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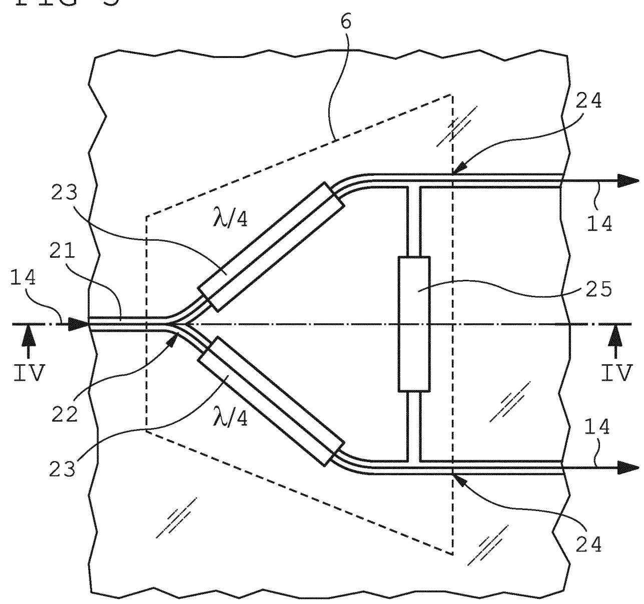
(54) RADIO FREQUENCY DEVICE

(57) A radio frequency device comprises a first substrate layer, whereby a first surface of the first substrate layer faces a second surface of the first substrate layer or of a second substrate layer. The radio frequency device further comprises at least one radio frequency signal power divider element (6) that is arranged on the second surface of the first or the second substrate layer or between the first and second substrate layer, whereby the power divider element (6) comprises an input line element (21) that branches at a bifurcation (22) into two output line elements (24), whereby the power divider element (6) is arranged to receive the radio frequency signal from the signal input element (2) that is transferred along the transmission path (14) into the input line element (21) of the power divider element (6) and divided into two output signals transmitted along the two output line elements (24), and whereby a resistor element (25) with a predetermined ohmic resistance is arranged between the two output line elements (24) that electroconductively connects the two output line elements (24) resulting in improved matching of the two output line signals.

FIG 3



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Description

Technical Field

[0001] The invention relates to a radio frequency device comprising a first substrate layer, whereby a first surface of the first substrate layer faces a second surface opposite of the first surface on the first surface layer of a second surface on a the second substrate layer arranged at a distance towards the first substrate layer, the radio frequency device further comprising electrically conductive transmission line elements arranged on the first and the second surface that allow for transmission of a radio frequency signal along a transmission path, and with a first coupling element that provides for a radio frequency signal transmission from a signal input element on the first surface on the first substrate layer into the transmission path along the transmission line elements on the second surface of the first or of the second substrate layer.

Background of the invention

[0002] Within many radio frequency devices, a radio frequency signal is transmitted along electrically conductive transmission line elements. Such transmission line elements can be arranged on a surface of a substrate layer. Some of the transmission line elements can also be arranged on the opposite surface of the same substrate layer. In this case a coupling element is required that couples the radio frequency signal from the first surface through the first substrate layer to the second surface on the opposite side of the first substrate layer.

[0003] Sometimes several transmission line elements forming a signal path for a radio frequency signal are arranged on two or more surfaces of at least two substrate layers that are itself arranged at a distance towards each other. Some of the transmission line elements are arranged on the opposing surfaces of the two substrate layers. The transmission line elements enable the transmission of a radio frequency signal along a transmission direction that is defined by the design, the arrangement and the orientation of the corresponding transmission line elements at the opposing surfaces, whereby the transmission direction is parallel to at least one of the opposing surfaces of the two substrate layers. If both surfaces of the two substrate layers are arranged parallel towards each other, the transmission direction is parallel to both opposing surfaces.

[0004] For many devices the transmission line elements can be manufactured by well-known methods like e.g. surface micromachining or bulk micromachining including deposition methods, lithographic methods or etching methods. It is also possible to generate the transmission line elements by printing methods.

[0005] Many radio frequency devices require two electrodes forming transmission line elements at a distance towards each other, like e.g. microstrip lines. If the transmission line elements are arranged on two surfaces whereby each surface is one surface of a respective substrate layer, the surfaces of the two substrate layers with the respective transmission line elements must be arranged at a distance towards each other in order to avoid an unwanted electroconductive connection between the two surfaces and the respective transmission line elements. Usually, a solid dielectric material layer is arranged between the two substrate layers with the respective transmission line elements, resulting e.g. in a microstrip line arrangement of the respective transmission line elements. However, for some applications the volume between the two substrate layers is at least partially filled by a fluidic material like air or a liquid crystal material, whereby the mechanic characteristics of such a fluidic material cannot provide for or guarantee the required distance. For such devices, usually one or more spacer elements are arranged between the two substrate layers that define and provide for the distance between the two substrate layers. The volume between the two substrate layers that is not filled by spacer elements can be used for and filled by the fluidic material.

[0006] For many applications a radio frequency signal will be transmitted along a transmission path that begins or ends on the same surface of a substrate layer, or on the outside of the two substrate layers if the transmission line elements are arranged on two surfaces of two substrate layers. Thus, the radio frequency signal must be fed at some point through the first substrate layer to the transmission line elements on the two surfaces. If at least one substrate layer easily allows for manufacturing an opening into the substrate layer and for inserting an electroconductive connection element like e.g. a wire or a pin from the outside through the opening, this electroconductive connection element can be used for providing an electrically conductive crossover between transmission line elements on the two surfaces that are placed next to or around the opening.

[0007] However, for some devices the one or two substrate layers are made from a material like e.g. glass that does not easily allow for openings through the substrate layer. For such substrate layers the electrically conductive crossover should not require openings within at least one of the substrate layers. Furthermore, if a fluidic dielectric material is used to fill the volume adjacent to the first substrate layer or between the two substrate layers, such an opening may promote or even create unwanted leakage of the fluidic material through the opening, resulting in the need for additional sealings that protect the opening.

[0008] In order to transmit the radio frequency signal to the transmission line elements inside of the two substrate layers, coupling elements can be used that do not require an opening in at least one of the substrate layers, but that make use of the transmission properties of a radio frequency signal over coupling electrode elements that are spaced at a distance from each other, e.g. that are separated by a substrate layer. By adapting and matching the shape, the size and the orientation of corresponding coupling electrode elements the radio frequency signal will be transmitted through the substrate layer and over the distance between the corresponding coupling electrode elements before being further transmitted along the transmission line elements inside of the two substrate layers. However, such a signal coupling usually results in a loss of signal intensity for each coupling that must be performed. Furthermore, the required footprint of the coupling electrode elements is quite large compared to the space requirement of the transmission line elements inside of the two substrate layers.

[0009] For some radio frequency devices like e.g. phased array antennas that operate with radio frequency signals, a large number of antenna elements, e.g. several hundred or several thousand antenna elements are arranged within a small area. Each antenna element requires at least one phase shifting element and connecting lines formed by transmission lines that connect the antenna element with the respective phase shifting element and with a feeding network. In order to allow for a compact phased array antenna device, it is considered favorable to make use of transmission line elements on two substrate layers that are arranged at a distance towards each other, whereby transmission line elements for connection lines or for phase shifting elements are arranged at two surfaces of the two substrate layers that face towards each other. The feeding network and the radiation elements of the antenna elements are usually arranged outside of the two substrate layers. Thus, the transmission path of a radio frequency signal begins with the feeding network outside of the two substrate layers and ends at the radiation elements that are also outside of the two substrate layers. In between the signal input and the signal output of the phased array antenna device, the radio frequency signal must be divided many times, modified and distributed towards the corresponding antenna elements. The transmission path of each part of the radio frequency signal also includes connecting lines and phase shifting elements inside of the two substrate layers. Hence, at least two coupling elements are required along the transmission path for inserting the radio frequency signal into the inside of the two substrate layers and for extracting the radio frequency signal to the outside again. Of course, it is the same for a radio frequency signal that is received by the large number of antenna elements and transmitted along the corresponding transmission paths towards the feeding network to be combined to an output signal information that is received by the phased array antenna device.

[0010] With respect to space requirements and to signal losses, it is considered advantageous to make use of the transmission line elements inside of the two substrate layers as much as possible. In case that the single input signal is divided up into the many output signals that are transmitted along a corresponding transmission path to the respective antenna elements and subsequently emitted by the antenna elements, for each antenna element at least two corresponding coupling elements are required. However, each coupling element requires space and a large footprint on at least one of the two substrate layers, which increases the space requirement of the radio frequency device.

[0011] Accordingly, there is a need for a cost-effective and space-saving embodiment of a radio frequency device that allows for the manufacture and arrangement of some transmission line elements at two sides of one substrate layer made of e.g. glass. It is considered an objective of the invention to be able to reduce the manufacturing costs and the space requirements, as well as any signal loss that is related to the propagation of the radio frequency signals along the transmission paths.

Summary of the invention

[0012] The present invention relates to a radio frequency device as described above, whereby at least one radio frequency signal power divider element is arranged on the second surface of the first substrate layer or between the first and second substrate layer, whereby the power divider element comprises an input line element that branches at a bifurcation into at least two output line elements, whereby the power divider element is arranged to receive the radio frequency signal from the signal input element that is transferred along the transmission path into the input line element of the power divider element and divided into at least two output signals transmitted along the at least two output line elements, and whereby a resistor element with a predetermined ohmic resistance is arranged between the at least two output line elements that electroconductively connects the at least two output line elements resulting in improved isolation of the two output line signals. Making use of such power divider elements that are manufactured and arranged on a surface of a substrate layer allows to reduce the number of coupling elements that are required for coupling the radio frequency signal from the outside into the inside of the two substrate layers.

[0013] According to an advantageous aspect of the invention, the power divider element is arranged on the second surface of the respective substrate layer whereby the respective substrate layer is made of glass or a material which is similarly difficult to perforate. The power divider element can be printed or deposited or glued onto the second surface of the respective substrate layer without any need for a perforation or hole through the substrate layer that allows for an electroconductive connection between the first and the second surface at the two sides of the first substrate layer.

[0014] In principle it is possible to only use one coupling element to only once transfer the incoming radio frequency signal from outside one of the two substrate layers to the other side of the first substrate layer, or into the volume between the two substrate layers or from within the two substrate layers to an outside surfaces of one of the two substrate layers, and afterwards to arrange a number of power divider elements on one of the two surface layers and preferably within the space between the two substrate layers to divide the incoming radio frequency signal into as many different transmission paths as there are antenna elements of the phased array antenna. Thus, the number of coupling elements that is required for feeding all antenna elements with a radio frequency signal is reduced to one coupling element that e.g. transfers the incoming radio frequency signal through the first substrate layer and e.g. into the volume between the two substrate layers, and just as many coupling elements as there are antenna elements for coupling the split-up radio frequency signals from the opposite side of the first substrate layer to the other side, or e.g. from inside of the two substrate layers to the radiation elements of the antenna elements that are outside of the two substrate layers.

[0015] It is easily understood that such a power divider element may also be used as a power combining element that combines the radio frequency signals from two or more incoming transmission paths into a single outgoing transmission path of a radio frequency signal. Thus, any reference to a power divider element within the further description and definition of the present invention shall not be regarded as limitation to the use as power dividing elements, but includes the possible use as power combining elements as well.

[0016] It has been found that by adding a resistor that electroconductively connects the two output line elements of the power divider element the isolation between said two output elements can be significantly increased, resulting in reduced standing wave ratio in the network. For larger networks of power divider elements this reduces radio frequency signal losses significantly. A resistor with an ohmic resistance can be easily manufactured by well-known methods like e.g. surface micromachining or bulk micromachining including deposition methods, lithographic methods or etching methods. It is also possible to generate the transmission line elements by printing methods. The resistor can be manufactured at the same time and with the same methods as the adjacent transmission line elements inside the two substrate layers, thus significantly reducing the manufacturing costs and the manufacturing time. It is also possible to manufacture the resistor with a sufficient degree of accuracy that allows for a perfect isolation or at least almost perfect isolation of the at least two output signals at the at least two output line elements, reducing standing waves which in turn reduces the signal losses at the power divider element.

[0017] According to an advantageous aspect of the invention, the second surface is opposite to the first surface on the first substrate layer. Then the coupling element allows for signal transmission through the first substrate layer without the need to arrange for an electroconductive connection through the first substrate layer. According to yet another embodiment of the invention, the radio frequency device comprises a second substrate layer, and the power divider element is arranged on the first or second surface between the first and second substrate layer. Thus, only one coupling element is required for feeding a radio frequency signal from outside the two substrate layers into two or more transmission paths that run between the first and second substrate layer.

[0018] By this, the number of coupling elements that are required for feeding a radio frequency signal to a large number of antenna elements can be significantly reduced.

[0019] According to an embodiment of the present invention, the at least one power divider element is a Gysel type power divider element that achieves isolation between more than two output line elements (24) while maintaining a matched condition on all input and output line elements. Gysel type power divider elements are well known in prior art and allow for the splitting of an incoming radio frequency signal into four or more outgoing transmission paths of the subdivided radio frequency signal.

[0020] In yet another embodiment of the present invention, the power divider element comprises an input line element that branches at a bifurcation into only two output line elements. A power divider element that divides the incoming radio frequency signal into only two output lines is easily manufactured and does not require many resistors with matched resistivity, which reduces the manufacturing costs and the fault-proneness.

[0021] According to an advantageous aspect of the invention, the power divider element is a Wilkinson type power divider element that achieves isolation between the two output line elements while maintaining a matched condition on all input and output line elements. A Wilkinson power divider element uses quarter wave transformers, which can be easily fabricated e.g. as quarter wave lines on printed circuit boards. It is also possible to use other forms of transmission line elements, e.g. lumped circuit elements like inductors and capacitors. The output line elements are isolated from each other, and for all input and output line elements matched conditions apply. This can be achieved by a signal path length of $\lambda/4$ for each of the output line elements and a combined total length of the two output line elements of $\lambda/2$. Furthermore, for a preset signal frequency of the radio frequency signal the impedance of each of the output line elements is matched by the resistor between the two output line elements such that the impedance of the resistor equals $\sqrt{2}/2$ the impedance of each of the output line elements, i.e. the impedance $2\ Z_0$ of the resistor equals the impedance $\sqrt{2}\ Z_0$ of each of the output line elements for a preset signal frequency of the radio frequency signal. Such a Wilkinson type power divider element allows for a minimal signal loss for the split-up of the incoming radio frequency signal into two outgoing signals of equal magnitude. Furthermore, the power divider element allows for the separation and isolation of the two output lines with minimal resistive loss to the radio frequency signal that is fed into the input line element

[0022] According to an advantageous embodiment of the invention the resistor element is made of a material with electrical conductivity less than the electrical conductivity of metals. For many practical applications the required ohmic resistance of the resistor element will be between 10 and 1000 Ohm. A resistor element with an ohmic resistance of e.g. 100 Ohm that is made by e.g. copper with a resistivity of approx. 1.7 10^{-8} Ohm m and a sheet resistance of approx. 0.017 Ohm requires a thin metal sheet surface of 0.5 mm length and of 0.00008 mm width. Thus, manufacture of such a resistor element with such small dimensions is very challenging and increases the risk of imprecisely configured or manufactured resistor elements with a resistance that significantly differs from the intended resistance. For this reason, it is considered advantageous to make use of a material with considerably less resistivity than metals, e.g. less than 5 10^{-7} Ohm m, and therefore with a larger sheet resistance than metals, e.g. more than 1 Ohm. Then the characteristic length and width of the resistor element can be set in the range of e.g. 0.01 mm to 1 mm each, which allows for precise design and manufacture of such a resistor element by using well-known manufacture methods.

[0023] It is considered a very advantageous opportunity that the resistor element is made of indium-tin-oxide. Indium-tin-oxide, also named as ITO has a resistivity of approx. 2 10^{-7} Ohm m and a sheet resistance of approx. 20 Ohm. A resistor element that is made from a thin sheet of ITO on the surface of a substrate layer can have dimensions of 0.5 mm length and 0.1 mm width, resulting in an ohmic resistance of 100 Ohm. Furthermore, ITO has characteristic features that can be exploited for further applications and components of the radio frequency device, which allows for the manufacture of the resistor element together with additional components of the radio frequency device at the same time or during the same manufacturing step, resulting the efforts and costs for manufacture of the resistor power divider element.

[0024] In yet another embodiment of the invention the output line element of a first power divider element is electroconductively connected to an input line element of a second power divider element, resulting in a sequence of power divider elements along the transmission path of the radio frequency signal between the first and second substrate layers. By combining several or many power divider elements into a sequence of power divider elements along the transmission path, it is possible to begin with a single transmission line element inside of the two substrate layers that is coupled to a coupling element that introduces a radio frequency signal into this single transmission line element. However, the radio frequency signal can be split-up many times by connecting a corresponding number of power divider elements to this single transmission line element, resulting in a large number of radio frequency signals that are propagated along the multitude of transmission paths created by the sequence of power divider elements. Thus, a large number of radio frequency signals that propagate at the same time along transmission paths arranged between the two substrate layers can be fed by means of a single coupling element, which reduces the signal loss and any unwanted signal leakage due to signal coupling into the inside of the two substrate layers.

[0025] According to a further embodiment of the invention, the radio frequency device comprises a sequence of several power divider elements with output line elements that are coupled with second coupling elements to corresponding radiation elements arranged outside of the first and second substrate layer, whereby a radio frequency signal that is introduced by the first coupling element into transmission line elements on the first and second surface of the first and second substrate layer, is divided several times and transmitted along corresponding transmission paths to the second coupling elements, which couple the transmitted and divided radio frequency signals into the corresponding radiation elements. Thus, it is possible to propagate a single input radio frequency signal to a large number of radiation elements of a phased array antenna without the need of two coupling elements for each radiation element. This allows for a more compact design of the radio frequency device and significantly reduces the loss of signal strength and interfering signal radiation along the transmission paths to the respective radiation elements.

[0026] According to a favorable aspect of the invention, for each radiation element of the radio frequency device there is at least one corresponding phase shifting device arranged between the first and second substrate layer along the transmission path of the radio frequency signal. Manufacture and operation of phase shifting devices that are arranged between the first and second substrate layer is comparatively simple and cost effective, and furthermore allows for a very compact and space-saving design of the radio frequency device, e.g. of a phased array antenna with a large number of radiation elements that are combined for emission or reception of radio frequency signals. By adding appropriate phase shifting devices the superposition of the radio frequency signals of each of the radiation elements can be enhanced and controlled, resulting e.g. in advantageous features like beam steering or enhanced signal quality.

Brief description of the drawings

[0027] The present invention will be more fully understood, and further features will become apparent, when reference is made to the following detailed description and the accompanying drawings. The drawings are merely representative and are not intended to limit the scope of the claims. In fact, those of ordinary skill in the art may appreciate upon reading the following specification and viewing the present drawings that various modifications and variations can be made thereto without deviating from the innovative concepts of the invention. Like parts depicted in the drawings are referred to by the same reference numerals.

Figure 1 illustrates a schematic representation of a top view of a radio frequency device,

Figure 2 illustrates a cross section view of the radio frequency device shown in figure 1 along line II-II in figure 1,

Figure 3 illustrates a schematic representation of a power divider element which is part of the radio frequency device shown in figures 1 and 2,

Figure 4 illustrates a cross section view of the power divider element shown in figure 3 along line IV-IV in figure 3,

Figure 5 illustrates a schematic representation of a top view of a phased array antenna with a number of radiation elements, and

Figure 6 illustrates a cross section view similar to figure 2 of another embodiment of the radio frequency device as shown in figure 1.

Detailed description of the invention

[0028] Figure 1 shows a top view of a schematic representation of a radio frequency device 1 according to an exemplary embodiment of the invention. Figure 2 shows a cross section view of the radio frequency device 1 shown in figure 1, whereby the cross section is indicated by line II-II in figure 1. The radio frequency device 1 comprises a signal input element 2 and a corresponding first coupling element 3 for an incoming radio frequency signal. The signal input element 2 is arranged on top of a first substrate layer 4, and the first coupling element 3 is arranged beneath the signal input element 2 under the first substrate layer 4. The first substrate layer 4 is made of glass and transparent, which allows to see further components of the radio frequency device 1 below the first substrate layer 4. Below the first substrate layer 4 is a second substrate layer 5, also made of glass and arranged in parallel and at a distance to the first substrate layer 4. In between the first and second substrate layer 4, 5 there is a power divider element 6, two phase shifting devices 7 and two further second coupling elements 8 that each couple to a respective radiation element 9 that is arranged outside the two substrate layers 4, 5 on top of the first substrate layer 4.

[0029] An incoming radio frequency signal that is fed to the signal input element 2 on an upper surface 10 of the first substrate layer 4 propagates through the first substrate layer 4 and couples with the first coupling element 3 beneath the signal input element 2 on a lower first surface 11 of the first substrate layer 4. The radio frequency signal then propagates through a first crossover element 19 to a transmission line element 12 on an upper second surface 13 of the second substrate layer 5. The first surface 11 of the first substrate layer 4 faces towards the second surface 13 of the second substrate layer 5. Both first and second surface 11, 13 are arranged in parallel and with a distance to each other.

[0030] The radio frequency signal is split up into two transmission paths 14 by the power divider element 6. Each transmission path 14 comprises a further transmission line element 15 that runs into a dedicated phase shifting device 7 with several electrode elements 16, 17 at the lower first surface 11 of the first substrate layer 4 and at the upper second surface 13 of the second substrate layer 5. The phase shifting device 7 allows for manipulating and controlling the phase shift of the radio frequency signal that propagates along the corresponding transmission path 14 through the phase shifting device 7. Afterwards, the radio frequency signal is transmitted along further transmission line elements 18 through a second crossover element 19 to a second coupling element 8. The radio frequency signal propagates through the first substrate layer 4 and couples to a radiation element 9 for emission of the radio frequency signal by the radiation element 9.

[0031] The volume between the two substrate layers 4, 5 is filled with a fluidic tunable dielectric material 20, which in this case is a liquid crystal material. The dielectric characteristics of the tunable dielectric material 20 can be manipulated and controlled by applying a bias voltage to bias electrodes that are not shown in figures 1 and 2, but create an electric field between the two substrate layers 4, 5 which affects the dielectric characteristics of the tunable dielectric material 20. By controlling the electric field between the electrode elements 16, 17 of the phase shifting devices 7, the phase shift of the radio frequency signal that propagates through the respective phase shifting device 7 can be modified and controlled.

[0032] The terms relating to the arrangement of the first and second substrate layer 4, 5 are only used for description and understanding of the example shown in figures 1 and 2 and do not limit the arrangement and orientation of the two substrate layers 4, 5 and the further components of the radio frequency device 1 to the exemplary embodiment and orientation in space as shown in figures 1 and 2. Furthermore, the direction of propagation of the radio frequency signal is not limited to starting at the signal input element 2 and ending at being emitted by the radiation elements 9. It is also possible to make use of the radio frequency device 1 as a receiver for radio frequency signals that will be received by the two radiation elements 9, transmitted along the inside between the two substrate layers 4, 5 and combined by the power divider element 6 into a single radio frequency signal that is further transmitted to the signal input element 2 for further processing and evaluation of the received radio frequency signal. A person skilled in the art may easily modify the design of the radio frequency device 1 to adapt the radio frequency device 1 for the intended use e.g. as a phased array antenna with beam steering capabilities on a car, ship or plane.

[0033] The power divider element 6 is illustrated in more detail in figures 3 and 4. The power divider element 6 is a Wilkinson type power divider which is described e.g. in E. J. Wilkinson, "An N-was Power divider", IRE Trans. on Microwave Theory and Techniques, vol. 8, January 1960, pp. 116-118, or D. M. Pozar, "Microwave Engineering", 4th Edition, John Wiley & Sons, New York, 1998, pp. 328-333. The power divider element 6 comprises an input line element 21 that branches at a bifurcation 22 into two divider elements 23. The length of each of the two divider elements 23 is designed to be $\lambda/4$ whereby λ equals the wavelength of the radio frequency signal that is transmitted along the transmission paths 14. After the bifurcation 22 into two divider elements 23 each of the two split-up transmission paths 14 runs into a corresponding output line element 24. The two output line elements 24 are electroconductively connected by a resistor element 25 that comprises a predetermined ohmic resistance.

[0034] The resistor element 25 is made of ITO, i.e. indium-tin-oxide with a resistivity of approx. 2 10^{-7} Ohm m and a sheet resistance of approx. 20 Ohm. The resistor element 25 is manufactured by deposition of a thin sheet of ITO on the upper second surface 13 of the second substrate layer 5. The thin sheet has dimensions of 0.5 mm length and 0.1 mm width, resulting in an ohmic resistance of 100 Ohm. Characteristic features of the material ITO of the resistor element 25 also include optical transparency and easy manufacture of thin sheet elements which is considered advantageous for use in radio frequency devices 1.

[0035] Figure 5 shows another embodiment of the radio frequency device 1 according to the invention described above. At the upper surface 10 of the first substrate layer 4 there is a single signal input element 2 that is coupled to a first coupling element 3 which is beneath the signal input element 2 and cannot be seen in figure 5. The first coupling element 3 is electroconductively connected with a cascade of power divider elements 6, whereby both of the output line elements 24 of a preceding power divider element 6 each runs into the input line element 21 of a subsequent power divider element 6. Thus, an incoming radio frequency signal is branched several times along the respective transmission path 14 until the split-up radio frequency signal propagates through a phase shifting device 7 and is coupled to a corresponding radiation element 9 which is arranged on the upper surface 10 of the first substrate layer 4. The power divider elements 6 and most of the transmission line elements 12, 15 and 18 are arranged between the two substrate layers 4, 5 on the upper second surface 13 of the second substrate layer 5. Even though only eight radiation elements 9 are shown in the exemplary embodiment of figure 5, it is easily possible to manufacture a similar radio frequency device 1 with a large number of radiation elements 9, e.g. with several hundreds or thousands of radiation elements 9, whereby such a radio frequency device 1 can be used as a phased array antenna. By arranging power divider elements 6 between the two substrate layers 4 and 5, the number of coupling elements 3 can be reduced. By arranging a power divider cascade with three consecutive power divider elements 6 along the transmission paths 14, a single coupling element 3 is required for feeding the radio frequency signal to eight radiation elements 9, reducing the number of required coupling elements 3 by the factor eight. It is also possible to make use of larger power divider cascades with more than three consecutive power divider elements 6 along each transmission path 1. For example, a power divider cascade with ten successive power divider elements 6 results in only a single signal input element 2 and the corresponding coupling element 3 for an incoming radio frequency signal that will be split-up and transmitted to 1024 radiation elements 9.

[0036] Due to the benefitting characteristics of the ITO material that is used for manufacture of the resistor element 25 within the power divider element 6 it is also possible to provide for a radiation shielding around the phase shifting devices 7 by creating a border strip line 26 that surrounds and encompasses the phase shifting device 7. By means of example, only one border strip line 26 is indicated in figure 5.

[0037] Figure 6 shows an embodiment of the radio frequency device 1 with only one substrate layer 4. The radio frequency device 1 comprises a signal input element 2 and a corresponding first coupling element 3 for an incoming radio frequency signal. The signal input element 2 is arranged on the first surface 10 on top of the substrate layer 4, and the first coupling element 3 is arranged beneath the signal input element 2 at the second surface below the substrate layer 4. The substrate layer 4 is made of glass and transparent. At the second surface 11 below the substrate layer 4, there is a power divider element 6, two phase shifting devices 7 and two further second coupling elements 8 that each couple to a respective radiation element 9 that is arranged at the first surface 10 on top of the substrate layer 4. The embodiment shown in figure 6 is an example for the use of a power divider element 6 on a single substrate layer 4 within the radio frequency device 1.

Claims

1. Radio frequency device (1) comprising a first substrate layer (4), whereby a first surface (11) of the first substrate layer (4) faces a second surface (13) opposite of the first surface (11) on the first substrate layer (4) or a second surface (13) on a second substrate layer (5) arranged at a distance towards the first substrate layer (4), the radio frequency device (1) further comprising electrically conductive transmission line elements (12, 15, 18) arranged on the first and the second surface (11, 13) that allow for transmission of a radio frequency signal along a transmission path (14), and with a first coupling element (3) that provides for a radio frequency signal

transmission from a signal input element (2) on the first surface (11) on substrate layer (4) into the transmission path (14) along the transmission line elements (12, 15, 18) on the second surface (13) on the first substrate layer (4) or on a second surface (13) between the first and the second substrate layer (4, 5), **characterized in that** at least one radio frequency signal power divider element (6) is arranged on the second surface (13) of the first or the second substrate layer (4, 5), whereby the power divider element (6) comprises an input line element (21) that branches at a bifurcation (22) into at least two output line elements (24), whereby the power divider element (6) is arranged to receive the radio frequency signal from the signal input element (2) that is transferred along the transmission path (14) into the input line element (21) of the power divider element (6) and divided into at least two output signals transmitted along the at least two output line elements (24), and whereby a resistor element (25) with a predetermined ohmic resistance is arranged between the at least two output line elements (24) that electroconductively connects the two output line elements (24) resulting in improved isolation of the at least two output line signals.

2. Radio frequency device (1) according to claim 1, **characterized in that** the second surface (13) is opposite to the first surface (11) on the first substrate layer (4).

3. Radio frequency device (1) according to claim 1, **characterized in that** the radio frequency device (1) comprises the first and one second substrate layer (4, 5) the power divider element (6) is arranged on the first or second surface (11, 13) between the first and second substrate layer (4, 5).

4. Radio frequency device (1) according to claim 1 or claim 2, **characterized in that** the at least one power divider element (6) is a Gysel type power divider element (6) that achieves isolation between more than two output line elements (24) while maintaining a matched condition on all input and output line elements (21, 24).

5. Radio frequency device (1) according to one of the claims 1 to 4, **characterized in that** the power divider element (6) comprises an input line element (21) that branches at a bifurcation (22) into only two output line element (25).

6. Radio frequency device (1) according to claim 5, **characterized in that** the at least one power divider element (6) is a Wilkinson type power divider element (6) that achieves isolation between the two output line elements (24) while maintaining a matched condition on all input and output line elements (21, 24).

7. Radio frequency device (1) according to one of the preceding claims, **characterized in that** the resistor element (25) is made of a material with electrical conductivity less than the electrical conductivity of metals.

8. Radio frequency device (1) according to claim 7, **characterized in that** the resistor element (25) is made of indium-tin-oxide.

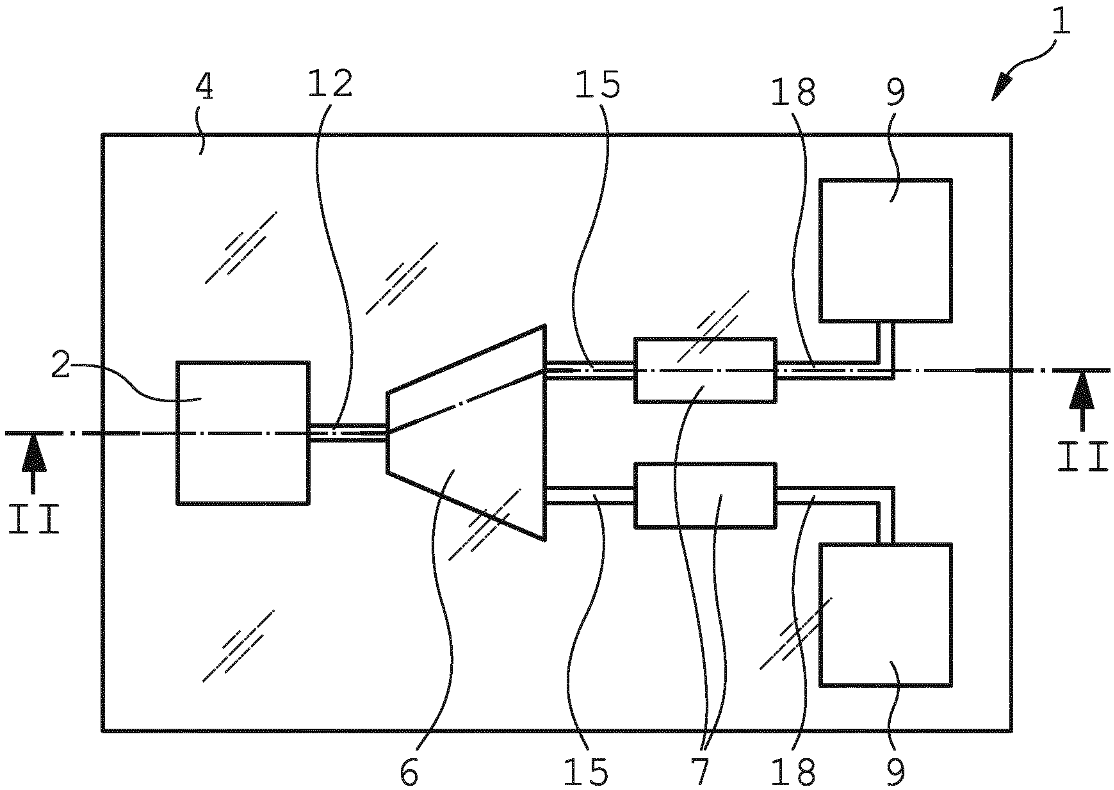
9. Radio frequency device (1) according to one of the preceding claims, **characterized in that** the output line element (24) of a first power divider element (6) is electroconductively connected to an input line element (21) of a second power divider element (6), resulting in a sequence of power divider elements (6) along the transmission path (14) of the radio frequency signal between the first and second substrate layers (4, 5).

10. Radio frequency device (1) according to one of the preceding claims, **characterized in that** the radio frequency device (1) comprises a sequence of several power divider elements (6) with output line elements (24) that are coupled with second coupling elements (8) to corresponding radiation elements (9) arranged outside of the first and second substrate layer (4, 5), whereby a radio frequency signal that is introduced by the first coupling element (3) into transmission line elements (12, 15, 18) on the first and second surface (11, 13) of the first and second substrate layer (4, 5) is divided several times and transmitted along corresponding transmission paths (14) to the second coupling elements (8), which couple the transmitted and divided radio frequency signals into the corresponding radiation elements (9).

11. Radio frequency device (1) according to claim 9, **characterized in that** for each radiation element (9) there is at least one corresponding phase shifting device (7) arranged between the first and second substrate layer (4, 5) along the transmission path (14) of the radio frequency signal.

12. Radio frequency device (1) according to one of the preceding claims, **characterized in that** the power divider element (6) is arranged on the second surface (13) of the respective substrate layer (4, 5) whereby the respective substrate layer (4, 5) is made of glass or a material which is similarly difficult to perforate.

FIG 1


1
4
12
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18
9
2
II
II
6
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18
9

FIG 2

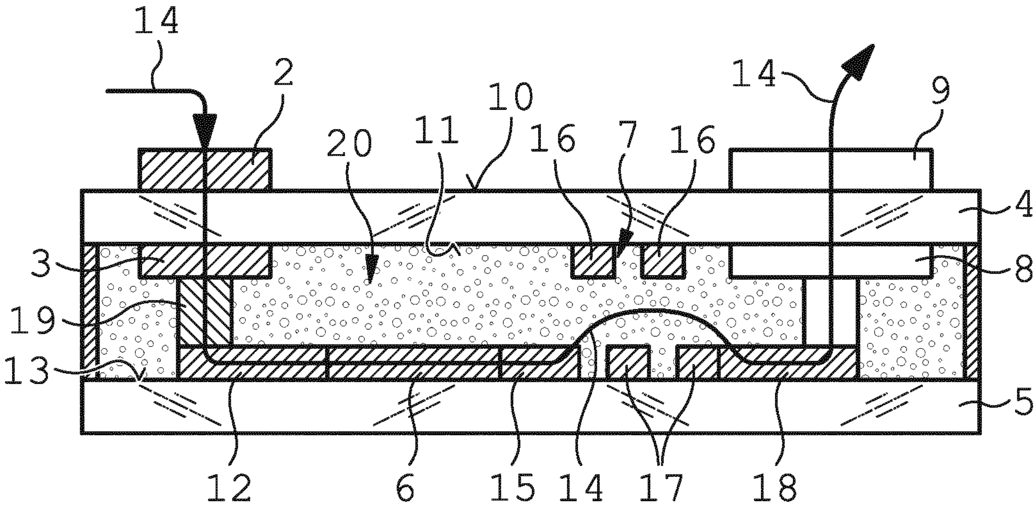
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FIG 3

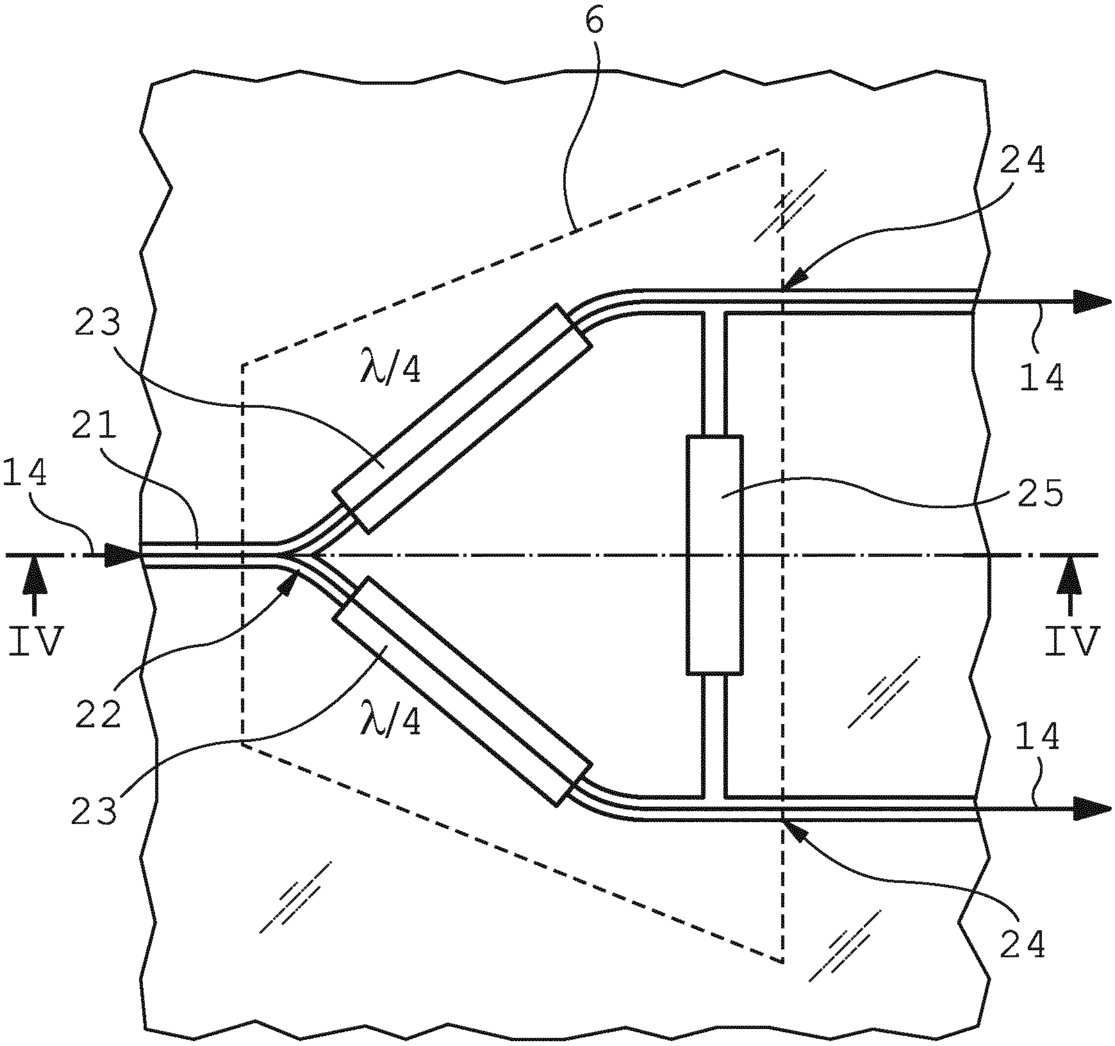


FIG 4

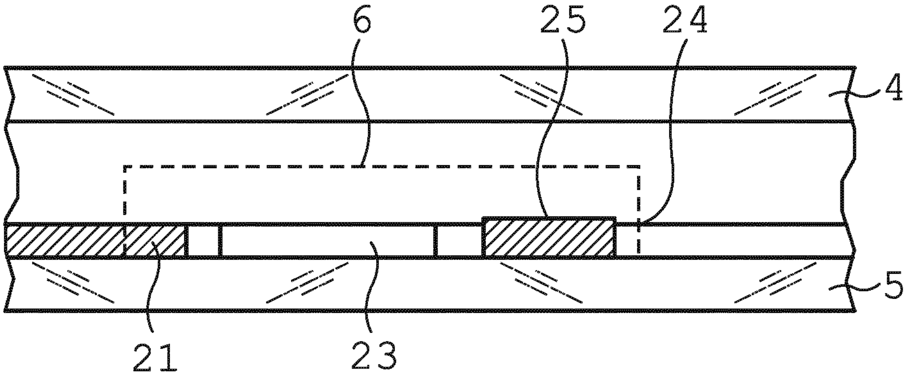
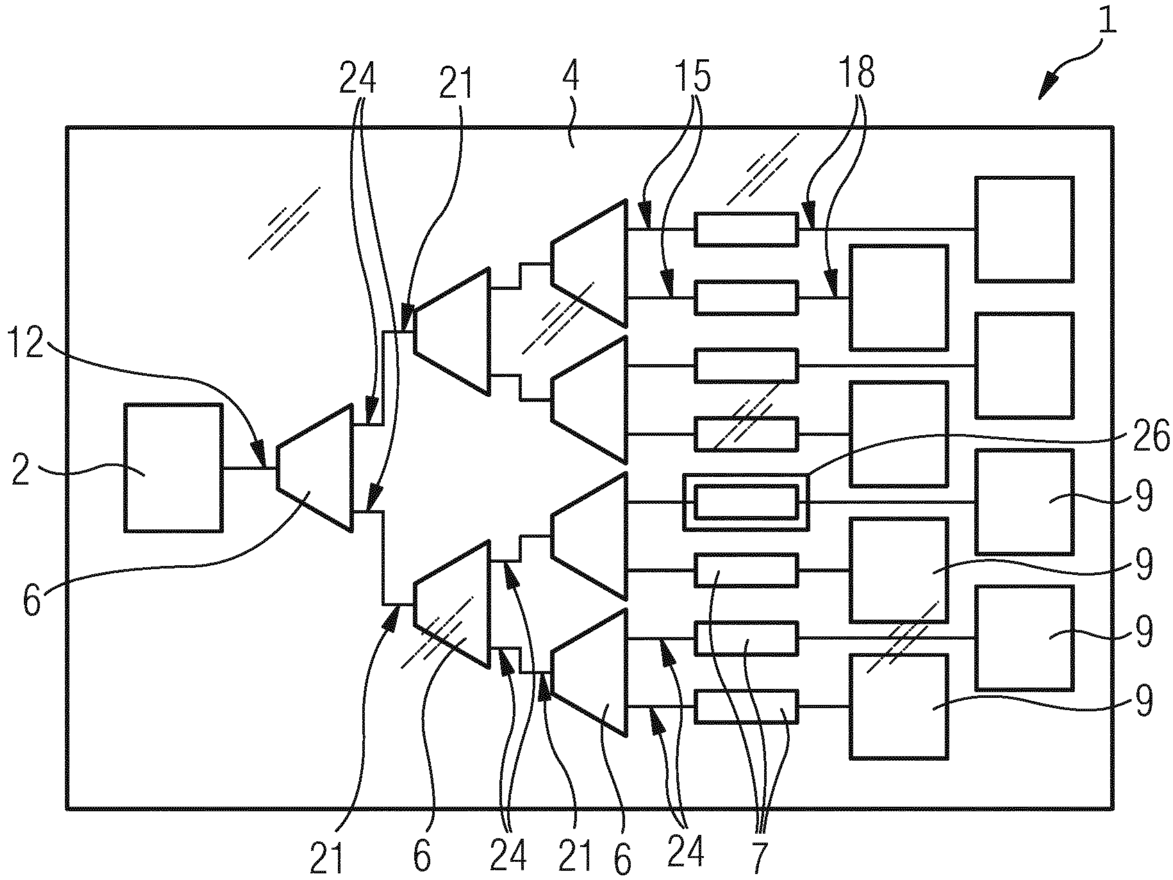


FIG 5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24
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24
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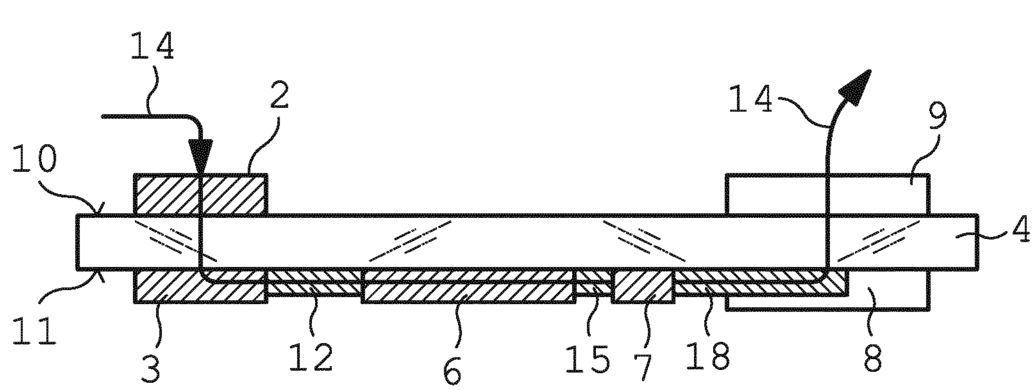
FIG 6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EUROPEAN SEARCH REPORT

Application Number
EP 19 17 7097

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A	WANG KAI-XU ET AL: "Gysel Power Divider With Arbitrary Power Ratios and Filtering Responses Using Coupling Structure", IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, PLENUM, USA, vol. 62, no. 3, 1 March 2014 (2014-03-01), pages 431-440, XP011541878, ISSN: 0018-9480, DOI: 10.1109/TMTT.2014.2300053 [retrieved on 2014-03-03] * chapter I; figure 10 *	4	
			TECHNICAL FIELDS SEARCHED (IPC)
			H01P H01Q

-/--

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	8 November 2019	Hueso González, J

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Application Number
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1

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
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08-11-2019

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