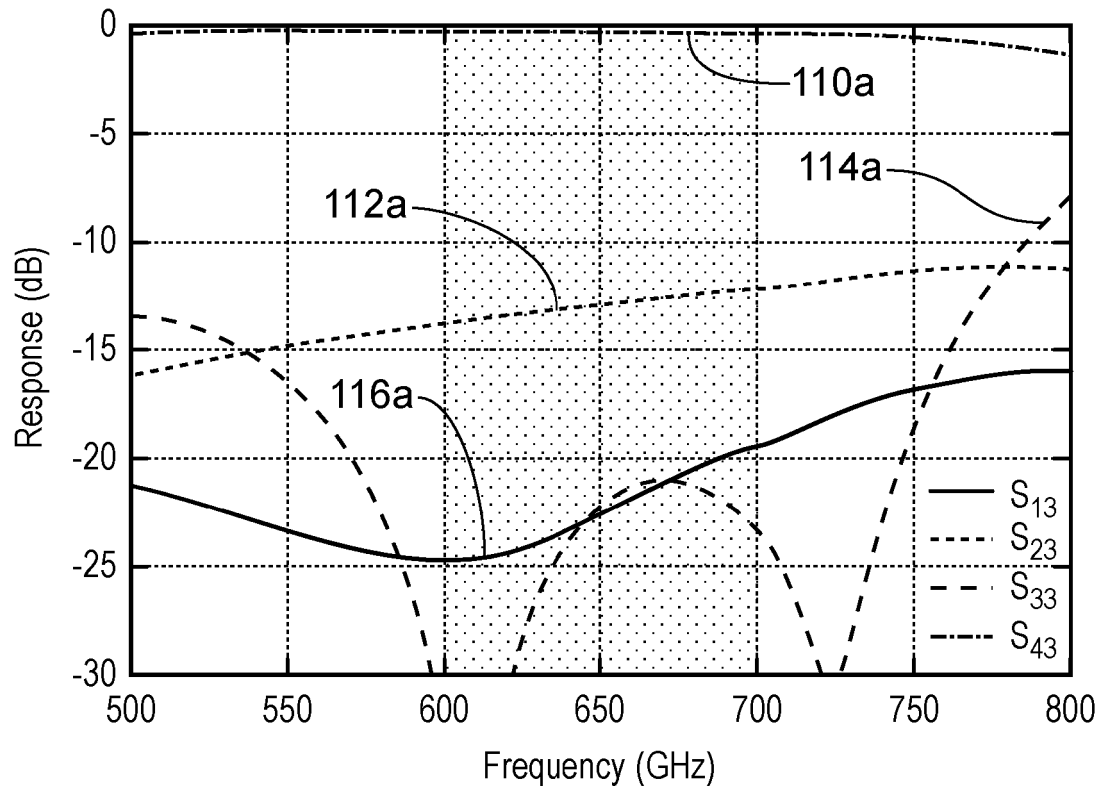


FIG. 2C

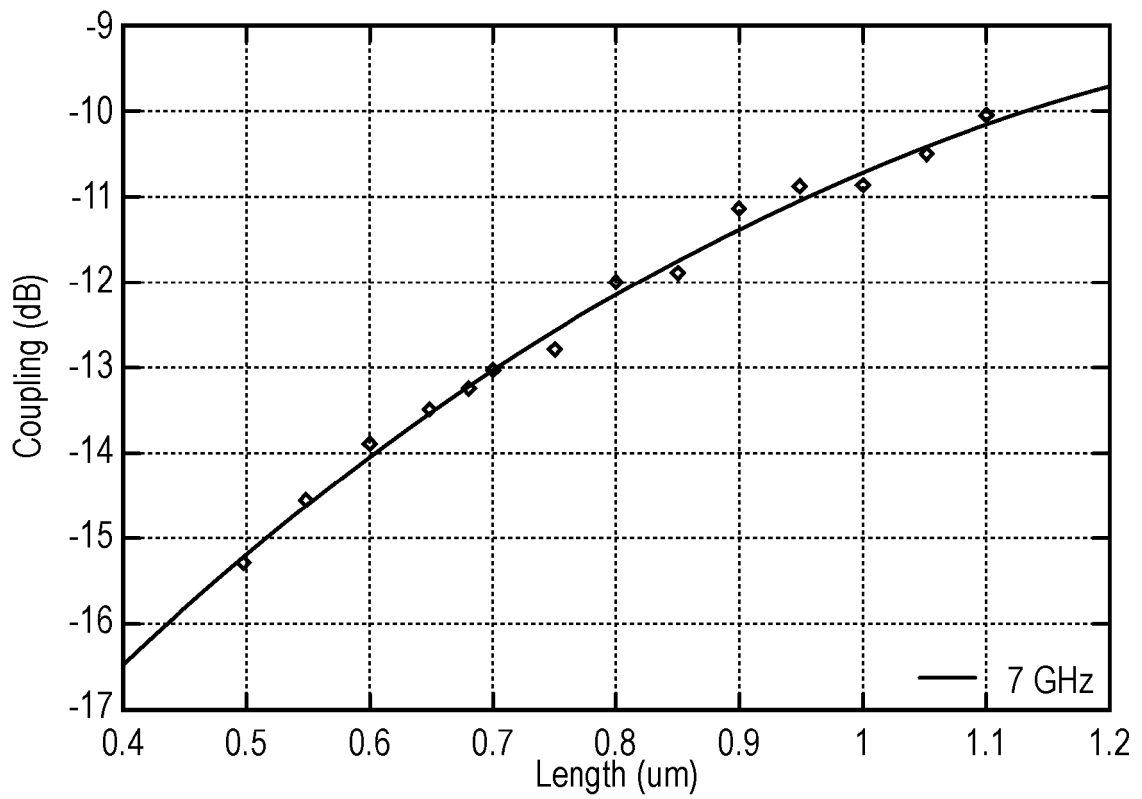


FIG. 3A

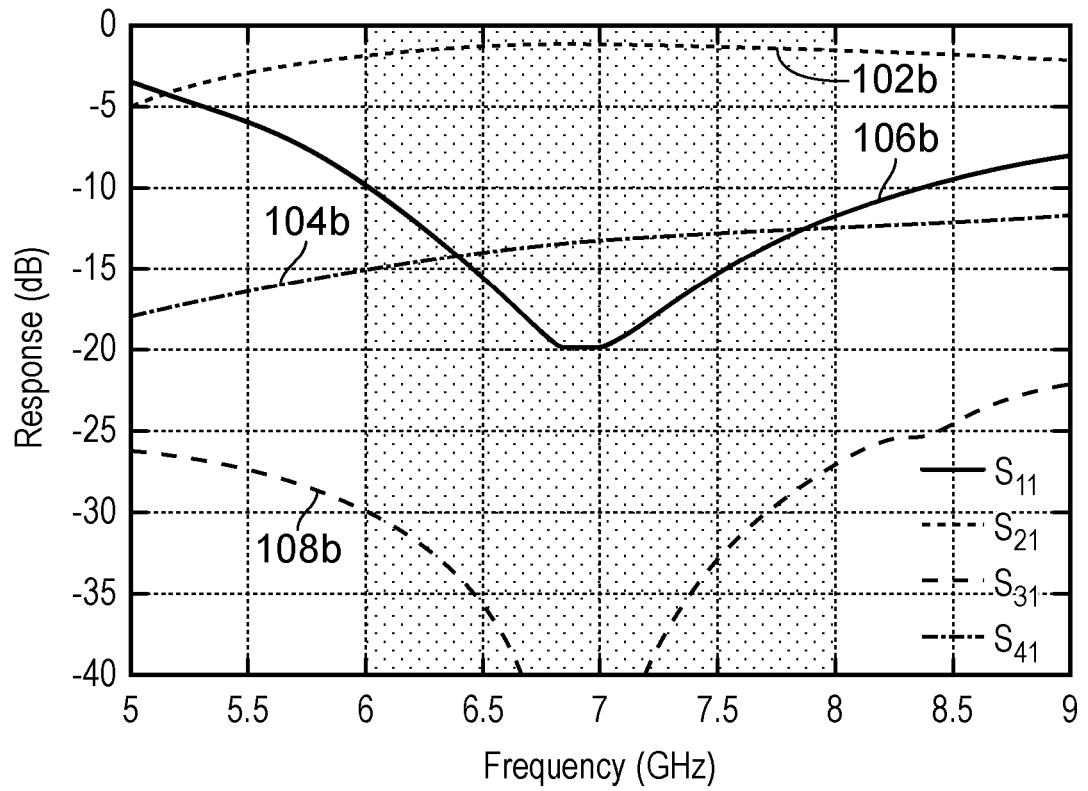


FIG. 3B

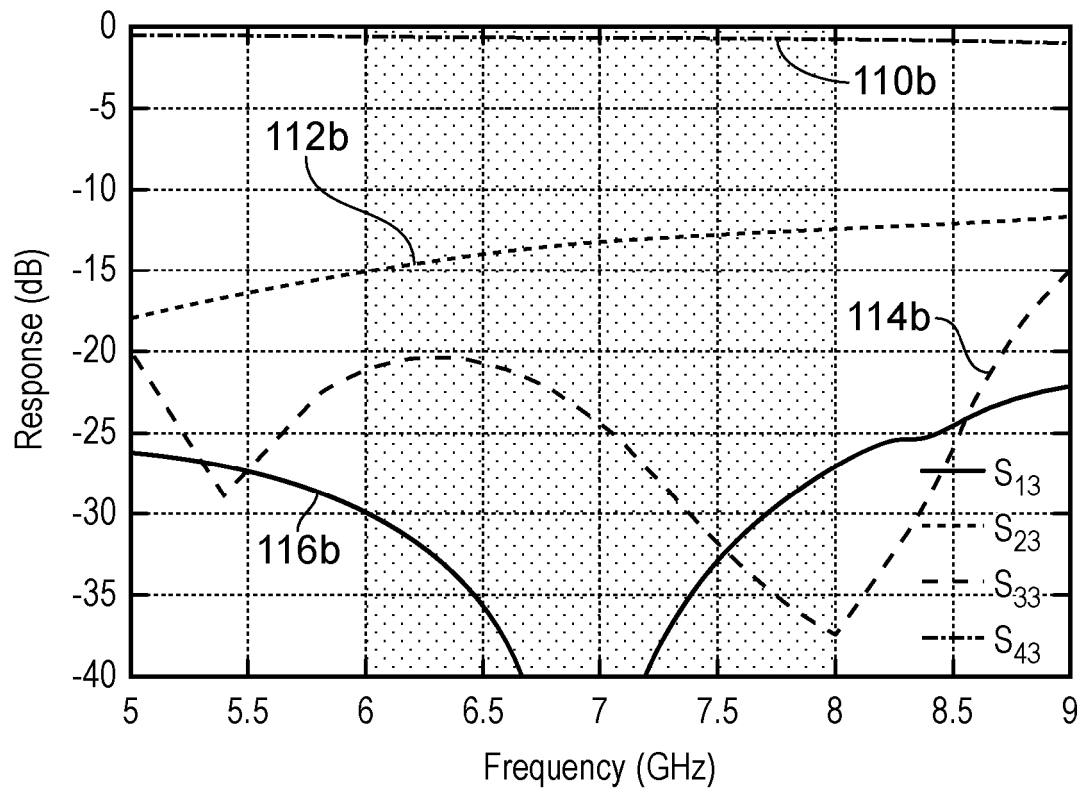


FIG. 3C

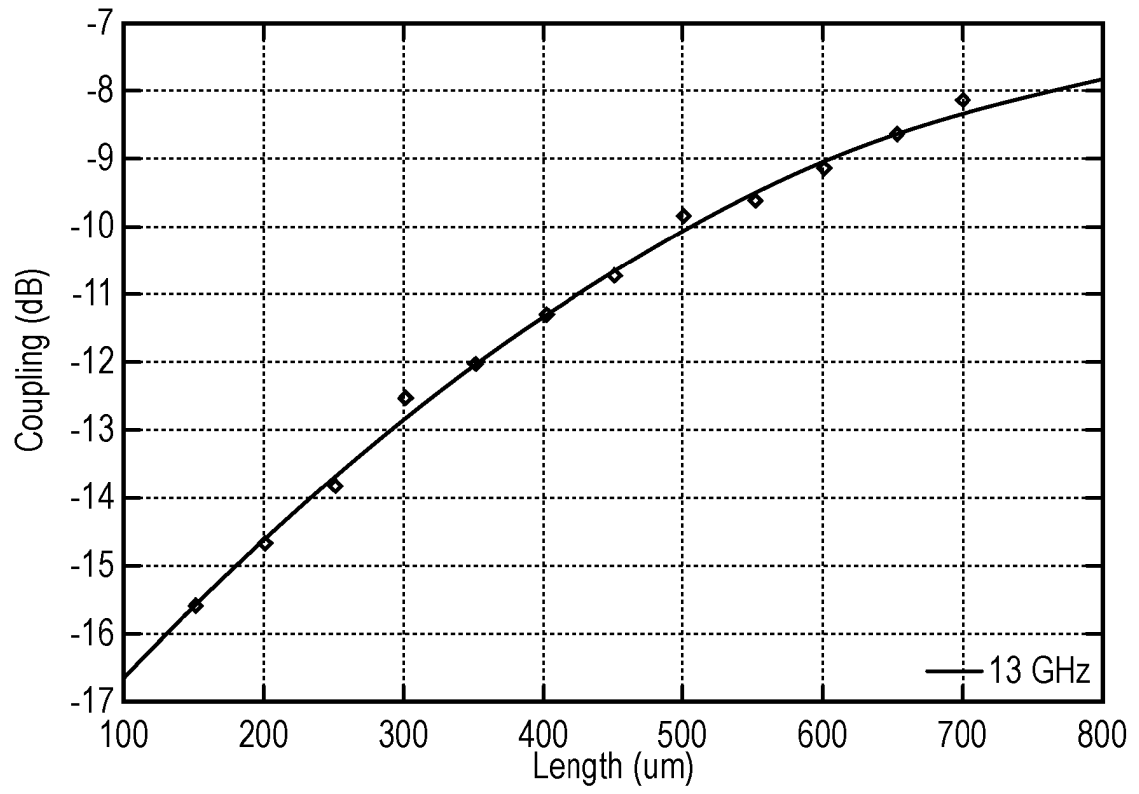


FIG. 4A

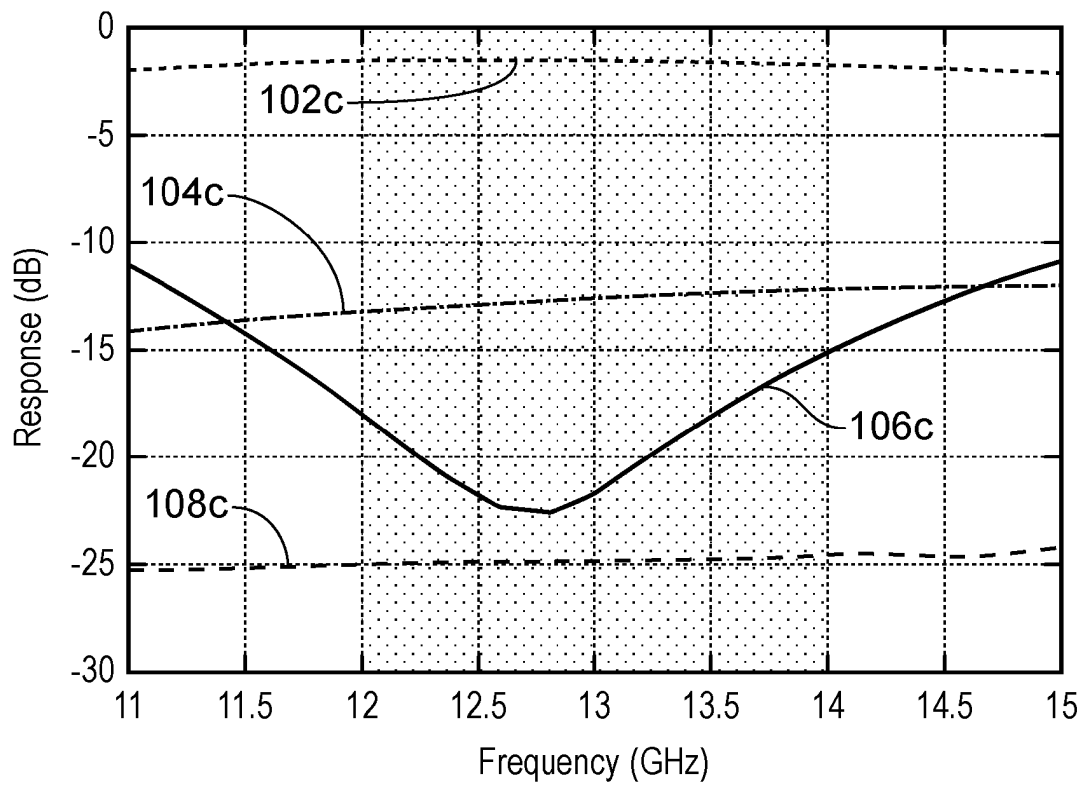


FIG. 4B

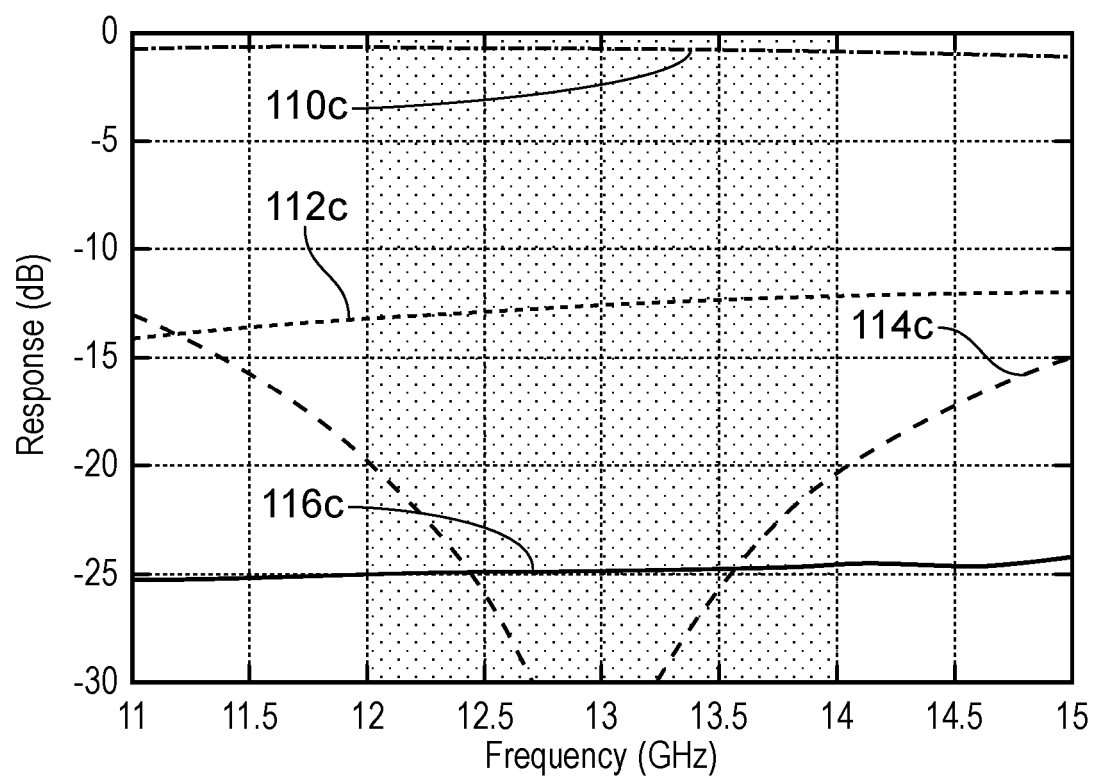


FIG. 4C

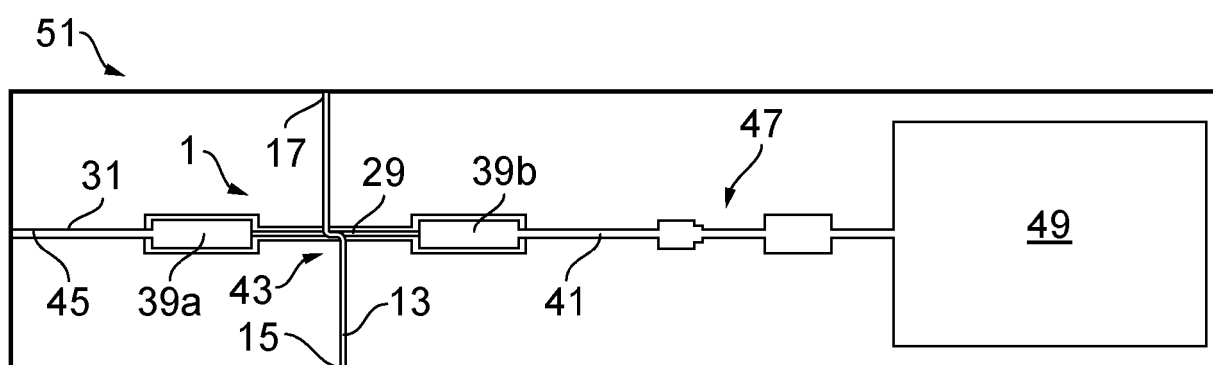


FIG. 5

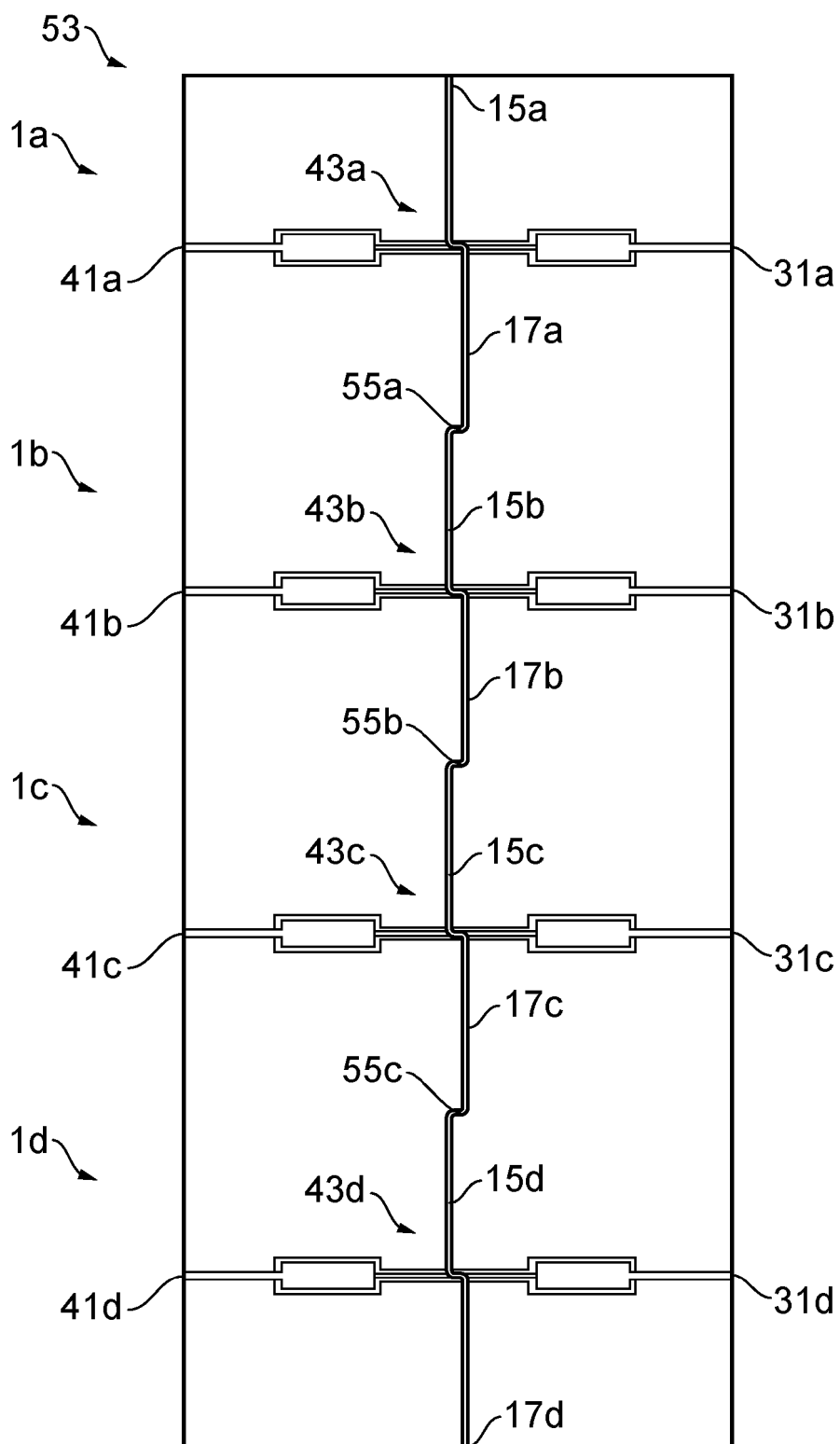


FIG. 6A

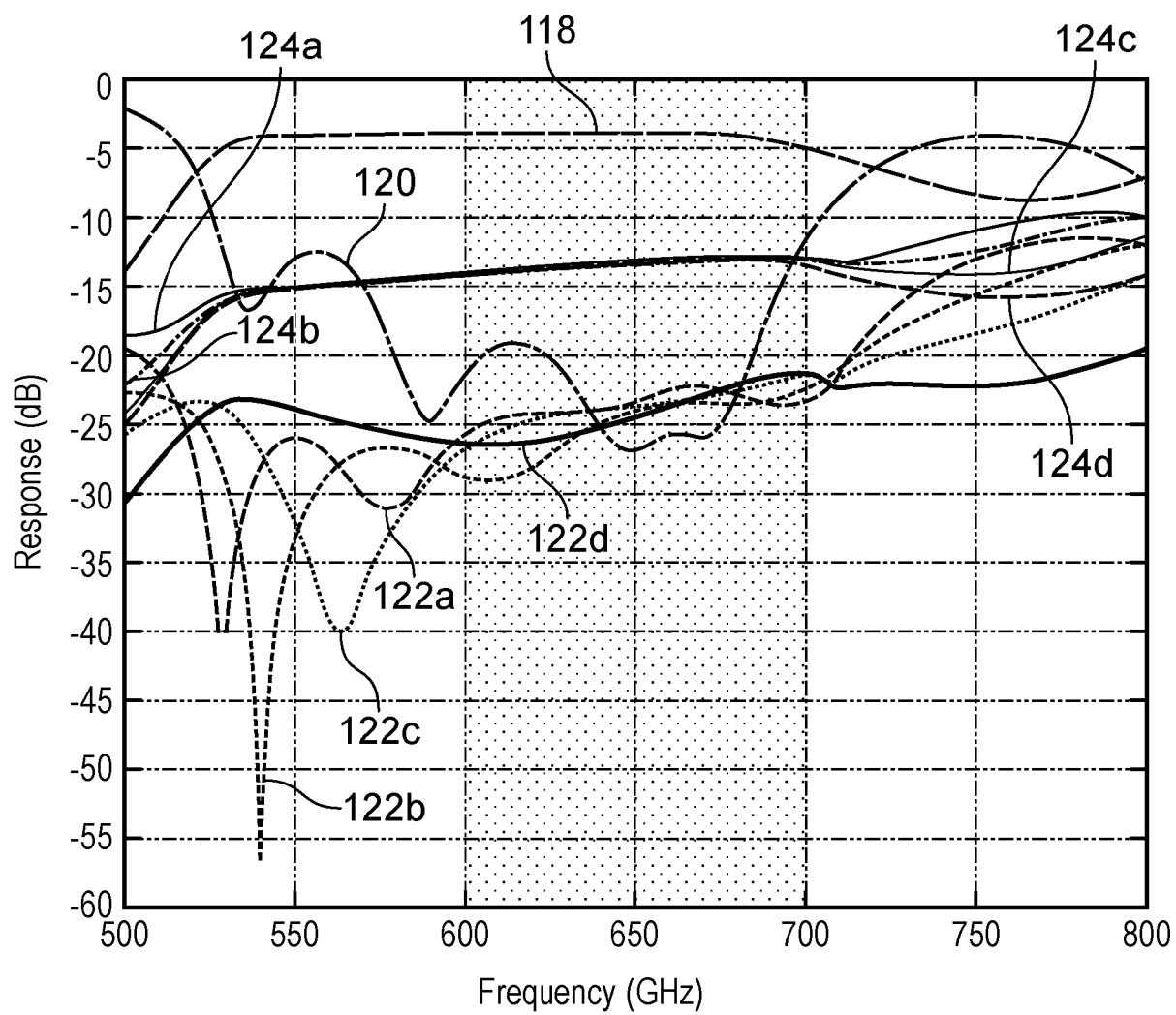


FIG. 6B

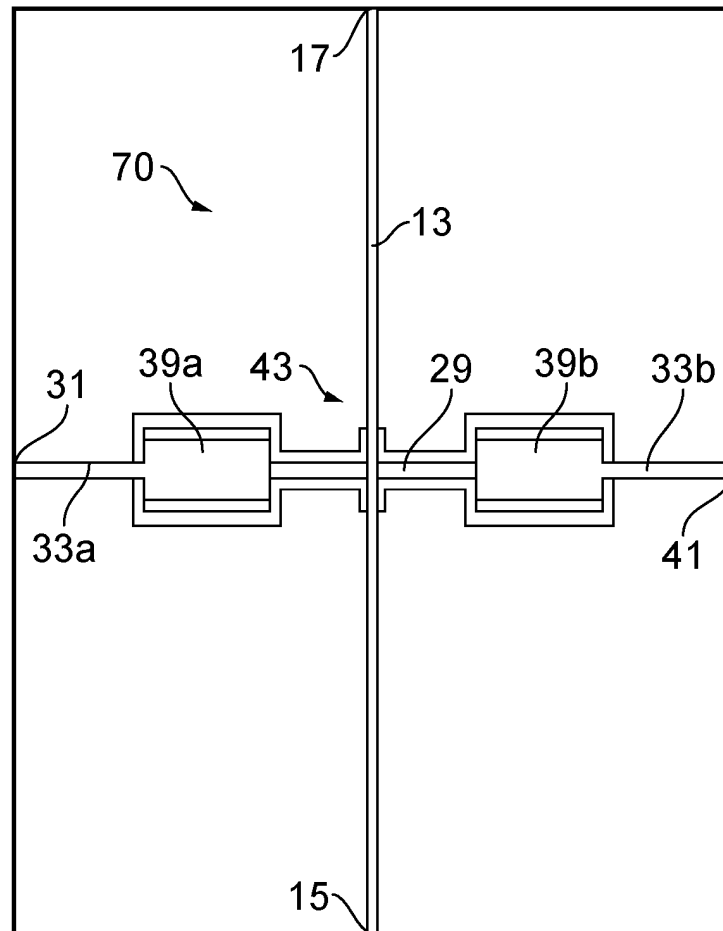


FIG. 7A

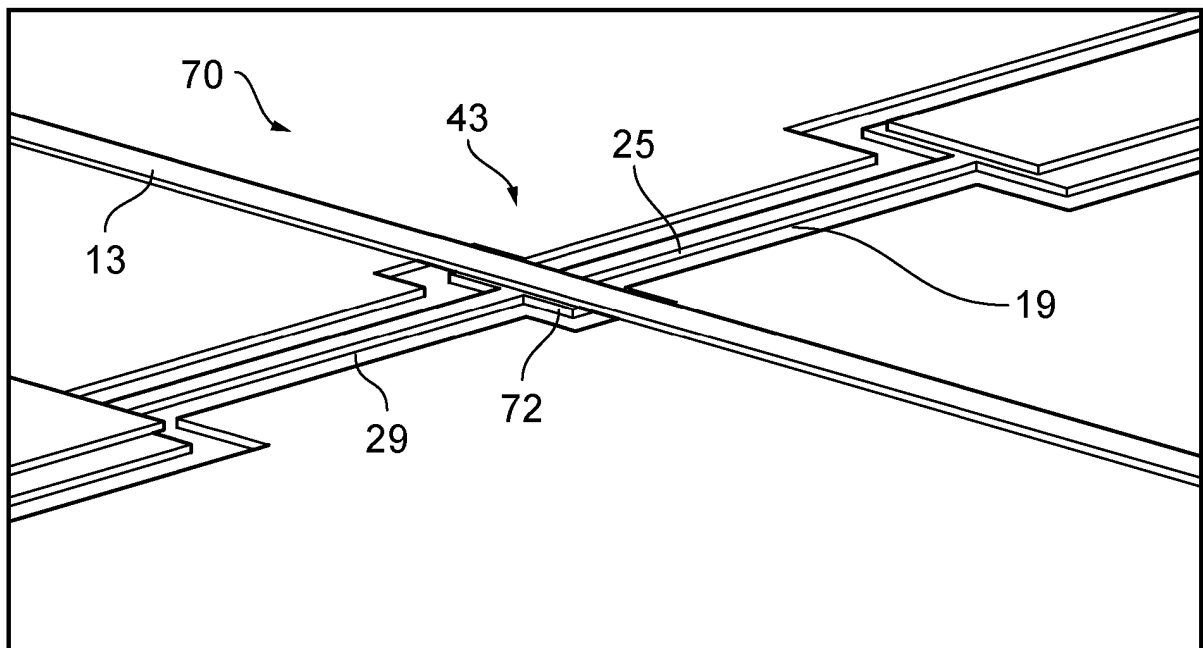


FIG. 7B

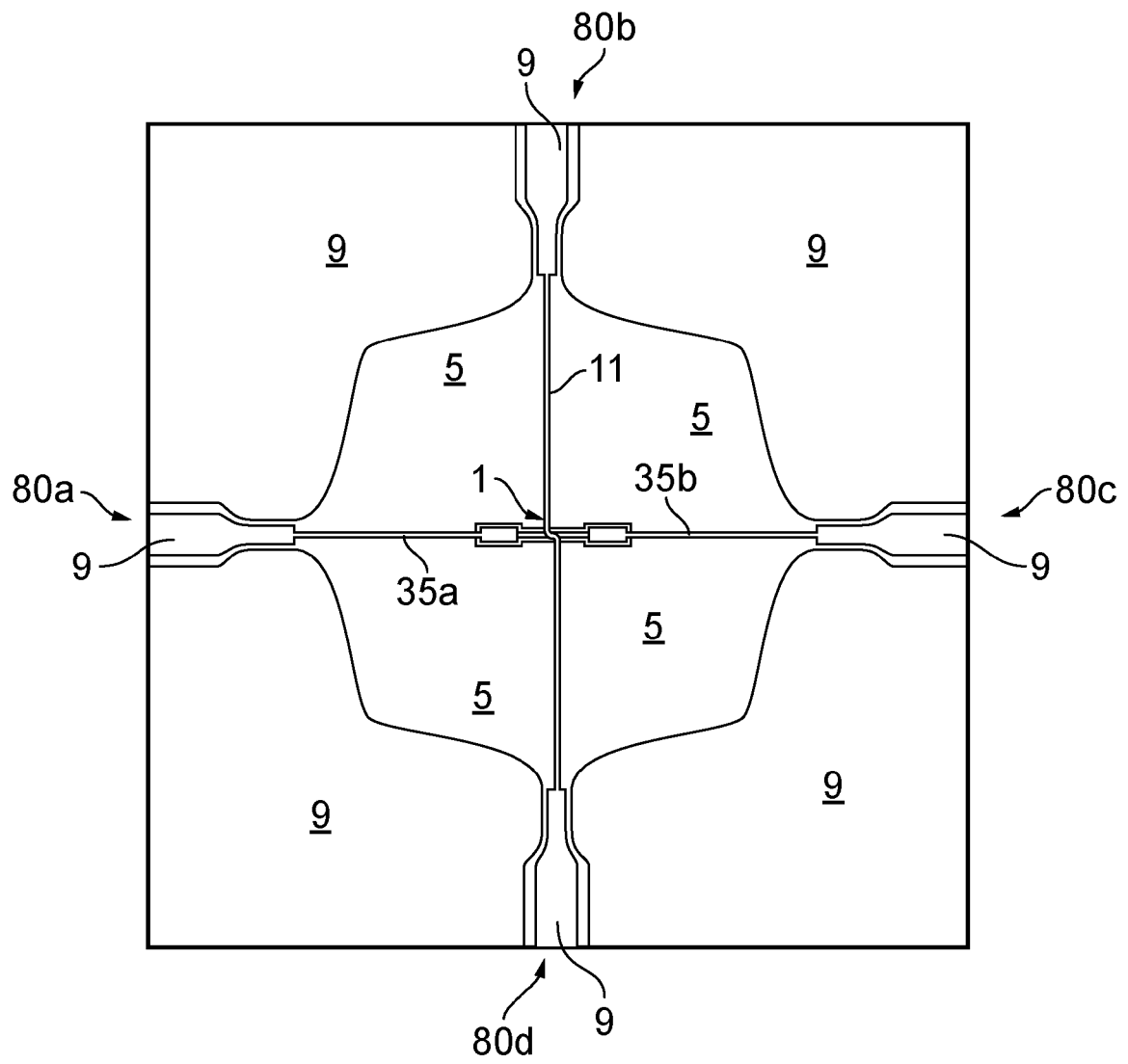


FIG. 8A

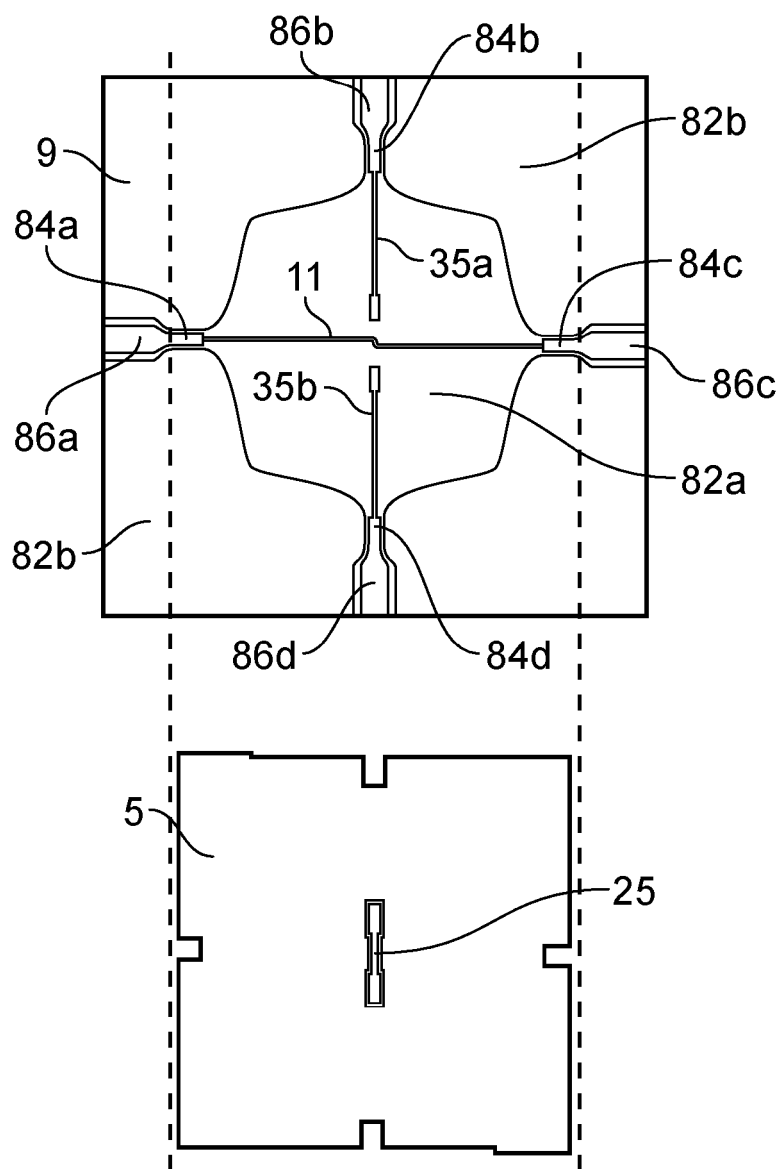


FIG. 8B

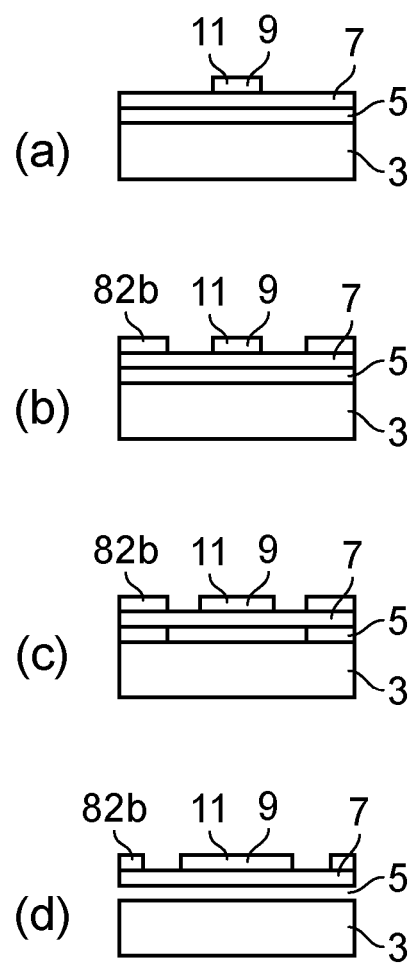


FIG. 8C

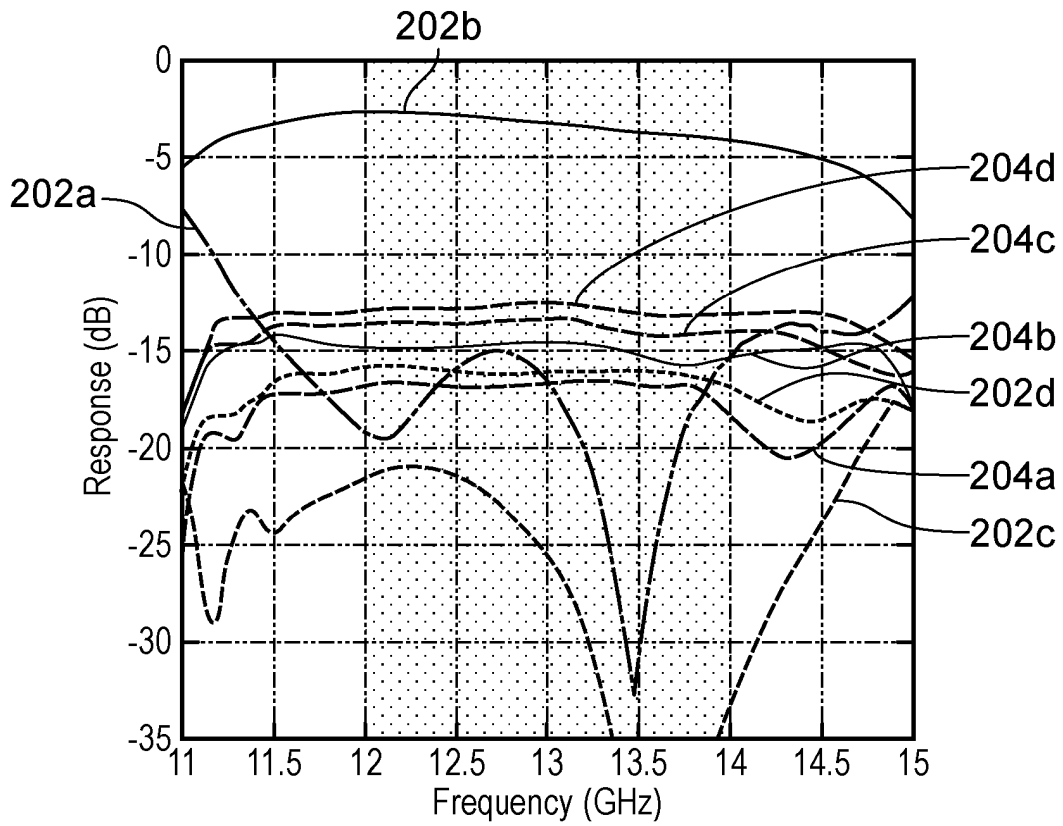


FIG. 9A

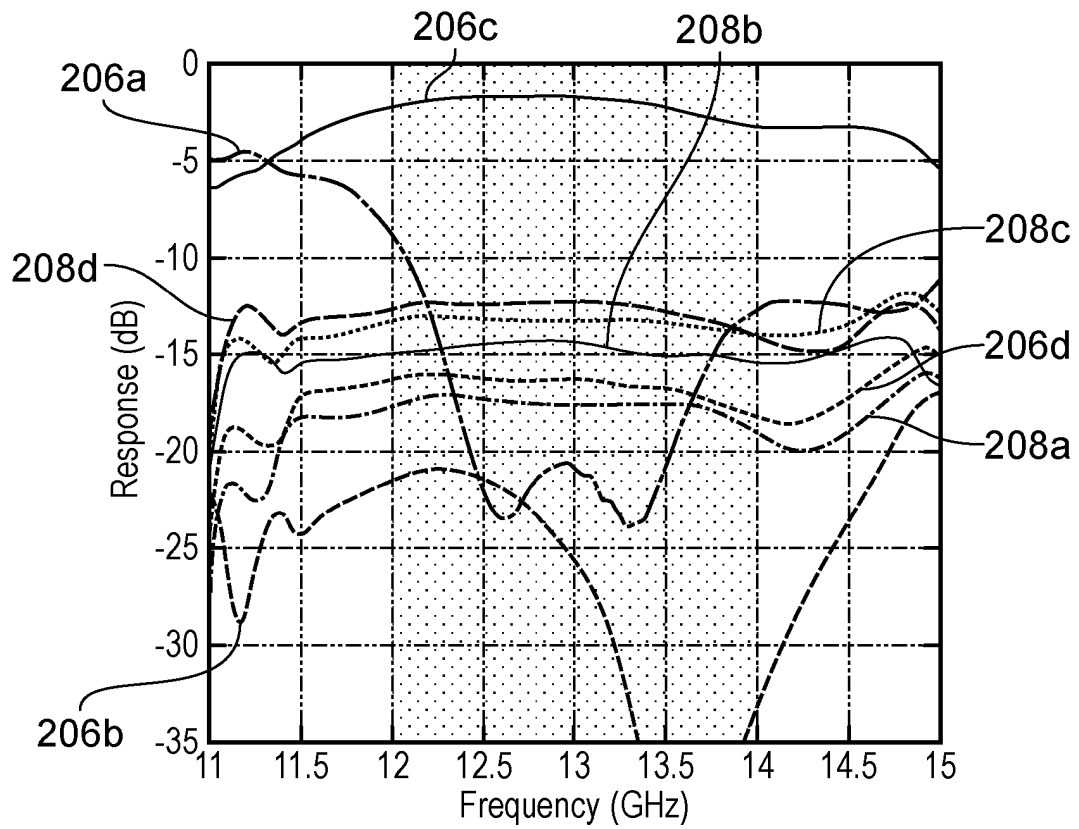


FIG. 9B

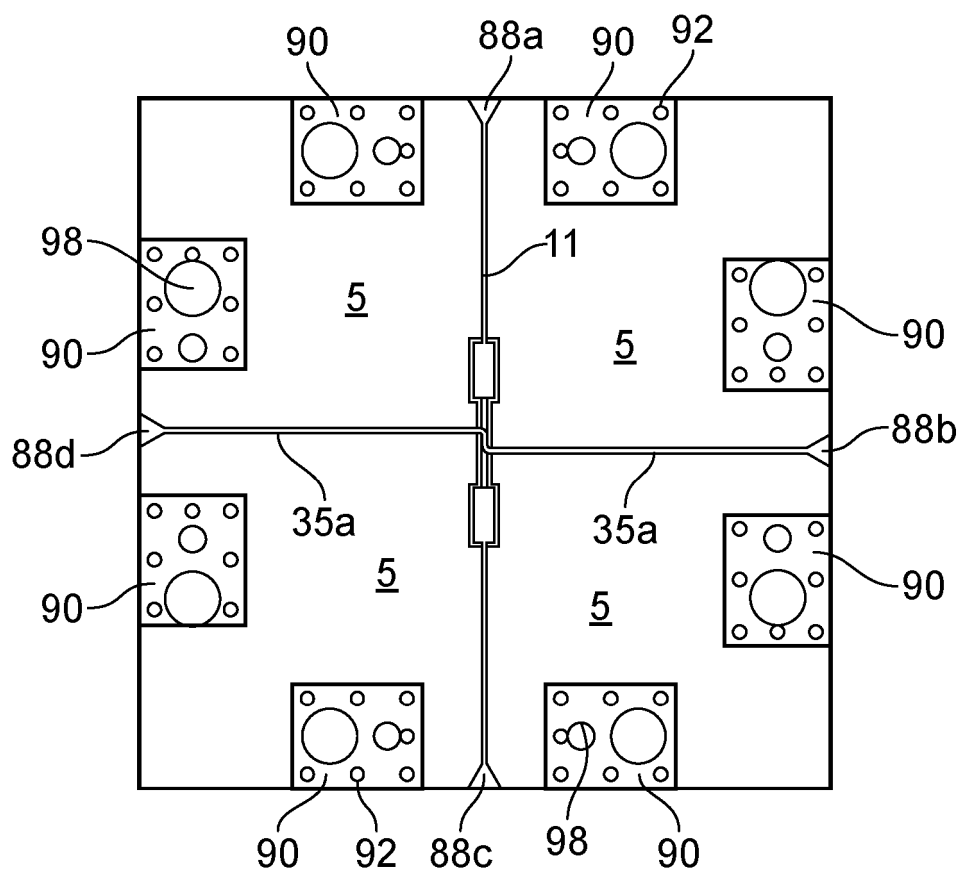


FIG. 10

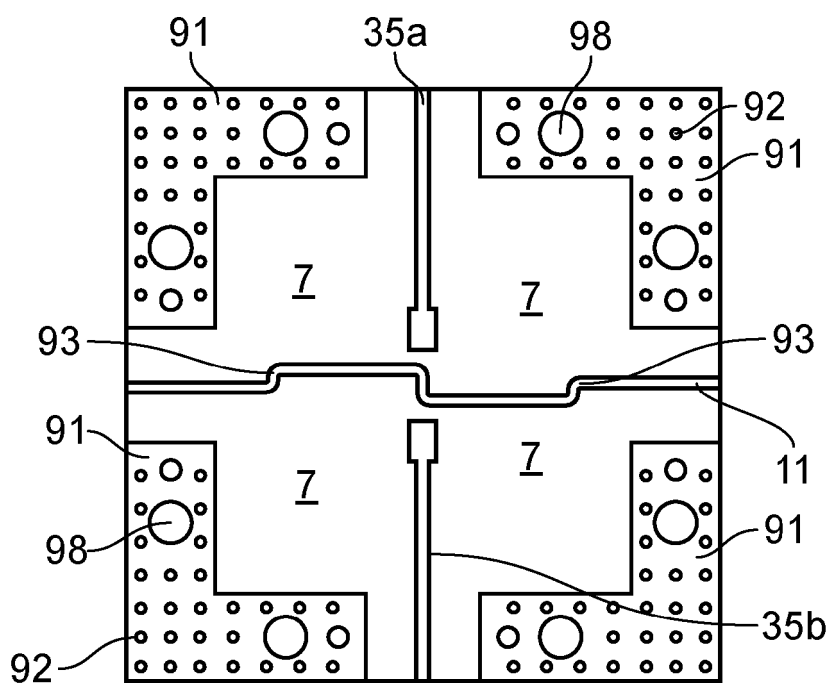


FIG. 11B

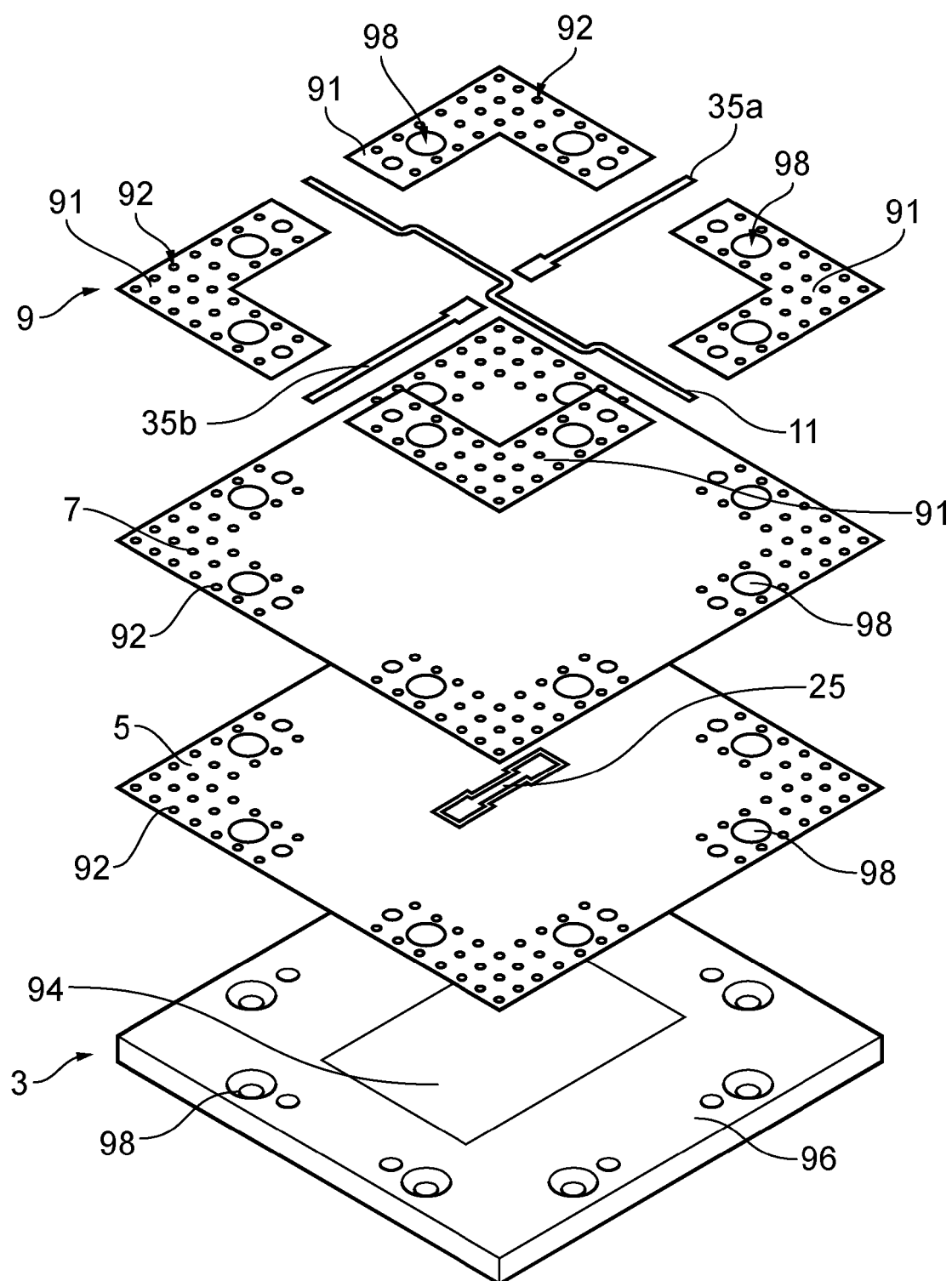
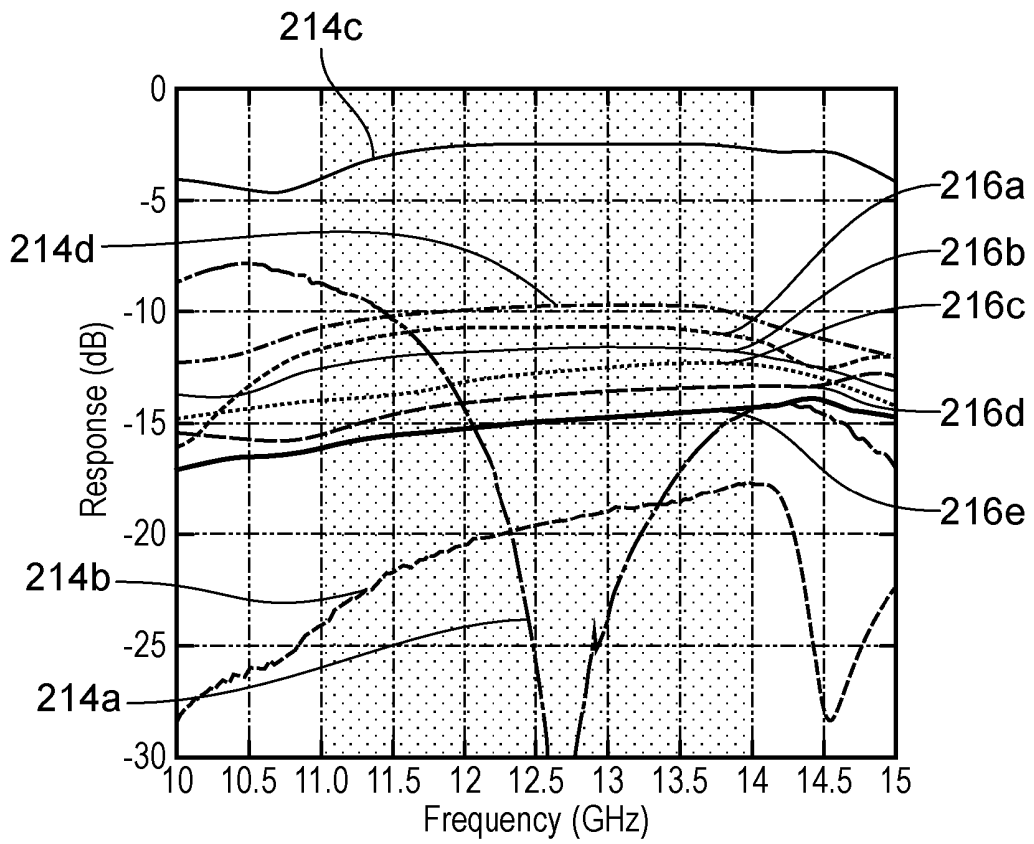
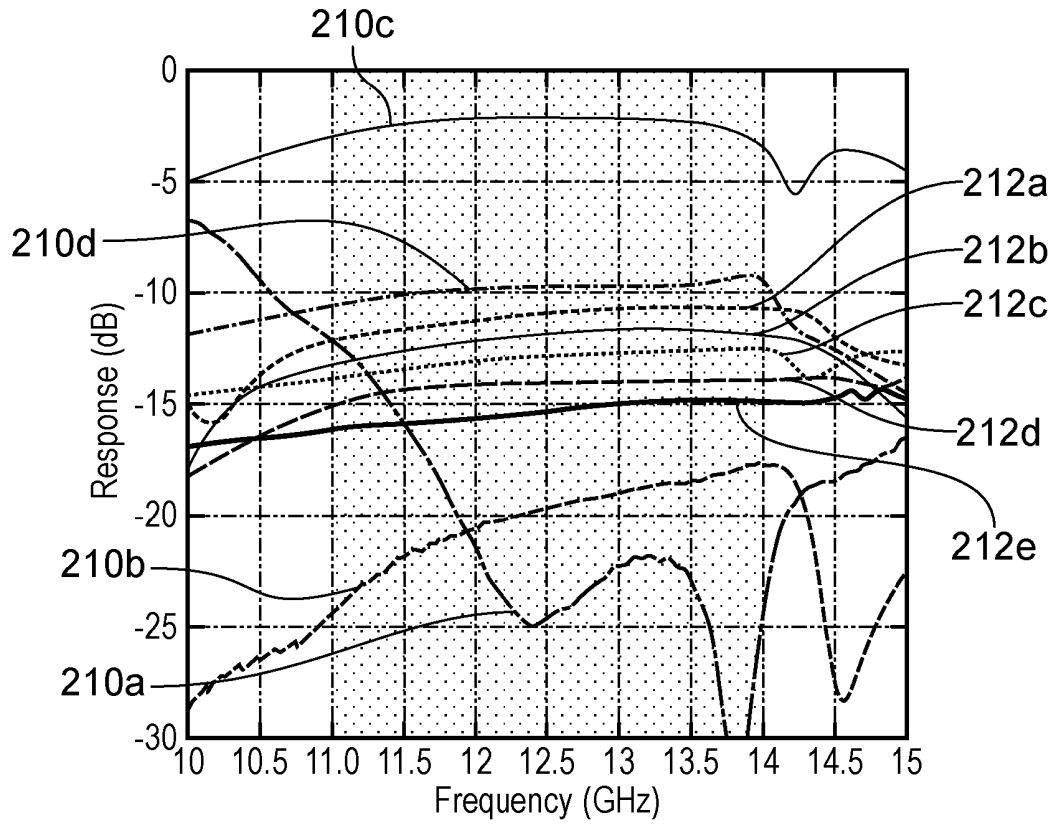


FIG. 11A



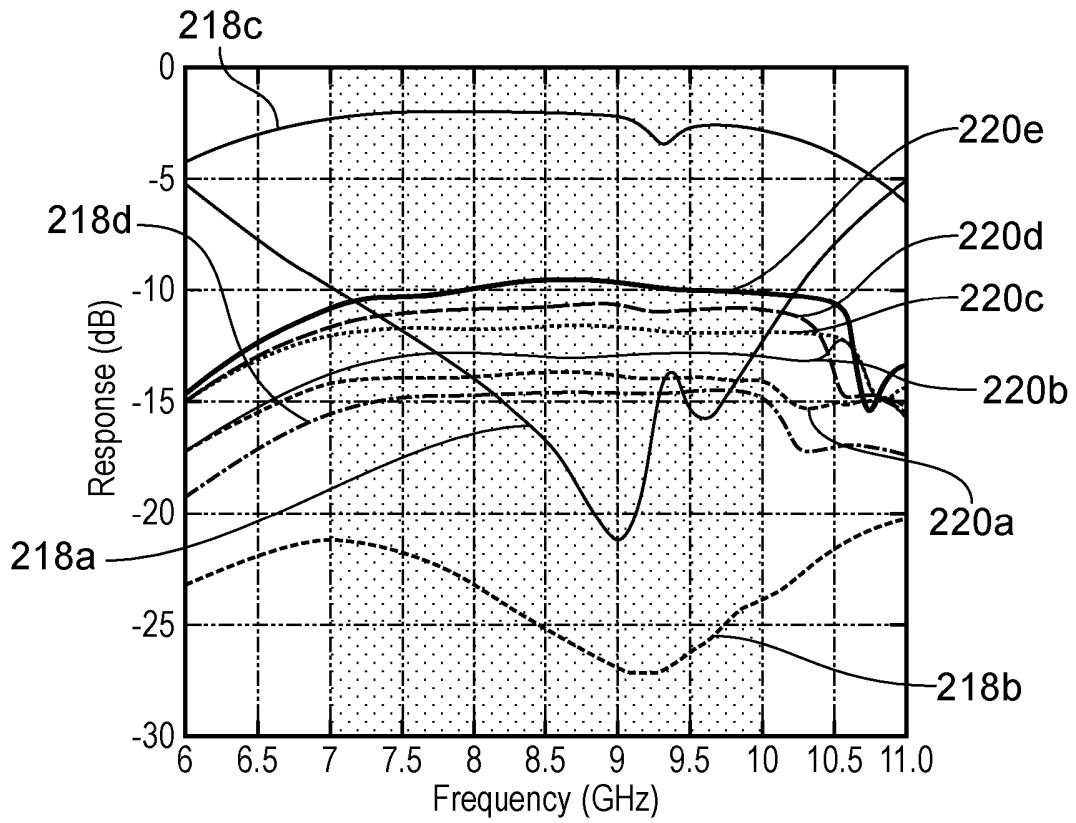


FIG. 12C

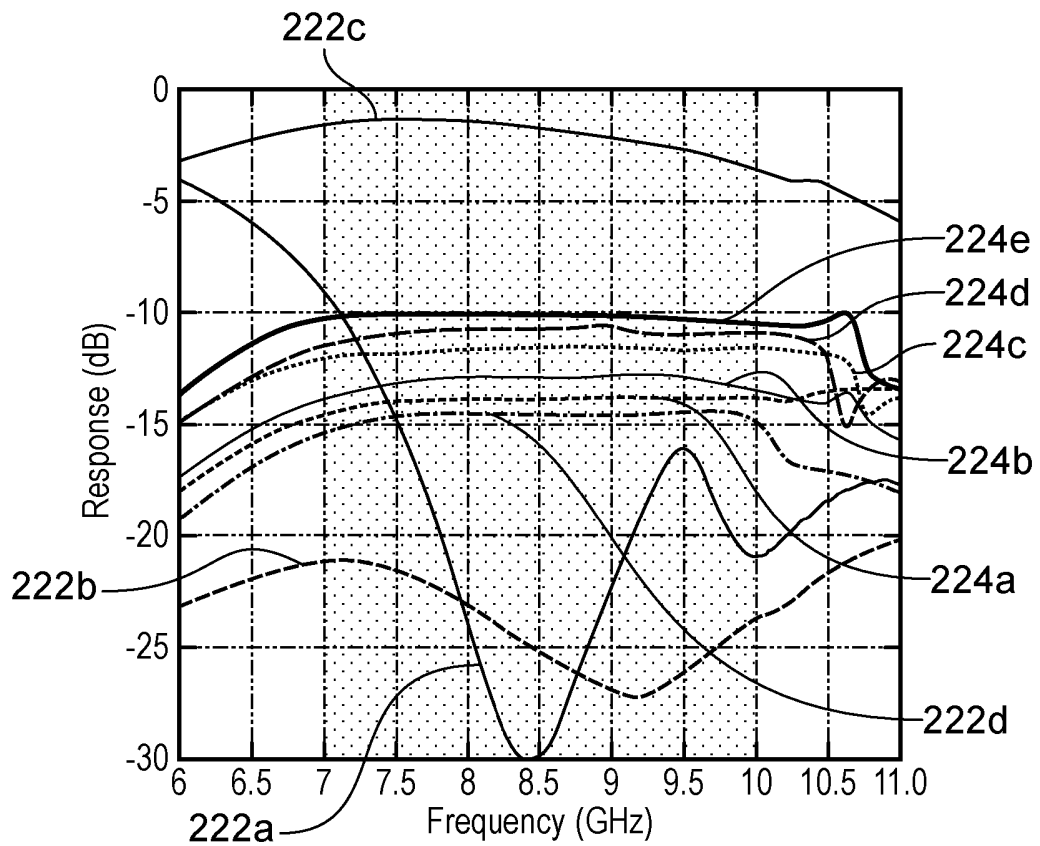


FIG. 12D

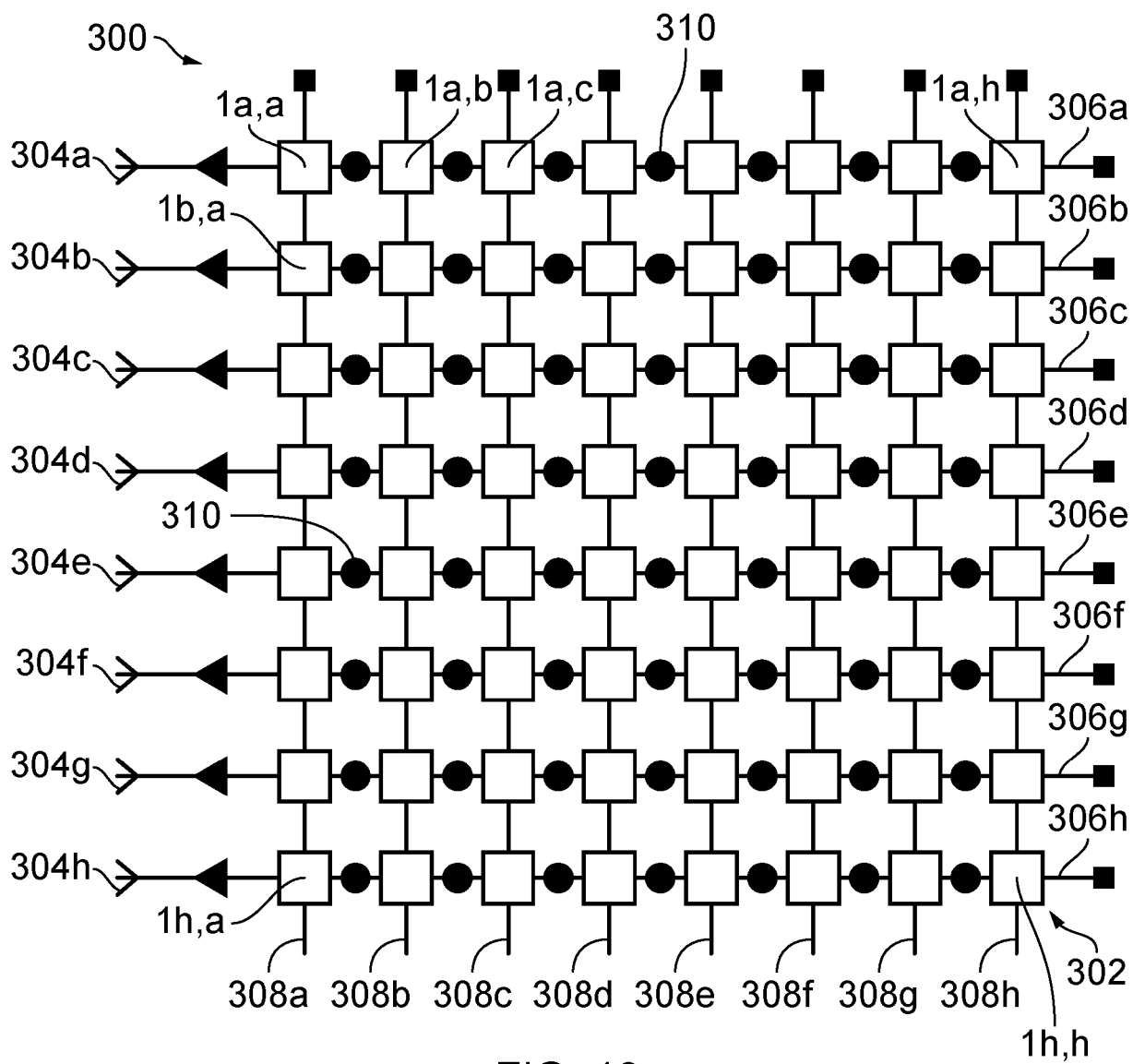


FIG. 13

REFERENCES CITED IN THE DESCRIPTION

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