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(54) MULTI-STAGE CASCADED POWER DIVIDER

(57) Multi-stage cascaded power divider having a single input port and a plurality of output ports, comprising one stage including at least one 3-way Wilkinson power divider and at least one stage consisting of at least one 2-way Wilkinson power divider, wherein the stage consist-

ing of at least one 2-way Wilkinson power divider is connected to the single input port and the stage including the at least one 3-way Wilkinson power divider is connected to the plurality of output ports.

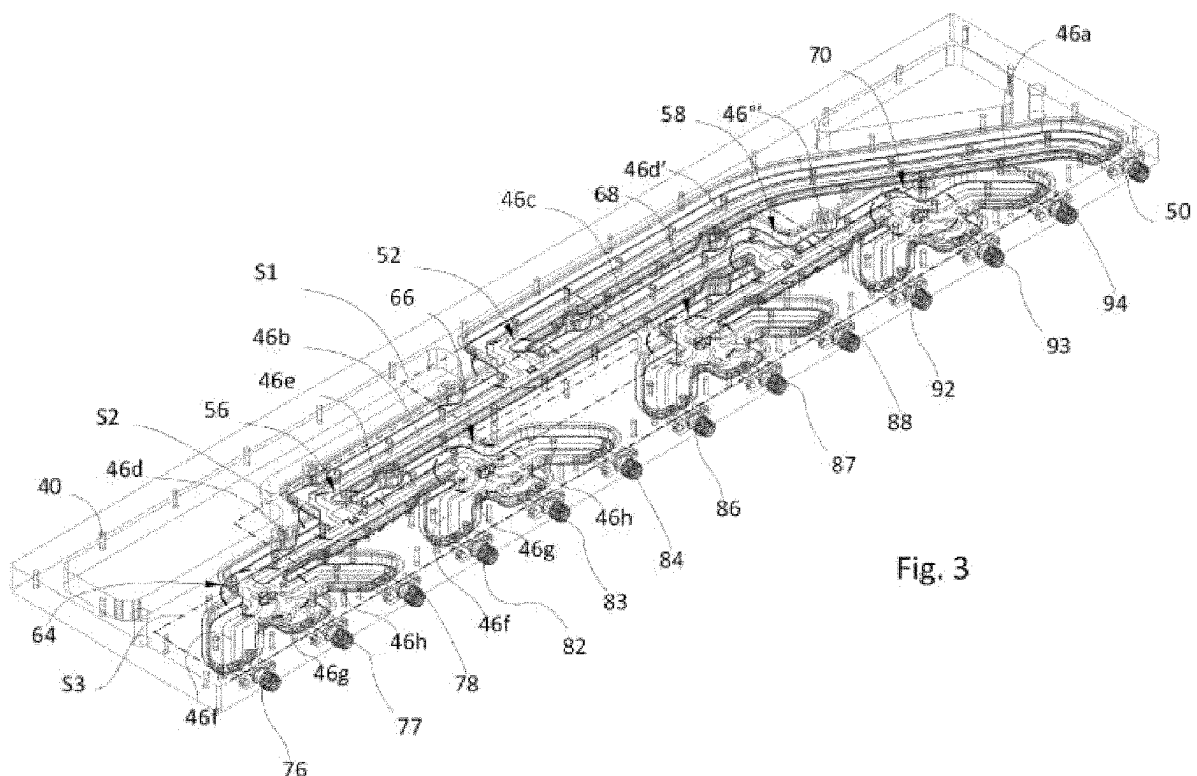


Fig. 3

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Description

[0001] The present invention is concerned with power dividers for use in radio-frequency field.

[0002] The invention pertains to the field of radio-frequency (RF) systems and components, particularly microwave components, such as power dividers for use in high power transmission systems.

[0003] In such systems, in order to generate power levels which cannot be obtained by a single amplifier unit, a solution is to place several amplifier units in parallel. Placing amplifier units in parallel requires to evenly split the incoming source signal by the number of amplifiers which shall be placed in parallel and then recombining the amplified output signals of all the amplifiers into a single high power output signal.

[0004] In order to minimize the losses associated with splitting and recombining signals operations, very stringent electrical requirements must be complied with, particularly in terms of phase matching and amplitude mismatch between ports.

[0005] Power dividers are known, in particular dividers designed with a circuit scheme known as "Wilkinson divider". Such power dividers have typically two output ports and such geometry can be realized in planar transmission lines, particularly in microstrip technology.

[0006] A Wilkinson divider splits an input signal into two equal power and phase output signals, or combines two equal power and phase signals into one in the opposite direction. A Wilkinson divider relies on quarter-wave transformers to match the split ports to the common port.

[0007] Because a loss-less reciprocal three-port network cannot have all ports simultaneously matched, one resistor is added between the output ports, allowing all three ports to be matched and isolating the output ports at the center frequency; as the resistor adds no resistive loss to the power split from the input port, an ideal Wilkinson 2-way divider is 100% efficient.

[0008] Wilkinson dividers (or splitters) having three output ports (or more) are also known. However, designing such dividers in planar form is difficult if not impractical or unfeasible for more than three output ports; in particular, a 3-way Wilkinson divider in a planar design (e.g. made with microstrip lines) requires that the resistor connecting (bridging) the two outermost ports behaves similarly (possibly identically) to the other two resistors, but this in practice is difficult to achieve at layout level. Therefore, such resistor is often omitted in a 3-way Wilkinson divider with the effect of degrading the isolation and imbalance between the ports.

[0009] When a multi-output power division is required, cascading several Wilkinson dividers design can be used to obtain a design for a multi-port divider.

[0010] For example, 12 ports dividers are commercially available from Microwave Engineering Corporation (with code PIN G630-54 SP), or from Pulsar Microwave Corporation.

[0011] Such 12 ports dividers have a microstrip con-

struction with a 3-2-2 division scheme (i.e. one 3-way divider is used as first stage, followed by a second stage of three 2-way dividers and a third stage of six 2-way dividers).

[0012] The applicant has observed that 2-way Wilkinson dividers can be designed with very good characteristics of isolation and phase/amplitude balancing between the arms; 3-way Wilkinson dividers, instead, have difficulties in balancing the three output ports (even if resistors are used). Trying to adjust (by tuning of some sort) this unbalance actually risks of unbalancing the other arms of the 3-way divider, since the 3-way divider has poor isolation. In addition, measuring all the ports of the 3-way divider at the same time is also problematic and requires a dedicated test setup. Accordingly, in a 3-2-2 division scheme, an unbalance in one of the three output ports is transferred to the 2-way dividers of the subsequent stages, with increased adjustment difficulties.

[0013] When paralleling several amplifier units in a rack system where these units need to be easily replaced for maintenance reasons, the power dividers of this type are generally installed in the rack with the output ports aligned together on the front side of the rack, for connection to the other system components (e.g. solid state amplifiers) via coaxial cables or the like.

[0014] The input port of the power divider can be arranged on the opposite side with respect to the output ports, i.e. in the rear side of the rack. This minimizes the internal losses of the power divider, but in a rack installation this is likely to create difficulties for accessing the input port for cabling and maintenance operations.

[0015] The input port may be arranged on the front side of the power divider, but in this case a more complex arrangement, with longer internal signal paths is required, which can potentially increase internal losses.

[0016] Within the scope of the present invention, it has been found that in a cascaded power divider comprising at least one 3-way power divider, by using the 3-way power divider as the last stage of the cascade, any unbalance introduced by the last 3-way divider can be locally tuned on that divider itself, requiring to measure and possibly tune the 3 ports of that divider only, without affecting all the other remaining ports (i.e. 9 ports in case of a 12-way power divider). This arrangement, in combination with 3-way Wilkinson-type power divider enables to significantly reduce the output errors.

[0017] The present invention concerns a multi-stage cascaded power divider having a single input port and a plurality of output ports, comprising a first stage consisting of a first 2-way Wilkinson power divider, a second stage consisting of a second and a third 2-way Wilkinson power dividers and a third stage consisting of four 3-way Wilkinson power dividers, wherein the first stage is connected to the single input port and the third stage including the 3-way Wilkinson power divider is connected to the plurality of output ports.

[0018] In this description and in the attached claims, the terms input port and output port are used to define the

ports of an apparatus used to divide the RF signal supplied to one port (input port) into a plurality of output ports; however, the same apparatus may be used to combine RF signals supplied to a plurality of ports into one port (output port): in such case, the terms "input" and "output" must be intended in reversed meaning.

[0019] Preferably, the multi-stage cascaded power divider comprises in sequence an input port, a first stage consisting of a first 2-way Wilkinson power divider having a first arm connected to the input port and two output arms, a second stage consisting of a second and a third 2-way Wilkinson power dividers, each divider having a first arm connected to one of the two output arms of the first 2-way Wilkinson power divider and two output arms, and a third stage consisting of four 3-way Wilkinson power dividers, each divider having a first arm connected to one of the two output arms of the second and third 2-way Wilkinson power dividers and respective output arms connected to the plurality of output ports.

[0020] Preferably, the multi-stage cascaded power divider is a planar, microstrip circuit construction, comprising a path of microstrip transmission lines.

[0021] Preferably the multi-stage cascaded power divider comprises a base, housing a printed circuit board (PCB) bearing the transmission lines path, such transmission lines forming the first, the second and the third 2-way Wilkinson power dividers and forming the four 3-way Wilkinson power dividers.

[0022] Preferably, the input port and the plurality of output ports are all arranged in a line along one side of the base.

[0023] Preferably, each of the four 3-way Wilkinson power dividers comprise resistors between the relevant output arms.

[0024] Preferably, the resistors electrically connecting the two output side arms of each of the four 3-way Wilkinson power dividers are bridging over the central arm and are electrically isolated from said central arm.

[0025] In a preferred embodiment the base is made of an electrically conductive metal alloy.

[0026] In particular, the base comprises a trench housing the PCB.

[0027] Preferably, at least a portion of the output arms of the 3-way Wilkinson power dividers is a suspended microstrip transmission line.

[0028] Preferably, at least a portion of the transmission lines of the first and second stage is a suspended microstrip transmission line.

[0029] Preferably, the input port and the plurality of output ports are electrically connected to coaxial connectors.

[0030] More details will be identified from the following description of one embodiment, with reference to the enclosed figures, wherein it is shown:

in figure 1 a plan view of a "3-2-2" 12-ports power divider according to the prior art;

in figure 1a an electric scheme of the "3-2-2" 12-ports power divider of figure 1;

in figure 2 a 2-way power divider of Wilkinson type;

in figure 2a an electric scheme of the 2-way, Wilkinson type, power divider of figure 2;

in figure 2b an electric scheme of the 3-way power divider as used in the "3-2-2" 12-ports power divider of figure 1;

in figure 3 a perspective view of a "2-2-3" 12-ports power divider according to the invention;

in figure 3a an electric scheme of the "2-2-3" 12-ports power divider of figure 3;

in figure 4 an exploded perspective view of the "2-2-3" 12-ports power divider of figure 3;

in figure 5 a plan view of a detail of a portion of the printed circuit board of the "2-2-3" 12-ports power divider of figure 3;

in figure 6 a plan view of a Wilkinson-type 3-way power divider in planar design;

in figure 6a an electric scheme of the 3-way, Wilkinson-type power divider of figure 6;

in figure 7 a cross-section along the plane VII-VII of figure 3;

in figure 8 a graph showing the results of a test made on the "3-2-2" 12-ports power divider of figure 1;

in figure 9 a graph showing the results of a test made on a "2-2-3" 12-ports power divider according to the invention.

[0031] Figure 1 shows a "3-2-2" power divider, according to a prior art embodiment.

[0032] Such prior art power divider comprises an input port 1, which is connected by a first waveguide 2 to first stage P1, consisting of a 3-way power divider 3.

[0033] The 3-way power divider 3 has three output waveguides 4, 5, 6, designed to have equal lengths, connected to a second stage P2, comprising three 2-way Wilkinson-type power dividers 7, 8, 9.

[0034] The electric scheme of the 3-way power divider 3 is shown in fig. 2b; the 3-way power divider 3 comprises an input port D and three arms e, f, g, connected to the relevant output ports E, F, G.

[0035] In turn, the output waveguides 10, 11, 12, 13, 14, 15 of the 2-way Wilkinson-type power dividers 7, 8, 9, are connected to a third stage P3 comprising six 2-way Wilkinson power dividers 16, 17, 18, 19, 20, 21, whose

output waveguides are connected to twelve output ports 22-33.

[0036] As known in the art, a Wilkinson-type power divider is a specific class of power divider circuits that can achieve isolation between the output ports while maintaining a matched condition on all ports. It uses quarter wave transformers, which can be easily fabricated as quarter wave lines on printed circuit boards.

[0037] As schematically shown in fig. 2 and in the electric scheme of fig. 2a, an exemplary 2-way Wilkinson-type power divider has an input port A, two arms b, c, preferably having equal length $\lambda/4$, and relevant output ports B, C. Between the output ports B, C a resistor R is inserted.

[0038] With this arrangement, no loss occurs when the signals at ports B and C are in phase and have equal magnitude. In case of noise input to ports B and C, the noise level at port A does not substantially increase, half of the noise power is dissipated in the resistor.

[0039] A cascaded power divider of the type shown in fig. 1 is referred to in the following as "3-2-2" type, having a 3-way divider first and two subsequent 2-way divider stages. In this design, it has been observed that in by having a non-ideal 3-way divider first (the divider 3), any unbalance in one the arms of the 3-way divider is spread to all the subsequent 2-2 divisions out of that arm. Trying to adjust (by tuning of some sort) this unbalance actually risks of unbalancing the other arms of the 3-way divider since the 3-way divider has poor isolation.

[0040] In addition, measuring all the twelve ports at the same time is problematic and requires a dedicated test setup.

[0041] In figure 3, 3a, 4, 5 a cascaded "2-2-3" power divider assembly is shown.

[0042] By "2-2-3" power divider we mean a power divider comprising a first 2-way power divider, whose output ports are connected to further two 2-way power dividers, whose output ports are finally connected to four 3-way power dividers.

[0043] The "2-2-3" power divider of fig. 3, 4 is a planar, microstrip construction which comprises a base 40, preferably of a ground connected, electrically conductive metal alloy, having a trench 42 housing a PCB ("printed circuit board") 44 bearing a path of waveguides 46. The housing is covered by a lid 45.

[0044] Conveniently, as shown in the cross-sectional view of figure 6, each waveguide 46 comprises a microstrip line 47 and ground conductors 48.

[0045] Hereinafter, the term "waveguide" will be used to refer to the microstrip line of each relevant section.

[0046] Preferably, the PCB 44 is made of a double-sided low loss material Taconic p/n TSM-DS3 - 20 mil (0.5 mm) thick.

[0047] The waveguides 46 comprise an input waveguide 46a, connected to an input coaxial connector 50, reaching a first stage S1 consisting of a first 2-way Wilkinson power divider 52, having two output waveguides 46b, 46c respectively connecting a second 2-way Wil-

kinson power divider 56 and a third 2-way Wilkinson power divider 58 of a second stage S2.

[0048] In turn, the second 2-way Wilkinson power divider 56 has two output waveguides 46d, 46e, reaching a first and a second 3-way Wilkinson-type power dividers 64 and 66 respectively of a third stage S3.

[0049] The third 2-way Wilkinson power divider 58, in turn, has two output waveguides 46d', 46e', reaching a third and a fourth 3-way Wilkinson-type power dividers 68 and 70 respectively of the third stage S3.

[0050] Within the present specification and in the attached claims, by 3-way Wilkinson-type power divider we mean a 3-way divider according to the electrical scheme of figure 6a, having an input port D1 and three arms e1, f1, g1, preferably having equal length, connected to three relevant output ports E1, F1, G1. Each output port is electrically connected to the other output ports by means of relevant resistors R1, R2, R3. Conveniently, all the three resistors R1, R2, R3 have the same value.

[0051] Conveniently, the output waveguides of the 3-way Wilkinson power dividers are designed to have the same length.

[0052] The first 3-way Wilkinson-type power divider 64 has three output waveguides 46f, 46g, 46h, which are finally connected with the output coaxial connectors 76, 77, 78, for connection with relevant coaxial cables.

[0053] Similarly, the second 3-way Wilkinson power divider 66 has three output waveguides 46i, 46l, 46m, which are finally connected with the output coaxial connectors 82, 83, 84.

[0054] The third 2-way Wilkinson power divider 58 has the relevant output waveguides 46n, 46o, connected to a third and a fourth 3-way Wilkinson power dividers 68 and 70 respectively, whose output waveguides are connected to the output connectors 86, 87, 88. Similarly, the fourth 3-way Wilkinson power dividers 70 has output waveguides connected to the output connectors 92, 93, 94.

[0055] Figure 5 shows in enlarged plan view a portion of the PCB 44, with the relevant waveguides 46 and the first and second 3-way Wilkinson power dividers 64 and 66.

[0056] The 3-way Wilkinson power divider, as shown in enlarged view in figure 6, comprises an input microstrip line 47a, two arc-shaped output side arms 47b, 47c, and a straight output central arm 47d.

[0057] The two side arms 47b, 47c, are electrically connected together via a resistor 100, bridging over the central arm 47d (isolated from the central arm 47d).

[0058] In turn, the two side arms 47b, 47c, are electrically connected to the central arm 47d via relevant resistors 101, 102.

[0059] Conveniently, the resistors 100, 101, 102 have equal resistance values.

[0060] As each of the arms 47b, 47c, 47d is connected to the others via relevant resistors, no substantial phase-unbalance is generated in the output microstrips 47e, 47f, 47g connected respectively with the arms 47b, 47c, 47d.

[0061] Conveniently, along some portions of the path of the waveguide 46 a cavity 110 is made in the trench of the base 40, as shown in fig. 7, particular in correspondence with the transition area from the microstrips 47 and the connectors, and along the waveguides 46a-46d. In such way, the relevant waveguide portion laying over the cavity is suspended, thereby improving the isolation and minimizing the transmission/insertion losses.

[0062] In the "2-2-3" power divider arrangement above, there are three 2-way dividers (dividers 52, 56, 58) and four 3-way dividers (dividers 64, 66, 68, 70). In summary, a total of 7 dividers are used. As each divider is likely to create "defects" in the network (e.g. phase-unbalance and the like among the branched lines) the "2-2-3" power divider arrangement is expected to minimize the disturbances compared with other arrangements where a total of 10 dividers or more are used to achieve the same number of outputs.

[0063] In addition, in this "2-2-3" configuration, since the 2-way dividers have good characteristics of isolation and phase/amplitude balancing between the arms, any unbalance introduced by one of the last 3-way dividers can be locally tuned on that divider itself (i.e. one needs to measure only the 3 ports of that divider) without affecting all the other remaining ports (i.e. 9 ports)

Tests

[0064] Tests were made to compare the behavior of the different power divider arrangements.

[0065] Testing conditions were the following:

- input signal frequency 6-14GHz;
- input signal power 0dBm.

[0066] All output ports were terminated with non-perfectly matched loads ($\text{Re}\{Z\}=50\text{ohm} \pm 20\%$; and $\text{Im}\{Z\}$ within a $\pm 10^\circ$ of phase variation).

[0067] A "3-2-2" power divider according to the scheme of fig. 1a and fig. 1 layout have been tested.

[0068] In a first test, the "3-2-2" power divider included 2-way dividers of Wilkinson type, according to the scheme of fig. 2a, with output arms a, b having impedance $Z_1=70\text{ohm}$ and a 100-ohm resistor R between the output arms. The 3-way divider was made according to the electric scheme of fig. 2b, and had output arms e, f, g having impedance $Z_2=86.6\text{ohm}$ each.

[0069] In a second test, a "2-2-3" power divider according to the scheme of fig. 3a and the layout of figs. 3, 4 have been tested.

[0070] In the tested "2-2-3" power divider the 2-way dividers were of Wilkinson type, according to the scheme of fig. 2a, with output arms a, b having impedance $Z_1=70\text{ohm}$ and a 100-ohm resistor R between the output arms, and the 3-way dividers were of Wilkinson type, according to the electric scheme of fig. 3a, having output arms e1, f1, g1 with impedance $Z_3=86.6\text{ohm}$ each; three resistors $R_3=150\text{ohm}$ were used between the output arms.

[0071] Graphs of fig. 8 shows the error E (in dB) in the output ports in "3-2-2" arrangements, in the band 6-14 GHz.

[0072] Graphs of fig. 9 show the error E (in dB) in the output ports in "2-2-3" power divider arrangement, including both 2-way and 3-way Wilkinson-type dividers.

[0073] As the tests show, by replacing the 3-way divider of the "3-2-2" arrangement with a 3-way, Wilkinson-type divider a significant error reduction was obtained.

[0074] The use of the "2-2-3" power divider arrangement further reduces the errors in all the ports.

[0075] Preferably, the power divider has been designed for use in C-Band microwave systems.

[0076] However, the same architecture may be scaled to work at other frequency bands, by respecting the physical limits related to the resistor dimensions.

Claims

1. Multi-stage cascaded power divider having a single input port and a plurality of output ports, **characterized in that** it comprises a first stage (S1) consisting of a first 2-way Wilkinson power divider, a second stage (S2) consisting of a second and a third 2-way Wilkinson power dividers and a third stage (S3) consisting of four 3-way Wilkinson power dividers, wherein the first stage is connected to the single input port and the third stage including the 3-way Wilkinson power divider is connected to the plurality of ports.
2. Multi-stage cascaded power divider according to claim 1, **characterized in that** it comprises in sequence an input port (50), a first stage (S1) consisting of a first 2-way Wilkinson power divider (52) having a first arm (46a) connected to the input port and two output arms (46b, 46c), a second stage (S2) consisting of a second and a third 2-way Wilkinson power dividers (56, 58), each divider having a first arm connected to one of the two output arms (46b, 46c) of the first 2-way Wilkinson power divider and two output arms (46d, 46e, 46d', 46e'), and a third stage (S3) consisting of four 3-way Wilkinson power dividers (64, 66, 68, 70), each 3-way Wilkinson power divider having a first arm connected to one of the two output arms of the second and third 2-way Wilkinson power dividers and respective output arms (46f, 46g, 46h) connected to the plurality of output ports (76, 77, 78, 82, 83, 84, 86, 87, 88, 92, 93, 94).
3. Multi-stage cascaded power divider according to claim 1, **characterized in that** it is a planar, microstrip circuit construction, comprising a path of microstrip transmission lines (46).
4. Multi-stage cascaded power divider according to claim 3, **characterized in that** it comprises a base

(40) housing a PCB (44) bearing the path of transmission lines (46), such transmission lines (46) forming the first, the second and the third 2-way Wilkinson power dividers (52, 56, 58) and forming the four 3-way Wilkinson power dividers (64, 66, 68, 70). 5

5. Multi-stage cascaded power divider according to claim 3, **characterized in that** the input port (50) and the plurality of output ports (76, 77, 78, 82, 83, 84, 86, 87, 88, 92, 93, 94) are all arranged in a line along one side of the base (40). 10
6. Multi-stage cascaded power divider according to claim 3, **characterized in that** each of the four 3-way Wilkinson power dividers (64, 66, 68, 70) comprise resistors (100, 101, 102) between the relevant output arms (46f, 46g, 46h). 15
7. Multi-stage cascaded power divider according to claim 6, **characterized in that** the resistors (100) electrically connecting the two output side arms (47b, 47c) of each of the four 3-way Wilkinson power dividers (64, 66, 68, 70) are bridging over the central arm (47d) and are electrically isolated from said central arm (47d). 20
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8. Multi-stage cascaded power divider according to claim 3, **characterized in that** the base (40) is made of an electrically conductive metal alloy. 30
9. Multi-stage cascaded power divider according to claim 3, **characterized in that** the base (40) comprises a trench (42) housing the PCB (44).
10. Multi-stage cascaded power divider according to claim 8, **characterized in that** at least a portion of the output arms of the 3-way Wilkinson power dividers is a suspended microstrip transmission line. 35
11. Multi-stage cascaded power divider according to claim 8, **characterized in that** at least a portion of the transmission lines of the first and second stage is a suspended microstrip transmission line. 40
12. Multi-stage cascaded power divider according to claim 8, **characterized in that** the input port and the plurality of output ports are electrically connected to coaxial connectors. 45

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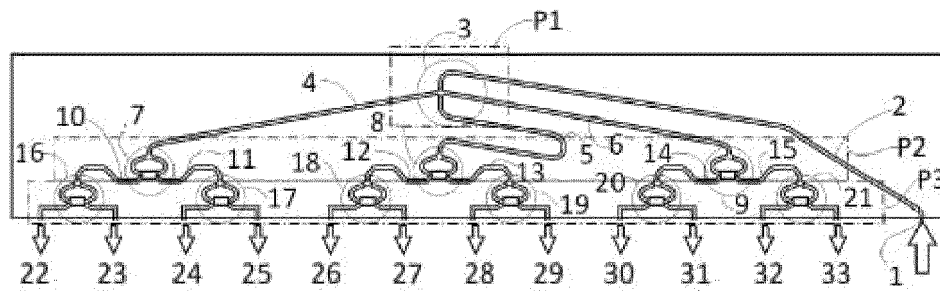


Fig. 1

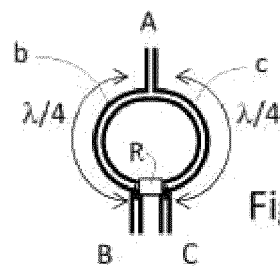


Fig. 2

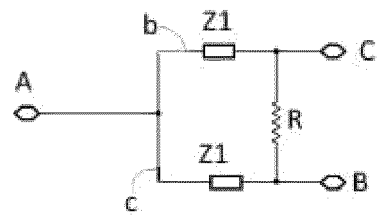


Fig. 2a

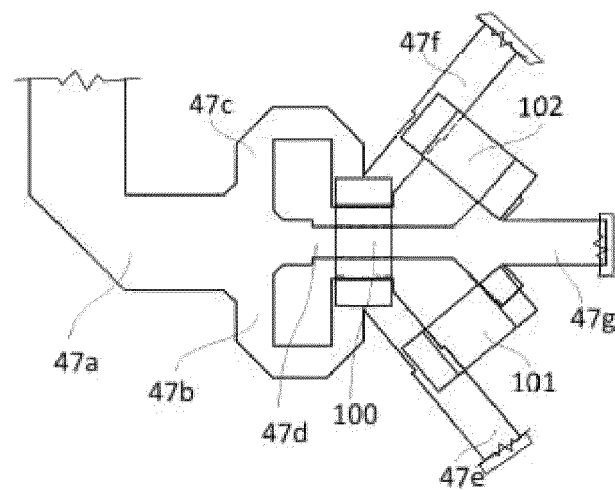


Fig. 6

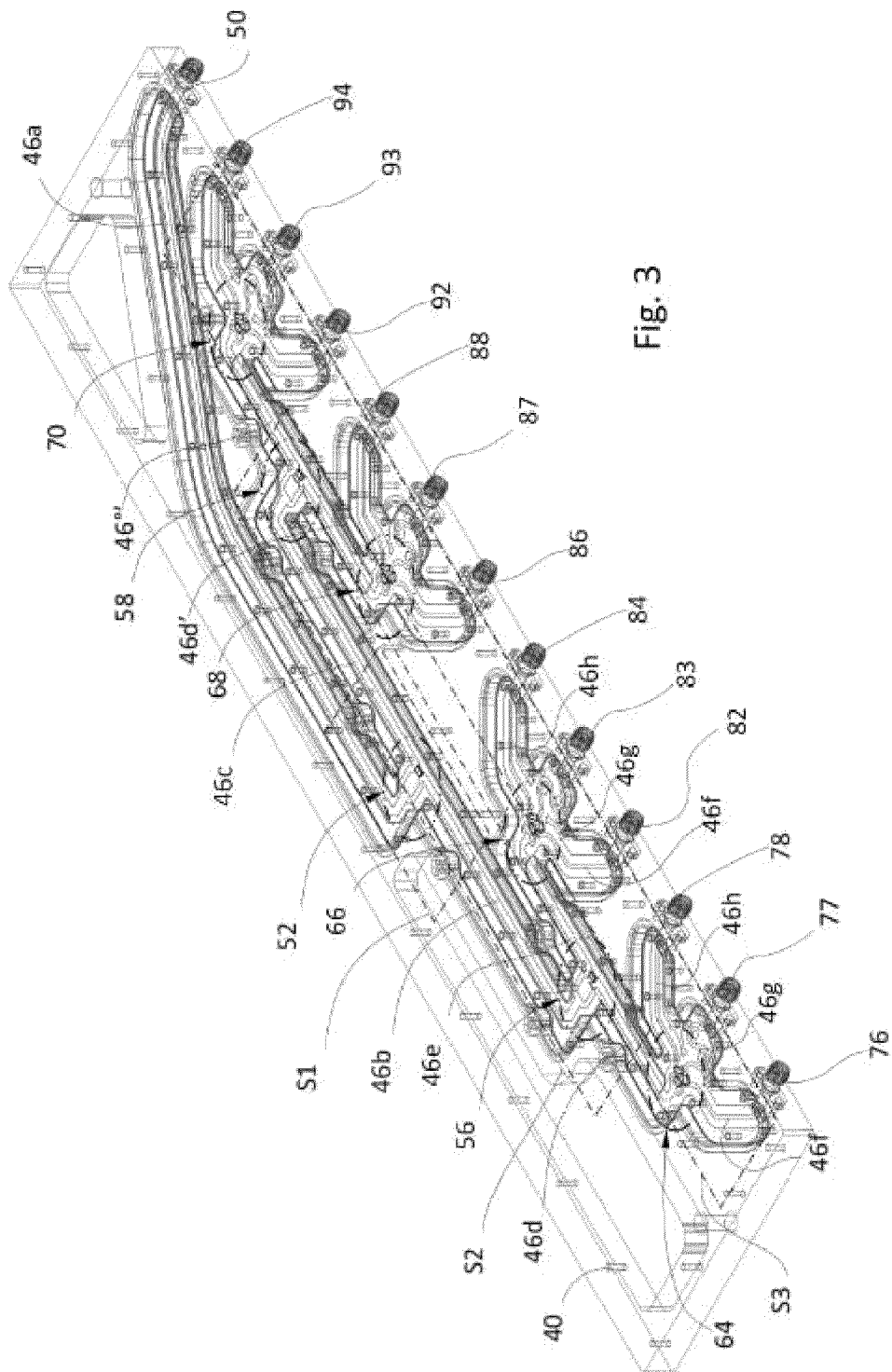


Fig. 3

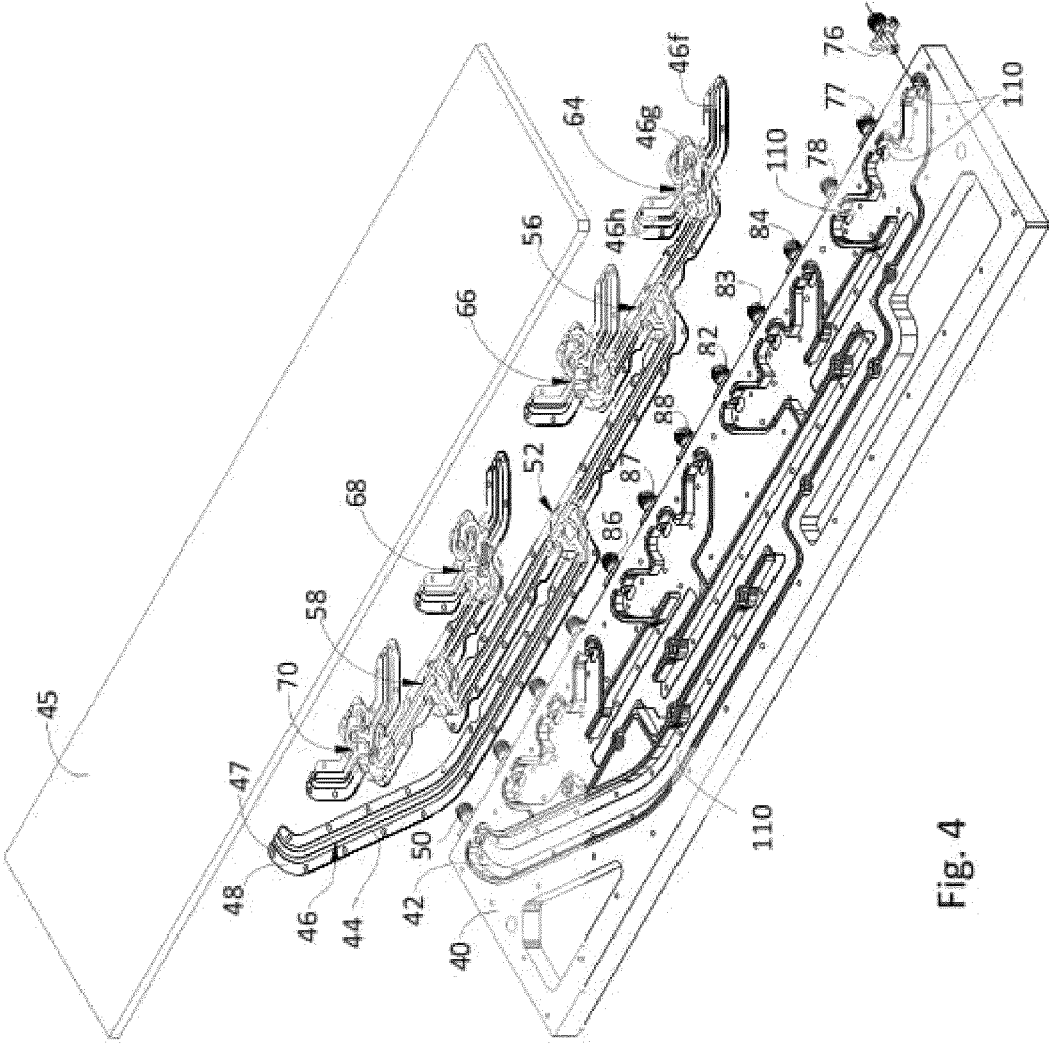
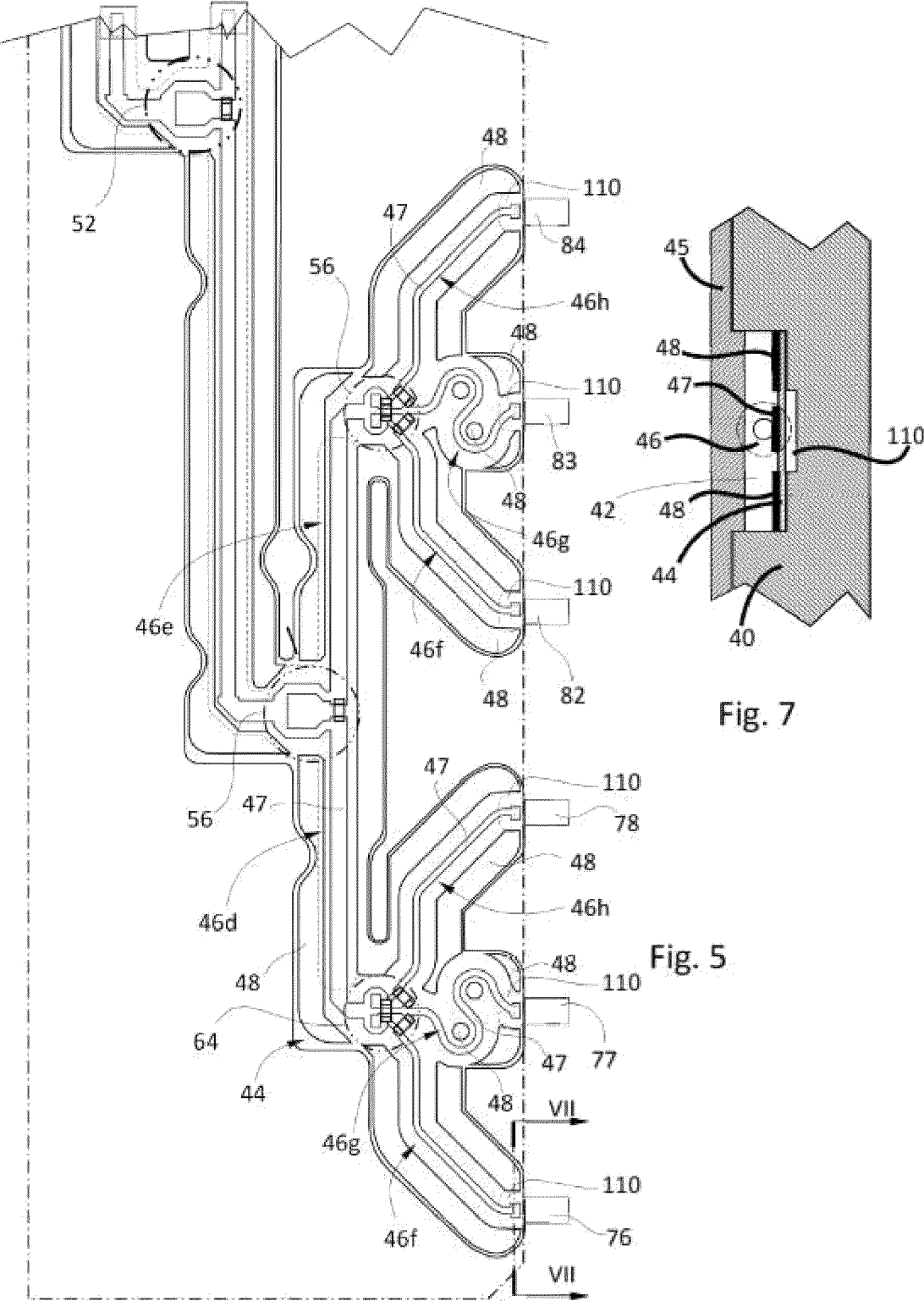


Fig. 4



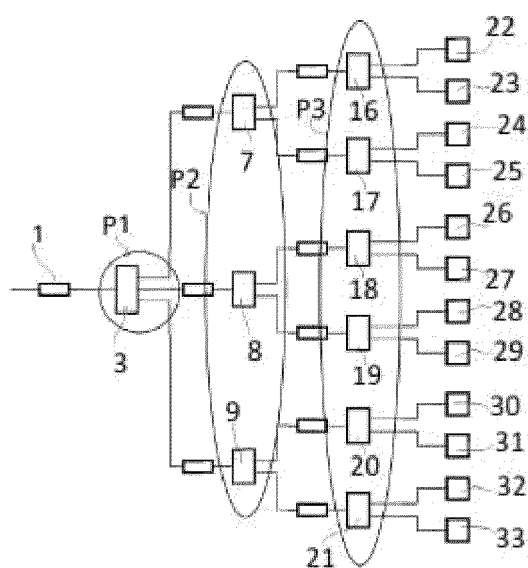


Fig. 1a

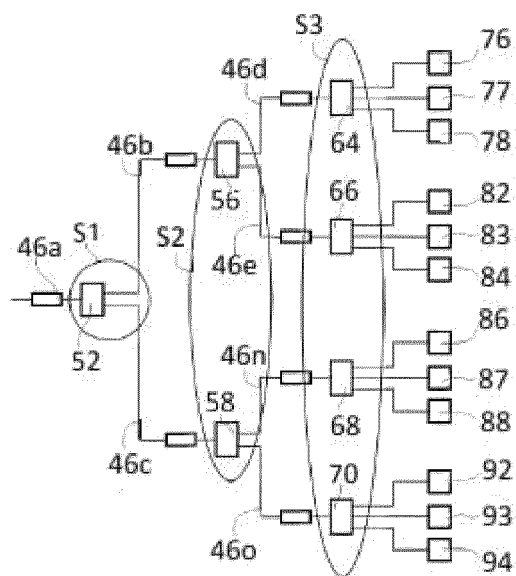


Fig. 3a

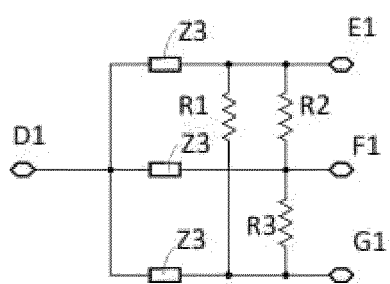


Fig. 6a

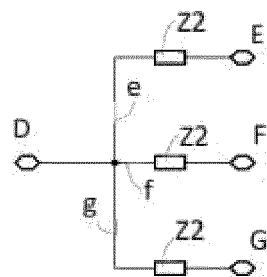


Fig. 2b

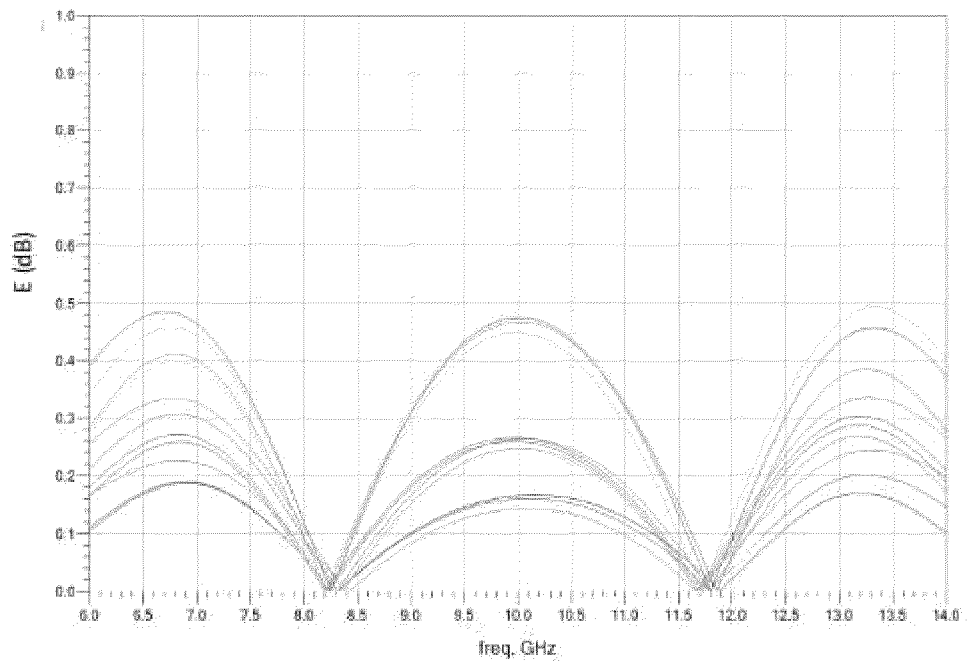


Fig. 8

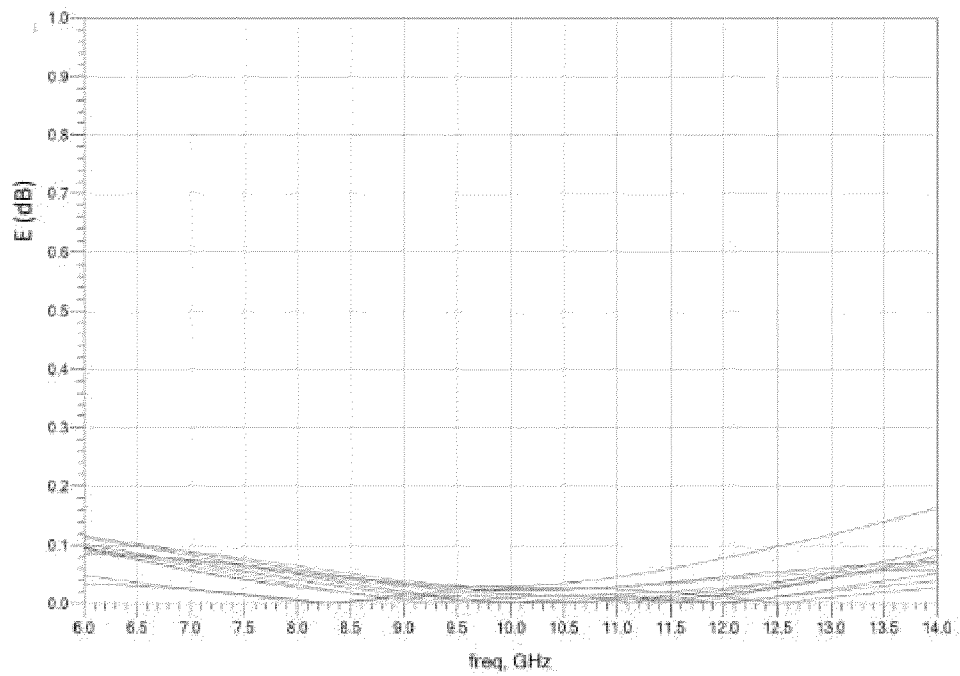


Fig. 9



EUROPEAN SEARCH REPORT

Application Number

EP 24 18 8486

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	NYCCY AGMA PRIBAWA ET AL: "Wilkinson topology-based 1:6 power divider for L-band frequency application", TELECOMMUNICATION SYSTEMS, SERVICES, AND APPLICATIONS (TSSA), 2012 7TH INTERNATIONAL CONFERENCE ON, IEEE, 30 October 2012 (2012-10-30), pages 215-217, XP032275842, DOI: 10.1109/TSSA.2012.6366054 ISBN: 978-1-4673-4549-1	1-8,12	INV. H01P5/16
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