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(54) AN ELECTRONIC CIRCUITRY FOR AN ACTIVE PHASED ARRAY RADAR SYSTEM

(57) An electronic circuitry (100) for an active phased array system with multiple transmit/receive, T/R, channels (101a 101b) is disclosed. The electronic circuitry (100) comprises: at least one pair of circuit carriers (110, 120), electronic components (200), at least one cooling plate (300), and one or more cooling channels (400). The at least one pair of circuit carriers (110, 120) includes a first circuit carrier (110) and a second circuit carrier (120), each circuit carrier (110, 120) having a front surface and a rear surface. The electronic components (200) are mounted on the front surface of the circuit carriers (110, 120), each electronic component (200) being associated with one or multiple of the T/R channels (101) to process transmit or receive signals. The at least one cooling plate (300) has two opposite sides, wherein the rear surface of the first circuit carrier (110) is attached to one side and the rear surface of the second circuit carrier (120) attached to an opposite side to hold the circuit carriers (110, 120) in a sandwich structure. The one or more cooling channels (400) are formed by the at least one cooling plate (300) between the rear surface of the first circuit carrier (110) and the rear surface of the second circuit carrier (120), the one or more cooling channels (400) are adapted to accommodate a coolant to cool the one or more electronic components (200).

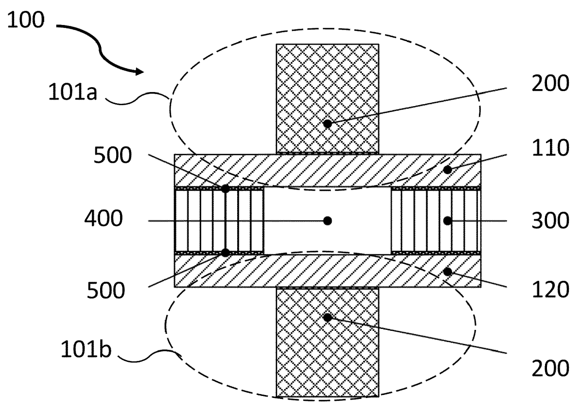

Fig. 1a

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Description

[0001] The present invention relates to an electronic circuitry for an active phased array system, to an active phased array system, a method for manufacturing the electronic circuitry, and, in particular, to a low-profile electronic circuitry with integrated cooling channels for liquid cooling.

BACKGROUND

[0002] The arrangement of T/R channels is important for all active phased array systems. Active electronically scanned array, AESA, technology typically needs solid-state T/R channels that can conventionally be built in tile-based or in plank-based arrangement.

[0003] **Fig. 5** illustrates the top view of a conventional tile-based arrangement 10 of T/R channels 11 of an active electronically scanned array having a plane architecture, wherein the radiating aperture is perpendicular to the drawing plane. Each tile includes several electronic components 20 and represents a T/R channel 11 which has height H and a width W. The individual T/R channels 11 are assembled in a plane of the radiating aperture. The minimum achievable radiator pitch in this arrangement is limited in both lateral dimensions by the size H x W of a T/R channel 11. For fully populated AESAs in X-band this arrangement can only be realized using a reduced T/R channel 11. Using this arrangement, a lot of additional functionality has to be discarded and the cooling of this setup is limited. The required T/R channel density of AESAs operating at higher frequencies than X-band or providing full polarimetric capability at X-band cannot be met.

[0004] Therefore, tile-based arrangements have the following drawbacks: (i) the achievable channel density per radiating aperture area is restricted in both lateral dimensions by the mounting area, (ii) the mounting area is limited, (iii) only T/R channels with limited functionality or performance can be integrated, and (iv) an acceptable heat dissipation out of the circuit carrier is challenging. Thus, the power class of corresponding antennas is reduced compared to plank-based arrangements.

[0005] **Fig. 6** illustrates the top view of a conventional plank-based arrangement 15 of T/R channels 30 of an AESA having a stack-up architecture. The individual T/R channels 30 are assembled on planks extending perpendicular to the drawing plane. Each plank is oriented perpendicular to the radiating aperture (and thus perpendicular to the drawing plane). A stack of several planks forms the antenna. A plank includes a base plate 17 and a plank carrier plate 18 which comprises cooling channels 19 of a liquid cooling system. The cooling channels 19 are an integrated part of the plank carrier plate 18 on which the T/R channels 30 are mounted. The T/R channels 30 or T/R multipacks are screwed or adhesively bonded or soldered to this carrier 18. Caused by the minimum realizable thickness of the individual elements of a plank, its height H does not support a dense stacking which is required for fully populated, dual-polarized antennas operating above X-band.

[0006] The base plates 17 and the plank carrier plates 18 are essential parts of a conventional plank-based arrangement 15 of T/R channels 30. The individual T/R channels 30 or multipacks comprising multiple channels are assembled on the dedicated circuit carriers 16 that are mounted on the base plates 17. The circuit carrier 16 together with the base plate 17 form an integral unit. Electronic components 20 are mounted on the integral unit, and the integral unit is designed to be positioned on the liquid cooling system. Therefore, the base plate 17 is an intermediate layer and the transfer of heat from the circuit carrier 16 to the base plate 17 is not optimized. For thermal and mechanical reasons, the base plate 17 of these assemblies comprise a metallic material. A row of T/R channel assemblies is mounted on the plank carrier 18. This is a metallic plate comprising channels 19 for a liquid or an air cooling system.

[0007] These conventional plank-based arrangements 15 have the drawbacks that a significantly increased antenna depth is needed compared to the tile-based arrangement 10 of Fig. 5. Yet, it offers a higher degree of freedom for the architecture of the individual channel, a higher power class for the T/R channels 30 and the potential for a higher T/R channel density per radiating aperture plane. Nevertheless, integration density is limited by the restricted miniaturization of T/R channel height H. Several layers with a dedicated function, each requiring a certain minimum height are necessary for this setup.

[0008] Therefore, with the increasing number of electronic components used in AESA systems, there is a demand for alternative solutions in order to be able to further optimize the antenna depth, increase the T/R channel density and improve the heat dissipation of a low-profile electronic circuitry with integrated cooling channels.

SUMMARY OF THE INVENTION

[0009] At least some of the above-mentioned problems are overcome by an electronic circuitry with integrated cooling channels according to claim 1 or a method for manufacturing the electronic circuitry according to claim 11. The dependent claims refer to further advantageous realizations of the subject matters defined in the independent claims.

[0010] The present invention relates to an electronic circuitry for an active phased array system with multiple transmit/receive, T/R, channels. The electronic circuitry comprises:

- at least one pair of circuit carriers including a first circuit carrier and a second circuit carrier, each circuit carrier having a front surface and a rear surface;
- electronic components mounted on the front surface of the circuit carriers, each electronic component being associated with one of the T/R channels (e.g. to process transmit and/or receive signals);
- at least one cooling plate with two opposite sides, wherein the rear surface of the first circuit carrier is attached to one side and the rear surface of the second circuit carrier is attached to an opposite side to hold the circuit carriers in a sandwich structure; and
- one or more cooling channels formed by the at least one cooling plate between the rear surface of the first circuit carrier and the rear surface of the second circuit carrier, the one or more cooling channels are adapted to accommodate a coolant to cool the one or more electronic components.

[0011] The front surface of the circuit carriers can be defined as the surface on which the electronic components will be mounted. The rear surface is then the surface opposite thereto. The electronic circuitry may further be arranged in superposed rows and forming a sandwich structure of a T/R module. The electronic components can be any part in the transmit and/or receive channels utilized in the AESA system to process transmit or receive signals or to provide needed power. In particular, the electronic components may include (power) amplifiers, RF switches, filter components, signal (pre)processors, etc. Optionally, antenna elements may also be part of the components, but they may also be separate components coupled to the electronic circuitry.

[0012] Optionally, the at least one cooling plate may be configured to form side walls of the one or more cooling channels and may be adapted to mechanically support the one or more circuit carriers and the electronic components mounted on the circuit carriers.

[0013] The material of the cooling plates may be selected so that the coefficient of thermal expansion, CTE, of the cooling plates and the circuit carriers match and the material of the cooling plates offers a good thermal conductivity.

[0014] Optionally, the at least one of the first and/or second circuit carriers may further include one or more cut-out portions. These cut-out portion(s) may expose parts of the cooling plate and may be used to mount one or more electronic components (directly) on the exposed cooling plate (e.g. to provide a better cooling for these components). Optionally, the exposed cooling plate forms a bridge between the at least one electronic component and a portion of the cooling channel to improve heat dissipation for the respective electronic component(s). The electronic component(s) may be highly dissipative electronic component(s).

[0015] The electronic circuitry may further comprise a heat spreader, located between the at least one electronic component and the exposed cooling plate(s).

[0016] For example, the one or more highly dissipative electronic component(s) (e.g. a power amplifier) may be positioned on the heat spreader(s) or directly on the cooling plate(s). The highly dissipative electronic components may be components of the three-dimensional AESA system that consume more energy than others, which may greatly increase the heat locally. So, these components benefit from effective heat dissipation. For these reasons, the highly dissipative electronic components may be mounted directly on a heat spreader that is located between the highly dissipative electronic components and the cooling plate or mounted directly on the cooling plate.

[0017] Optionally, the one or more electronic component(s) may process or enable to transmit and/or to receive signals, wherein the transmitted and the received signals are radio frequency or microwave signals. The radiating aperture (main direction of transmission/reception) is perpendicular to the sandwich structure of the T/R module.

[0018] Optionally, the at least one first circuit carrier and at least one second circuit carrier may be mounted on the at least one cooling plate by a fastener. The fastener may be one or more of the following: an adhesive, a solder, a gasket, a sinter-connection, a combination of thereof. The fastener may be positioned on the surface of the cooling plate(s) and/or on the surface of the circuit carrier(s) and adapted to connect the rear surface of the first circuit carrier and the rear surface of the second circuit carrier to the cooling plate(s). Optionally, the surface of the cooling plate(s) and/or the surface of the circuit carrier(s) is partially or completely covered by the fastener. The fastener may also be a mechanical fixing mean such as a screw, bolt, nail, welded-on, injection molded, or other mechanism known to those skilled in the art.

[0019] Optionally, the one or more cooling plate(s) may be surface coated and being leakproof with respect to the coolant. Moreover, the fastener may also be leakproof with respect to the coolant. For example, the material of the circuit carriers and the fastener may be compatible with the coolant and may be fitted to prevent coolant leakage and to provide an optimal fluid circulation. Therefore, the coolant may absorb the heat energy inside the cooling channels and may form an active high-performance circulating heat dissipation system. Additionally, the one or more circuit carriers may be a solid block with a square or a rectangular or else formed shape. The circuit carriers may have any shape, also circular or as a polygon. For example, the circuit carrier may contain arbitrarily shaped indentations, e.g. for fixing or attachment points.

[0020] Optionally, multiple pairs of circuit carriers are formed, wherein each of the multiple pairs supports a plurality of electronic components to form a plurality of separate T/R channels in a row. The multiple pairs of circuit carriers may be stacked on top of each other to form multiple separate T/R channels in a column. For this, a mounting structure for securing the stacked pairs may be provided. This stacked arrangement may be an AESA frontend. The involved T/R channels may control an array of antenna elements or may process their signals (receive/transmit signals).

[0021] It is understood that the number of electronic components or T/R channels may be different in different rows. Therefore, the array does not need to have a rectangular shape. It may have any shape, also circular or as a polygon.

[0022] Embodiments relate also to an active phased array system including an array of antenna elements connected to an electronic circuitry as described before. The antenna elements may be arranged to transmit and/or to receive RF signals in main direction or in an angular range about the main direction. When the electronic components are mounted on the at least one pair of circuit carriers along a line, the antenna elements may then be arranged to align the main direction perpendicular to a normal direction of the at least one pair of circuit carriers and perpendicular to a line of mounting the electronic components.

[0023] The present invention also relates to a method for manufacturing an electronic circuitry for an active phased array system with multiple T/R channels. The method comprises the following steps:

- providing at least one pair of circuit carriers including a first circuit carrier and a second circuit carrier, each circuit carrier having a front surface and a rear surface;
- providing at least one cooling plate with one or more cooling channels formed by the at least one cooling plate; and
- attaching the first circuit carrier and the second circuit carrier to opposite sides of at least one cooling plate in a sandwich structure so that the electronic components are assembled on opposite sides of the sandwich structure;
- mounting electronic components on the front surfaces of the circuit carriers, each electronic component being associated with one or multiple of the T/R channels to process transmit or receive signals,

wherein the one or more cooling channels are formed between the rear surface of the first circuit carrier and the rear surface of the second circuit carrier to accommodate a coolant to cool the one or more electronic components.

[0024] According to further embodiments, all features as described for the electronic circuitry may be realized by further optional method steps. Moreover, the order of steps can be different. For example, the electronic components can first be mounted on each circuit carrier before the circuit carriers with the electronic components are attached on opposite sides of the cooling plate. But is can also be the other way around, i.e. the electronic components may also be mounted on each circuit carriers only after they have been attached on opposite sides of the cooling plate.

[0025] When compared to the conventional arrangement of the multiple T/R channels (e.g. tile-based, plank-based as shown in Fig. **5** and Fig. 6), embodiments of the present invention provide the following advantages. Although in conventional arrangements any number of electronic components can be mounted on a circuit carrier, currently there is no optimized arrangement of the electronic components in an electronic circuitry available that is able to operate with reduced T/R channels height and in the same time to maintain a high-performing heat dissipation system. Therefore, embodiments of the present invention can particularly be used for such electronic circuitry where also the heat transfer from the highly dissipative electronic components are optimized by a cut-out portion of the circuit carrier. Consequently, embodiments are of benefit for providing a low-profile electronic circuitry with integrated cooling channels for liquid cooling that is part of a multiple T/R channels with reduced height and of at least one T/R module.

[0026] During the operation of the electronic circuitry, which is part of multiple T/R channels or of at least one T/R module, the electronic components need to be cooled down and maintained at a safe temperature so as to maximize the efficiency and the stability of the AESA. This effect is achieved by low-profile electronic circuitry with integrated cooling channels.

[0027] Using conventional arrangements of T/R channels, the necessary miniaturization especially in direction perpendicular to the plane of a plank is not feasible. The invention overcomes this limit and allows for a higher integration density of T/R channels in this direction by providing a highly miniaturized setup of the electronic circuitry of the T/R channels integrating even the liquid cooling in the T/R multipack assembly itself. In general, embodiments are applicable wherever electronic circuitries with a very low profile and a dedicated cooling are of advantage.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] Some embodiments of the present invention will be described in the following by way of examples only, and with respect to the accompanying figures, in which:

Fig. 1a shows a schematic arrangement of an electronic circuitry with integrated cooling channel according to an embodiment of the present invention (cross-sectional view);

Fig. 1b shows a schematic arrangement of an electronic circuitry with integrated cooling channel and an alternative fastener according to another embodiment of the present invention (cross-sectional view).

Fig. 2a shows a schematic arrangement of an electronic circuitry with a cut-out portion on the circuit carrier and optimized thermal coupling of electronic component(s) directly mounted on the cooling plate(s) according to an embodiment of the present invention (cross-sectional view);

Fig. 2b shows a schematic arrangement of the electronic circuitry with a cut-out portion on the circuit carrier and optimized thermal coupling of electronic component(s), where a heat spreader is located between the electronic component(s) and the cooling plate(s) according to another embodiment of the present invention (cross-sectional view);

Fig. 3 shows a low-profile electronic circuitry for an active phased array system that is part of multiple T/R channels and of at least one T/R module according to an embodiment of the present invention (cross-sectional view);

Fig.4 shows a schematic flow chart of a method for manufacturing the electronic circuitry according to embodiments;

Fig. 5 illustrates an example of a tile-based arrangement of T/R channels of an AESA having a plane architecture, according to prior art (top view); and

Fig. 6 illustrates an example of a plank-based arrangement of T/R channels of an AESA having a stack-up architecture, according to prior art (cross-sectional view);

DETAILED DESCRIPTION

[0029] Various examples will now be described more fully with reference to the accompanying drawings in which some examples are illustrated.

[0030] Accordingly, while examples are capable of various modifications and alternative forms, the illustrative examples in the figures will herein be described in detail. It should be understood, however, that there is no intent to limit examples to the particular forms disclosed, but on the contrary, examples are to cover all modifications, equivalents, and alternatives falling within the scope of the disclosure. Like numbers refer to like or similar elements throughout the description of the figures.

[0031] It will be understood that when an element is referred to as being "connected" or "coupled" to another element, it can be directly connected or coupled to the other element or intervening elements may be present. In contrast, when an element is referred to as being "directly connected" or "directly coupled" to another element, there are no intervening elements present. Other words used to describe the relationship between elements should be interpreted in a like fashion (e.g., "between" versus "directly between," "adjacent" versus "directly adjacent," etc.).

[0032] The terminology used herein is for the purpose of describing illustrative examples only and is not intended to be limiting. As used herein, the singular forms "a," "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises," "comprising," "includes" and/or "including," when used herein, specify the presence of stated features, steps, operations, elements and/or components, but do not preclude the presence or addition of one or more other features, steps, operations, elements, components and/or groups thereof.

[0033] Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which examples belong. It will be further understood that terms, e.g., those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

[0034] **Fig. 1a and fig. 1b** show two embodiments of an electronic circuitry 100 for an active phased array system with two T/R channels 101a, 101b. The principle schematic stack-up of the present embodiments of the invention is shown in a cross-sectional view. The shown circuitry 100 may also be part of a larger circuitry.

[0035] The depicted electronic circuitry 100 comprises a pair of circuit carriers 110, 120, including a first circuit carrier 110 and a second circuit carrier 120, each circuit carrier 110, 120 having a front surface and a rear surface. The electronic circuitry 100 further comprises two electronic components 200 mounted on the front surfaces of the circuit carriers 110, 120, each electronic component 200 being associated with one of the T/R channels 101a, 101b to transmit and receive a plurality of signals. Optionally, multiple of the depicted circuitry 100 may be combined to form a T/R module with any number T/R channels 101.

[0036] The electronic components 200 are assembled on both sides of the circuit carriers 110, 120. All standard assembly methods are feasible. Depending on the chosen assembly processes it may be possible to perform the components assembly on the circuit carriers 110, 120 before their mounting on the cooling plate 300, too.

[0037] The electronic circuitry 100 may further comprise at least one cooling plate 300 with two opposite sides onto which the rear surface of the first circuit carrier 110 and the rear surface of the second circuit carrier 120 may be mounted on opposite sides to hold the circuit carriers 110, 120 with the electronic components 200 in a sandwich structure. The at least one cooling plate 300 is configured to cool the electronic components 200.

[0038] Moreover, the electronic circuitry 100 may comprise one or more integrated cooling channels 400 formed by the at least one cooling plate 300 between the rear surface of the first circuit carrier 110 and the rear surface of the second circuit carrier 120 and maybe adapted to accommodate a (circulating) coolant to cool the one or more electronic components 200.

[0039] The at least one cooling plate 300 may be configured to form side walls of the one or more cooling channels 400 and may be adapted to mechanically support the one or more circuit carriers 110, 120 and the electronic components 200 mounted on the circuit carriers 110, 120. The advantage of cooling plate(s) 300 is to prevent the electronic components, for example electronic components 200, from overheating.

[0040] For example, the cooling plate(s) 300 may be configured to be in thermal contact with the electronic components 200 and may act as cooling fins to facilitate the heat transfer from the electronic components 200 to the coolant. Therefore, the circuit carriers 110, 120 may be adapted to form the top and the bottom wall of the cooling channels 400 and the cooling channels 400 are filled up with a coolant. As a result, the cooling plate(s) 300 together with the cooling channels 400 may allow a better heat dissipation for the increased density of electronic components 200 which is made possible by embodiments.

[0041] Thus, the cooling plate(s) 300 exhibit a second functionality besides their primary function to form the mechanical carrier of the setup. In order to optimize the overall height of the setup, the cooling channels 400 within the cooling plate 300 do not need a top and/or bottom wall in general. The cooling channels 400 may directly be closed by the circuit carriers 110, 120, which may be formed as printed circuit boards or as ceramic substrates like e.g. low-temperature co-fired ceramics, LTCC.

[0042] The integrated cooling channels 400 may serve as a liquid coolant passages for the coolant and may ensure the circulation of the liquid from one region to another. The coolant may effectively extract heat from the electronic components 200 and minimize the cooling system power consumption. Optionally, the coolant may be an air coolant. Furthermore, the cooling channels 400 may have a meandering shape with an inlet and outlet that provides a connection to an optional external heat sink (e.g. active cooling unit, ventilation, cooling ribs etc.).

[0043] The material of the circuit carrier 110, 120 may include, but not limited to aluminum, ceramic, electrically and thermally conductive plastics, etc. For example, the material of the circuit carrier 110, 120 may be compatible and leakproof with respect to the coolant. Furthermore, the connection between cooling plate(s) 300 and circuit carriers 110, 120 may also be leakproof with respect to the coolant.

[0044] The at least one first circuit carrier 110 and the at least one second circuit carrier 120 may be mounted on the at least one cooling plate 300 by a fastener 500, and the fastener 500 on **Fig. 1a** and **Fig. 1b** may be the same or different.

[0045] For example, the fastener 500 between each circuit carrier 110, 120 and the cooling plate(s) 300 may be one or more of the following: an adhesive, a solder, a gasket, a sinter connection, or a combination of thereof. In Fig. 1a, the fastener 500 is formed as an interface layer to the cooling plate 300. However, the fastener 500 may also be achieved by welded-on or mechanically (e.g. screwing) only locally as it is indicated in Fig. 1b. For example, the fastener 500 may be introduced in-between cooling plate(s) 300 and circuit carriers 110, 120.

[0046] The cooling plate(s) 300 may also be composed of hollow channels, for example fin structure, micro-structure, porous structure, etc. The surface of the cooling plate(s) 300 maybe coated. The coating on the surface of the cooling plate(s) 300 may be for example an anti-corrosion coating, a conversion coating, a hydrophobic coating, etc. For example, the coolant may be water, glycol solution, silicone oil, nano-fluids, etc..

[0047] The electrical connection to and from the electronic components 200 may be provided by the circuit carriers 110, 120. They may be circuit boards using bonding wires or solder to provide the electric contacts. The electric bonding wire structure is not shown on the figures. The electric wire system connecting the electronic circuitries 100 may be realized with any standard wires and/or cables available in any active phased array system.

[0048] **Fig. 2a** shows a cross-sectional view of a schematic arrangement of the electronic circuitry 100 according to another embodiment. In this embodiment, at least one cut-out portion 115 is formed in the circuit carrier 110. The cut-out circuit carrier 115 may leave the surface of the cooling plate(s) 300 free and may accommodate an electronic component 250 which may be highly dissipative and thus may be directly mounted on the cooling plate(s) 300. Therefore, the thermal coupling of the highly dissipative electronic components 250 to the cooling system is further optimized.

[0049] Moreover, the cooling channels 400 may be covered locally by a remaining ceiling/bottom of the cooling plate(s) 300 to provide a bridge structure 305. For example, the highly dissipative electronic components 250 can be attached directly to the cooling plate(s) 300 and a very low thermal resistance to the cooling channels 400 can be achieved, because the thickness of the bridge 305 can be as low as needed for a mechanical support. The electric contacting can again be established using wire bonding and/or other contacting means.

[0050] **Fig. 2b** also shows a cross-sectional view of a schematic arrangement of the electronic circuitry 100 according to yet another embodiment having at least one cut-out portion 115 on the circuit carrier 110. The cut-out portion 115 may again be configured to provide an optimized thermal coupling for one or more of the electronic components 200, 250. Optionally, a heat spreader 600 can be introduced between the electronic component 200, 250 and the cooling plate 300. The electronic components 200, 250 may be mounted (directly) on a heat spreader 600. Some of the electronic components 200 may again be highly dissipative electronic components 250. The heat spreader 600 may be located between the highly dissipative electronic components 250 and the cooling plate(s) 300 and maybe of particular advantage if the electronic component 200, 250 extends laterally beyond the cooling channel 400 or the bridge 305 is very thin and needs a reinforcement. Furthermore, the heat spreader may implement a lateral spreading of the heat generated by the highly dissipative component thus enlarging the effective area of heat transfer to the cooling plate. Therefore, the highly dissipative electronic components 250 may be connected directly or as close as possible to the cooling system without intermediate circuit carriers 110, 120.

[0051] The electronic components 200 and the highly dissipative electronic components 250 are often packed closely together, operate in a narrow and closed environment, limiting the available space for a cooling system. Using the cut-out portions 115 with optional heat spreaders 600 may provide the advantage that each electronic component 200 can be cooled as desired.

[0052] When the heat dissipation would not be optimized, the internal temperature of the system could increase resulting in damages of the electronic components 200, 250, degrade performances or failing functions, thus affecting the reliability of the AESA. Embodiments mitigate this risk significantly. For example, the heat spreader 600 may be configured to provide a uniform temperature distribution, a faster heat exchange, thus, maintain the safe operating temperature of the electronic components 200, 250, especially the highly dissipative electronic component 250.

[0053] The heat spreader 600 may be made of materials with high thermal conductivity for efficient heat transfer. In addition, the heat spreader 600 may also be mounted on the top of the cooling plate(s) 300. The cooling plate(s) 300 may provide the side walls of the one or more cooling channels 400 through which the coolant flows and the cut-out portion 115 is configured to cool down the highly dissipative electronic components 250.

[0054] Alternatively or in addition, cut-out portions 115 may be formed within the other circuit carriers such as the second circuit carrier 120. Or, at mounting positions of an accordant electronic component 200, 250 a cut-out portion maybe implemented in substrate layers of the circuit carriers 110, 120.

[0055] **Fig. 3** shows a cross-sectional view of an electronic circuitry 100 for an active phased array electronic system according to yet another embodiment. It represents a T/R module with an array of T/R channels 101, 101a, 101b extending laterally in two directions.

[0056] The T/R module may comprise M (M=1,2, 3, ...) T/R channels 101 in each row (horizontal direction) and N (N=1,2, 3, ...) T/R channels 101 in each column (vertical direction). Each T/R channel may have a vertical height H and a horizontal width W.

[0057] This configuration can be manufactured by stacking multiple pairs of circuit carriers 110, 120 on top of each other, wherein each of the multiple pairs include a first circuit carrier 110 and a second circuit carrier 120 and may support a plurality of electronic components 200, 250. According to embodiment, the number of T/R channels 101 in each row may be different. The resulting AESA frontend may comprise M times N T/R channels 101 defining a rectangular array.

[0058] For example, a T/R module or T/R multipack is a double-sided module including a certain number of T/R channels 101. By arranging several T/R modules next to each other and stacking them vertically, this may become the AESA frontend.

[0059] However, the array of T/R channels 101 does not need to be rectangular, it may have any shape (e.g. circular, oval, polygon with any number of corners). This array-shaped electronic circuitry 100 may be configured to form a body of an AESA frontend, wherein antenna elements can be mounted on this array (e.g. top side in Fig. 3). As result, the AESA frontend represents a non-planar sandwich structure extending as a three-dimensional structure.

[0060] **Fig 4** shows a schematic flow chart for a method for manufacturing an electronic circuitry 100 for an active phased array system with multiple transmit/receive, T/R, channels 101a 101b. The method comprises:

- providing S110 at least one pair of circuit carriers 110, 120 including a first circuit carrier 110 and a second circuit carrier 120, each circuit carrier 110, 120 having a front surface and a rear surface;
- providing S120 at least one cooling plate 300 with one or more cooling channels 400 formed by the at least one cooling plate 300;
- attaching S130 the first circuit carrier 110 and the second circuit carrier 120 to opposite sides of at least one cooling plate 300 in a sandwich structure; and
- mounting S140 electronic components 200 on the front surfaces of the circuit carriers 110, 120, each electronic component 200 being associated with one or multiple of the T/R channels 101 to process transmit or receive signals.

[0061] According to further embodiments, the order of steps (S110-S140) can be different. For example, the electronic components can first be mounted on each circuit carrier before the circuit carriers with the electronic components are attached on opposite sides of the cooling plate. But is can also be the other way around, i.e. the electronic components may also be mounted on each circuit carriers only after they have been attached on opposite sides of the cooling plate.

[0062] The one or more cooling channels 400 can be formed between the rear surface of the first circuit carrier 110 and the rear surface of the second circuit carrier 120 to accommodate a coolant to cool the one or more electronic components 200.

[0063] Embodiments provide the following advantages:

- The height miniaturization in a plank-based arrangement is improved by introducing the layer stack-up of the electronic circuitries 100.
- Some layers can take over multiple functions. Thus, the total number of layers and the height of the setup can be reduced significantly resulting in a very low profile for the electronic circuitry 100.
- The electronic circuitry 100 can replace the use of the conventional base plate, for example as an intermediate layer in conventional plank-based arrangement of T/R channels
- The sandwich structure of the electronic circuitries 100 is optimized, therefore the height of one T/R channel 101 is half of the height of an electronic circuitry 100. Therefore, broadband, multifunctional, fully populated and lightweight AESAs can be achieved that operate at higher frequencies than state-of-the-art AESAs operating in X-band or below.
- The sandwich structure reduces the depth of the T/R channels 101 compared to the conventional arrangement of T/R channels (e.g. plank-based).
- Overall a lighter AESA frontend is made possible.
- An efficient cooling is provided by the cooling channel(s) 400, which in particular enable a liquid cooling with a coolant.
- The coolant flows directly beneath the heat generating electronic components 200, 250, so that minimal metallic or other material is required to promote heat conduction to the coolant. Therefore, a better heat exchange for the electronic components 200, 250 is achieved.
- Manufacturing costs of the T/R module of an active phased array system with hierarchical architecture can be reduced and the manufacturing yield can be improved.

[0064] In summary, with the sandwich structure of the electronic circuitry 100, a significantly smaller pitch between electronic components 200, 250 may be achieved that allows for electronic beam scanning over the relevant angular range without the occurrence of grating lobes. The smaller radiator pitch is intensified by the demand for full polarimetric operation of the antenna. The requirement for smaller radiator pitch transfers directly to the maximum size which can be accepted for the individual T/R channels 101.

[0065] The layer stack-up of the electronic circuitry 100 including cooling channel(s) 400 and the potential for double-sided assembly allows for a reduced T/R channel 101 height. Thus, integration density of T/R channels 101 in the height dimension can be enhanced significantly as visible in Fig. 3. At the same time, the present setup of the electronic circuitry 100 allows for a very direct connection of dissipative electronic components (e.g. 200, 250) to the (liquid) cooling system. Therefore, an efficient heat transfer out of the assembly is ensured.

[0066] The description and drawings merely illustrate the principles of the disclosure. It will thus be appreciated that those skilled in the art will be able to devise various arrangements that, although not explicitly described or shown herein, embody the principles of the disclosure and are included within its scope.

[0067] Furthermore, while each embodiment may stand on its own as a separate example, it is to be noted that in other embodiments the defined features can be combined differently, i.e. a particular feature described in one embodiment may also be realized in other embodiments. Such combinations are covered by the disclosure herein, unless it is stated that a specific combination is not intended.

List of reference signs

[0068]

100	electronic circuitry
101, 101a, 101b T/R	channels
110, 120	circuit carriers
115	cut-out portion of a circuit carrier
200	electronic components
250	(highly dissipative) electronic components
300	cooling plates
305	bridge formed by cooling plates
400	cooling channels
500	fastener
600	heat spreader

Claims

1. An electronic circuitry (100) for an active phased array system with multiple transmit/receive, T/R, channels (101a

101b), the electronic circuitry (100) comprising:

at least one pair of circuit carriers (110, 120) including a first circuit carrier (110) and a second circuit carrier (120), each circuit carrier (110, 120) having a front surface and a rear surface;
electronic components (200) mounted on the front surface of the circuit carriers (110, 120), each electronic component (200) being associated with one of the T/R channels (101);
at least one cooling plate (300) with two opposite sides, wherein the rear surface of the first circuit carrier (110) is attached to one side and the rear surface of the second circuit carrier (120) is attached to an opposite side to hold the circuit carriers (110, 120) in a sandwich structure; and
one or more cooling channels (400) formed by the at least one cooling plate (300) between the rear surface of the first circuit carrier (110) and the rear surface of the second circuit carrier (120), the one or more cooling channels (400) are adapted to accommodate a coolant to cool the one or more electronic components (200).

2. The electronic circuitry according to claim 1, where the at least one cooling plate (300) is configured to form side walls of the one or more cooling channels (400) and is adapted to mechanically support the one or more circuit carriers (110, 120) and the electronic components (200) mounted on the circuit carriers (110, 120).

3. The electronic circuitry according to claim 1 or claim 2, where at least one of the first and/or second circuit carriers (110, 120) includes a cut-out portion (115) to expose a portion of one of the cooling plates (300), wherein at least one of the electronic components (250) is mounted on the exposed portion of the cooling plate (300).

4. The electronic circuitry according to claim 3, wherein the exposed cooling plate (300) forms a bridge (305) between the at least one electronic component (250) and a portion of the cooling channel (400) to improve heat dissipation for the at least one electronic component (250).

5. The electronic circuitry according to claim 3 or claim 4, further comprising:
a heat spreader (600), located between the at least one electronic component (200, 250) and the exposed cooling plates (300).

6. The electronic circuitry (100) according to any one of claims 1 to 5, wherein multiple pairs of circuit carriers (110, 120) are formed, each of the multiple pairs supports a plurality of electronic components (200) to form a plurality of separate T/R channels (101) in a row, and wherein the multiple pairs of circuit carriers (110, 120) are stacked on top of each other to form multiple separate T/R channels in a column.

7. The electronic circuitry according to any one of claims 1 to 6, wherein the at least one first circuit carrier (110) and at least one second circuit carrier (120) are mounted on the at least one cooling plate by a fastener (500), the fastener (500) being one or more of the following:

- an adhesive;
- a solder;
- a gasket;
- a sinter connection;
- a combination of thereof.

8. The electronic circuitry according to any one of claims 1 to 7, where the one or more cooling plates (300) are surface coated and being leakproof with respect to the coolant.

9. An active phased array system including an array of antenna elements connected to an electronic circuitry (100) according to any one of claim 1 to 8.

10. The system according to claim 9,

wherein the electronic components (200) are mounted along a line on the at least one pair of circuit carriers (110, 120) and
wherein the antenna elements are arranged to transmit and/or to receive RF signals in main direction or in an angular range about the main direction, the antenna elements being arranged to align the main direction perpendicular to a normal direction of the at least one pair of circuit carriers (110, 120) and perpendicular to a line of mounting the electronic components.

11. A method for manufacturing an electronic circuitry (100) for an active phased array system with multiple transmit/receive, T/R, channels (101a, 101b), the method comprising:

providing (S110) at least one pair of circuit carriers (110, 120) including a first circuit carrier (110) and a second circuit carrier (120), each circuit carrier (110, 120) having a front surface and a rear surface;
providing (S120) at least one cooling plate (300) with one or more cooling channels (400) formed by the at least one cooling plate (300);
attaching (S130) the first circuit carrier (110) and the second circuit carrier (120) to opposite sides of at least one cooling plate (300) in a sandwich structure so that the electronic components (200) are assembled on opposite sides of the sandwich structure; and
mounting (S140) electronic components (200) on the front surfaces of the circuit carriers (110, 120), each electronic component (200) being associated with one or multiple of the T/R channels (101),
wherein the one or more cooling channels (400) are formed between the rear surface of the first circuit carrier (110) and the rear surface of the second circuit carrier (120) to accommodate a coolant to cool the one or more electronic components (200).

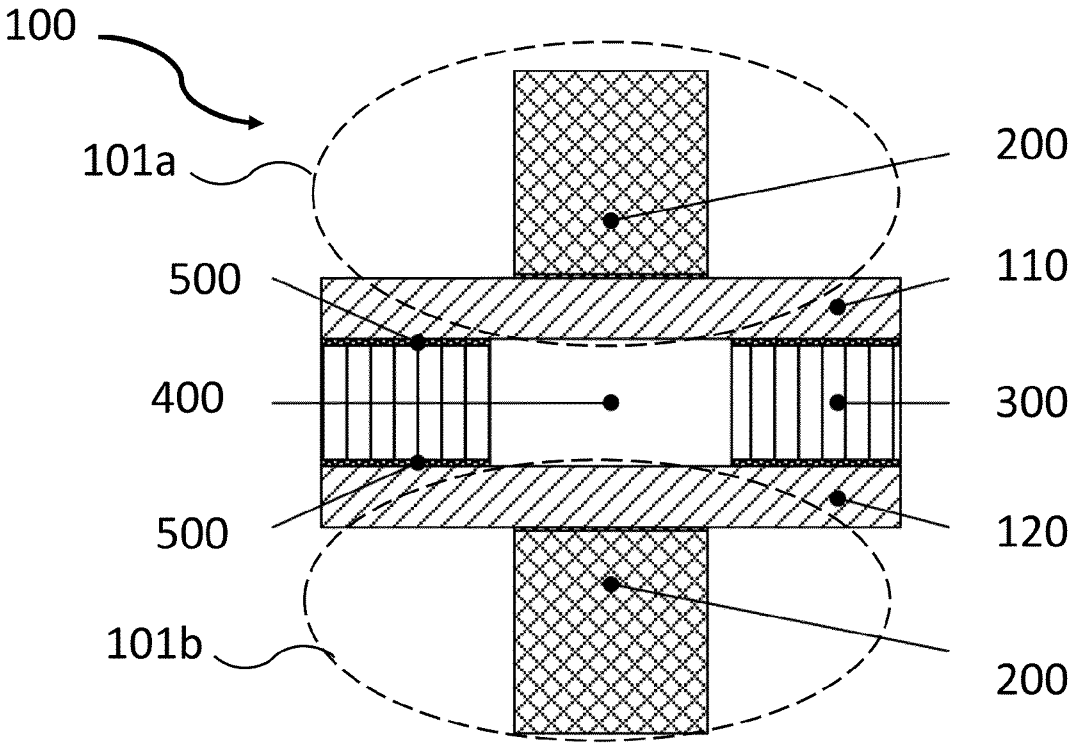
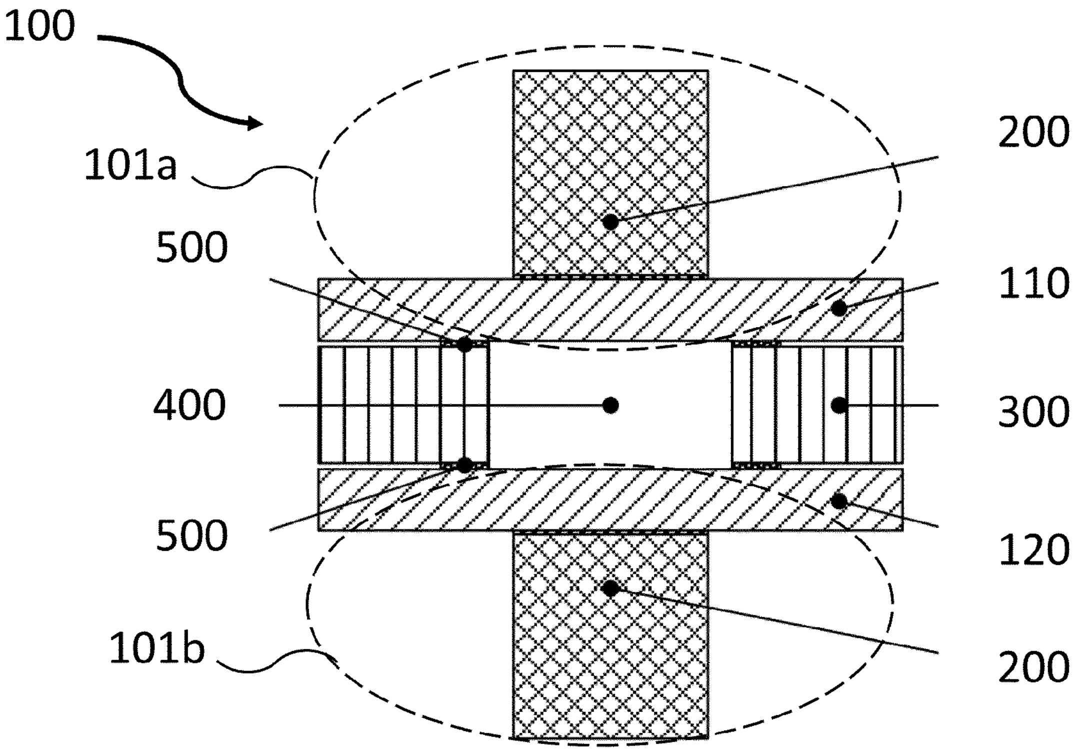

100
101a
200
500
110
400
300
500
120
101b
200

Fig. 1a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101a
200
500
110
400
300
500
120
101b
200

Fig. 1b

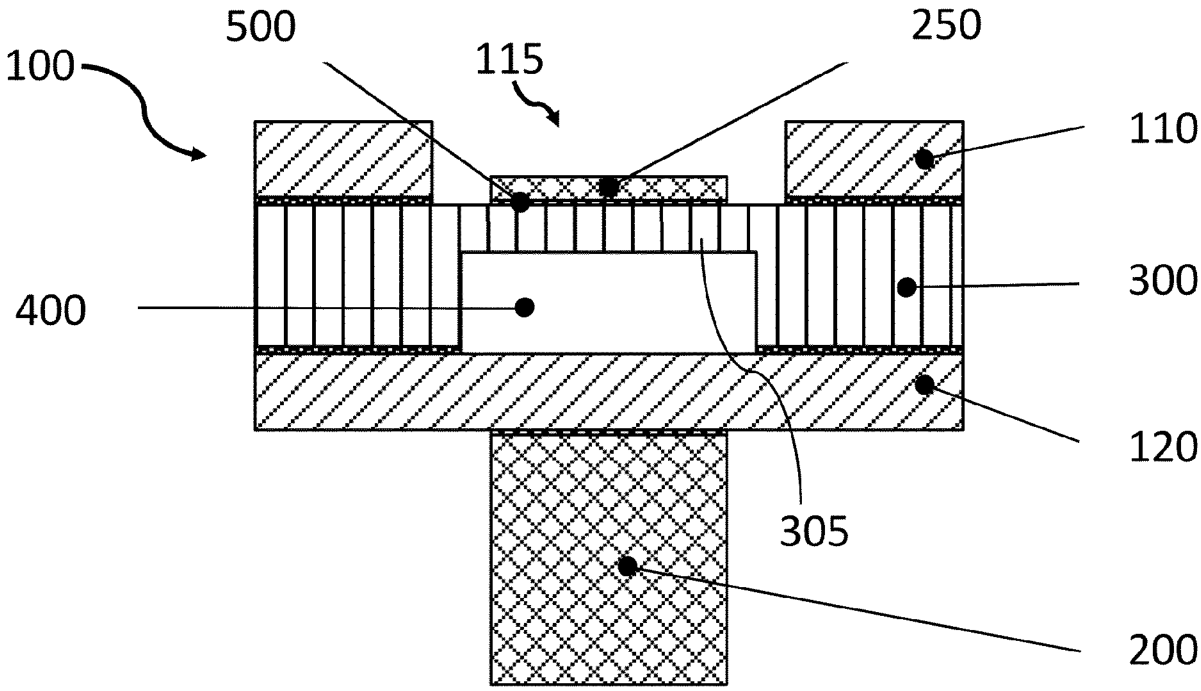
100
500
115
250
110
300
400
120
305
200

Fig. 2a

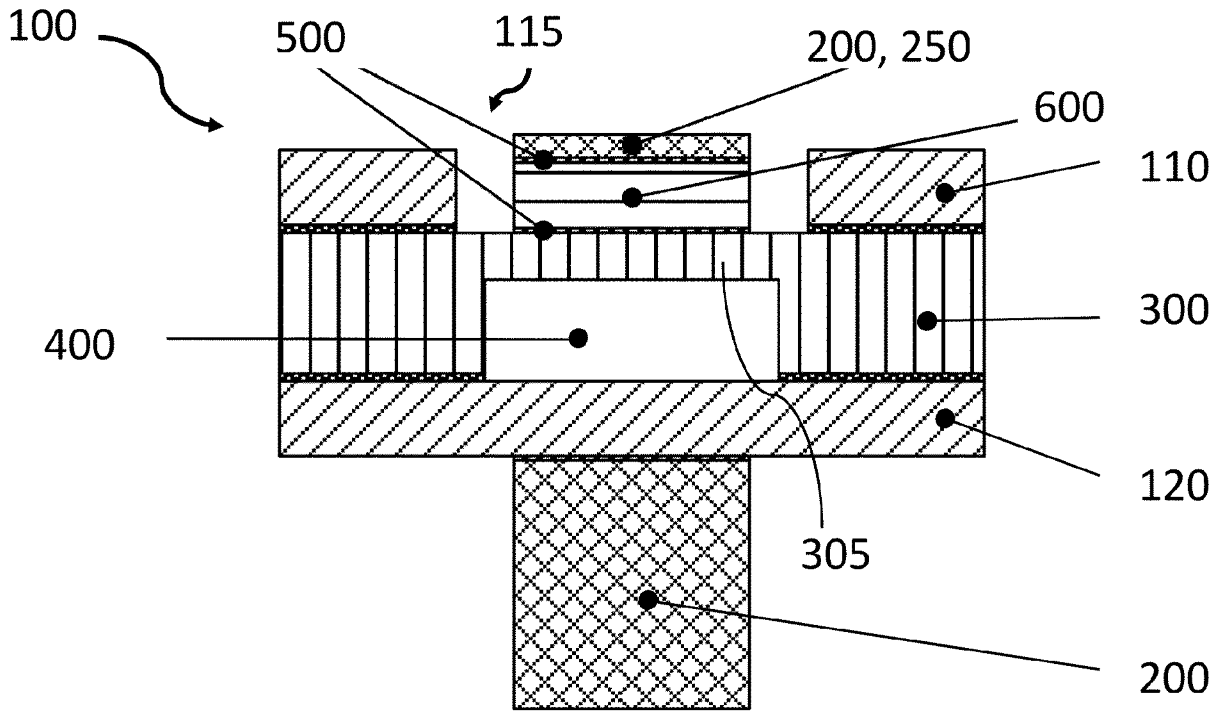
100
500
115
200, 250
600
110
300
400
120
305
200

Fig. 2b

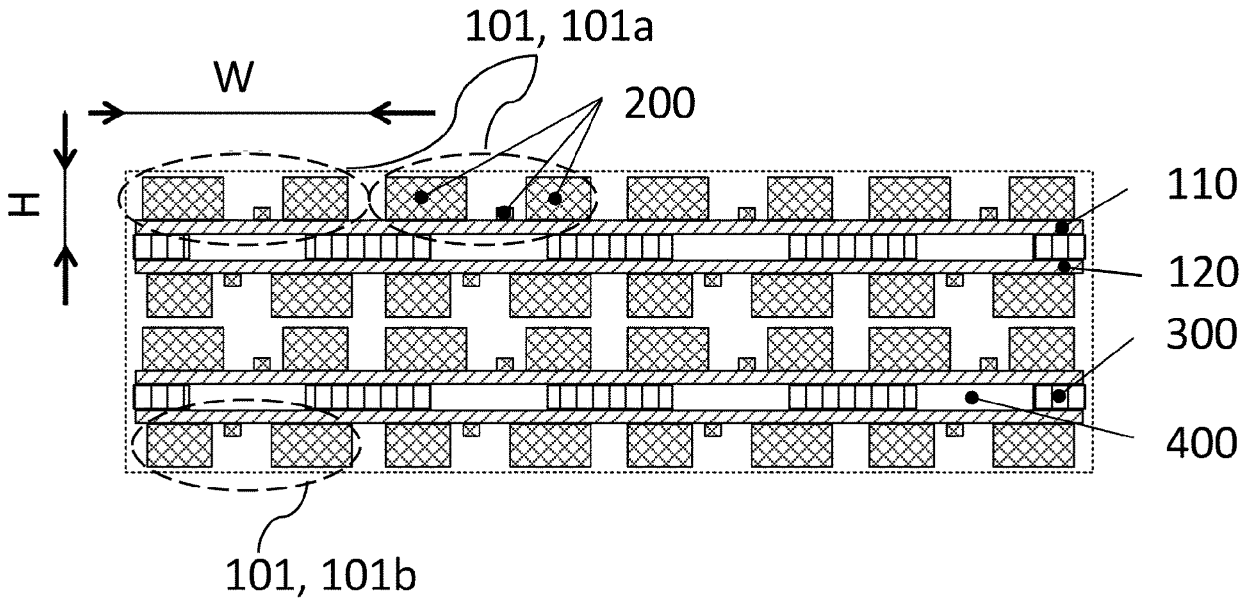

Fig. 3

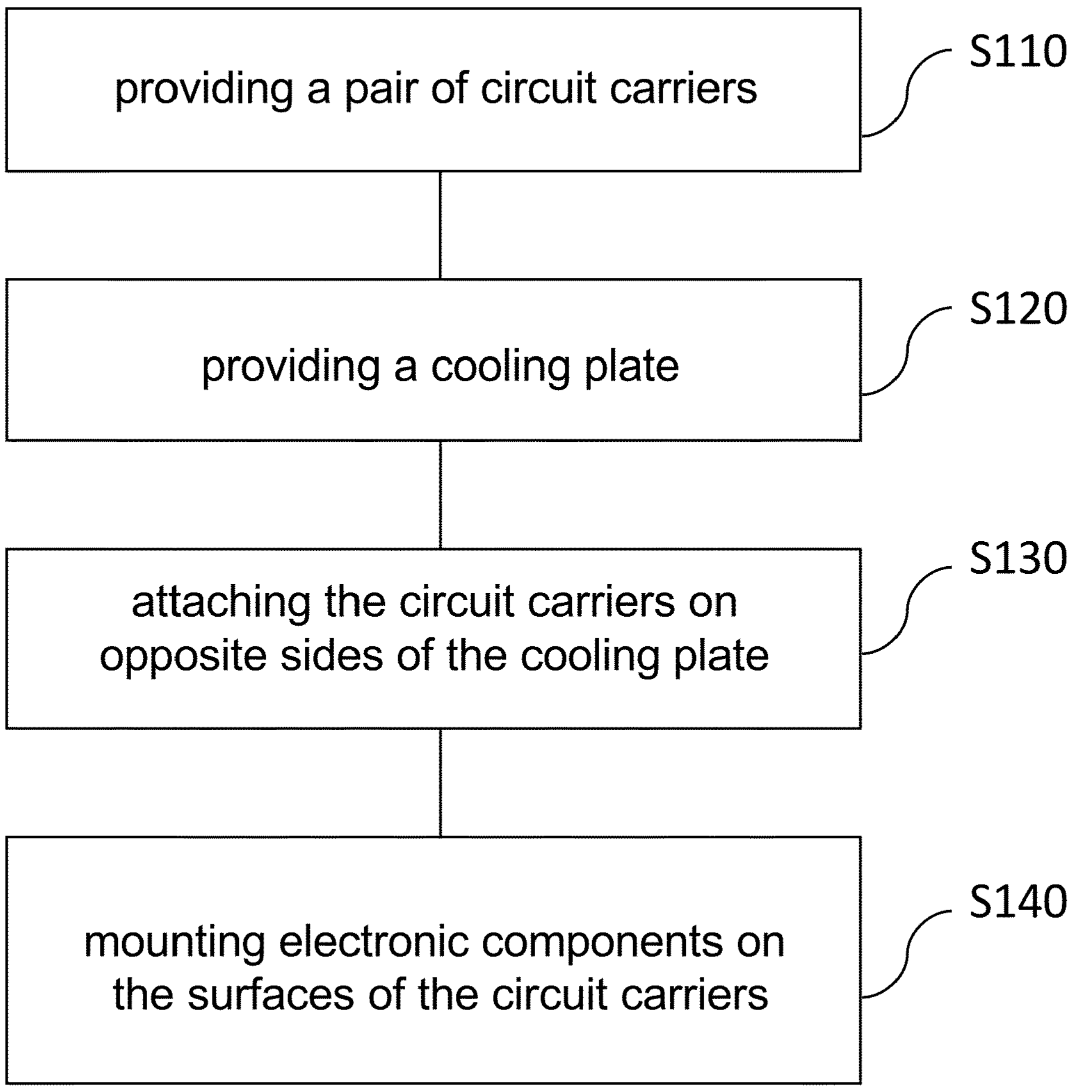
providing a pair of circuit carriers
S110
providing a cooling plate
S120
attaching the circuit carriers on opposite sides of the cooling plate
S130
mounting electronic components on the surfaces of the circuit carriers
S140

Fig. 4

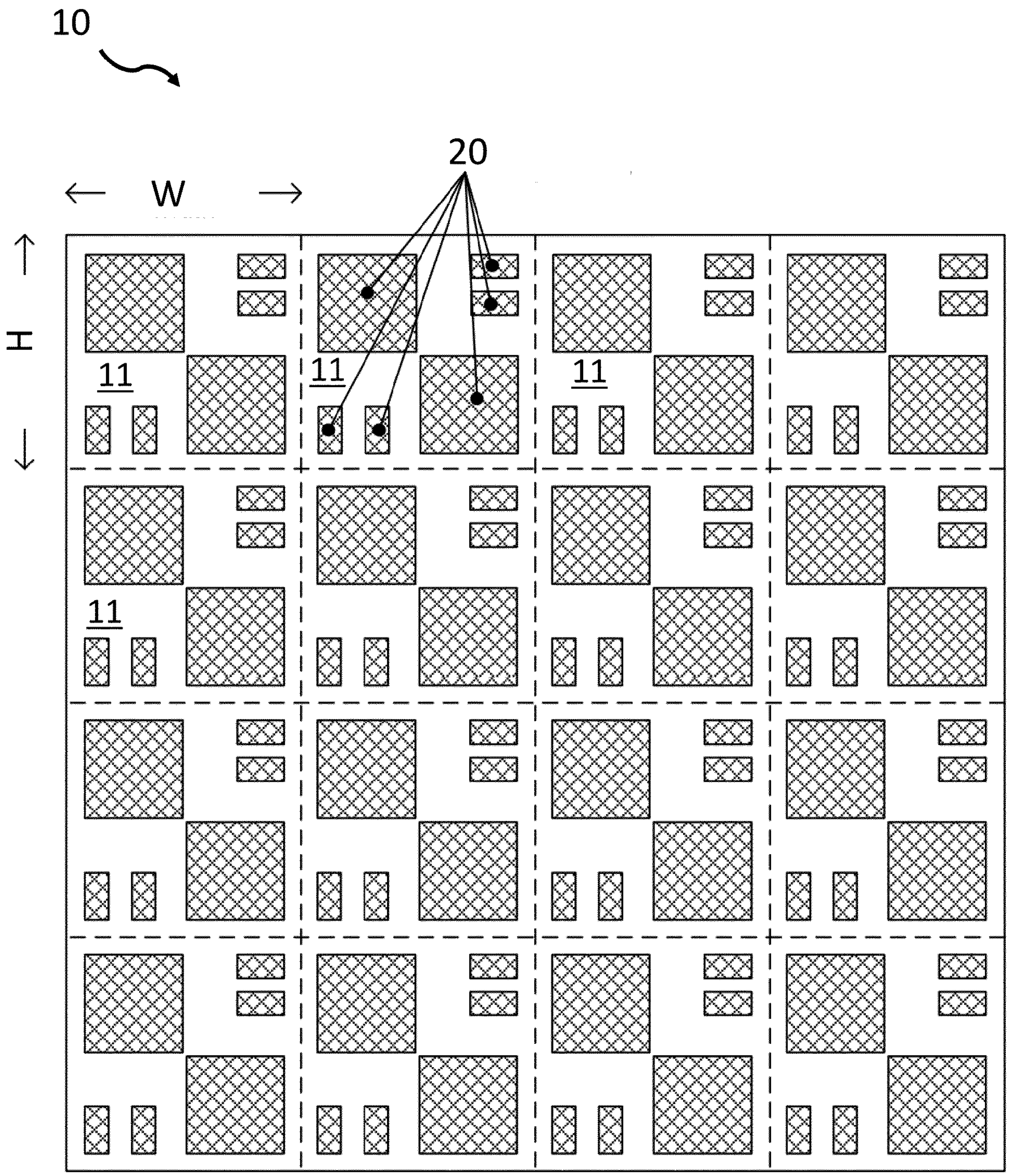

Fig. 5

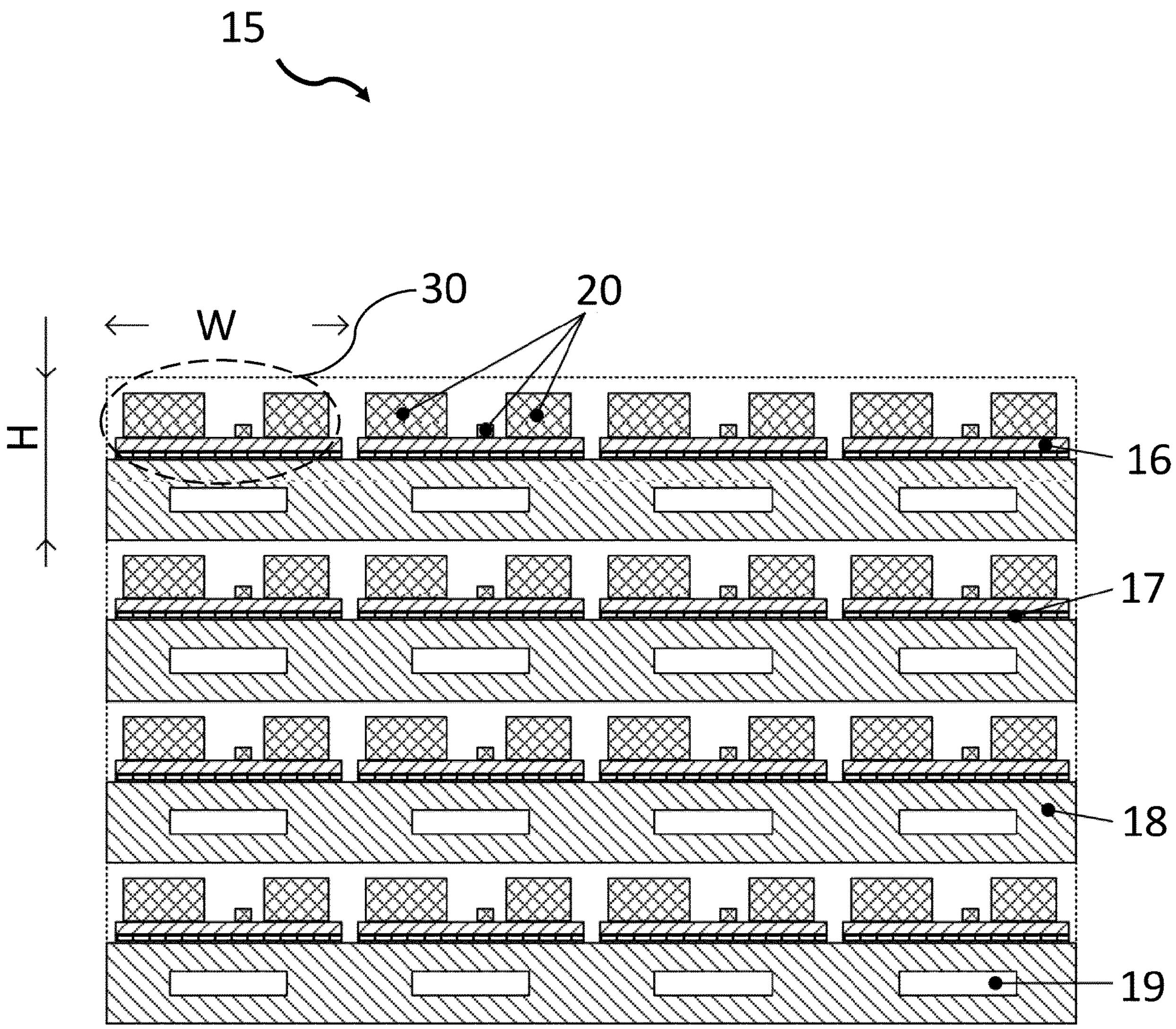

Fig. 6

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EUROPEAN SEARCH REPORT

Application Number
EP 22 20 9721

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 A	KR 102 089 545 B1 (HANWHA SYSTEMS CO LTD [KR]) 16 March 2020 (2020-03-16) * paragraphs [0001] - [0172]; figures 1-23 *	1,2,6-11 3-5	INV. H01Q1/02 H01Q3/26 H01Q21/00
X A	RIEGER RALF ET AL: "Design and Realization of a Highly Integrated and Scalable X-Band Tile Array", 2022 IEEE INTERNATIONAL SYMPOSIUM ON PHASED ARRAY SYSTEMS & TECHNOLOGY (PAST), IEEE, 11 October 2022 (2022-10-11), pages 1-5, XP034250376, DOI: 10.1109/PAST49659.2022.9974983 [retrieved on 2022-12-19] * pages 1-5; figures 1-8 *	1,2,6-11 3-5	
A	EP 2 808 941 A1 (BAE SYSTEMS PLC [GB]) 3 December 2014 (2014-12-03) * paragraphs [0001] - [0040]; figures 1-6 *	1-11	

TECHNICAL FIELDS SEARCHED (IPC)

H01Q

The present search report has been drawn up for all claims

3

Place of search	Date of completion of the search	Examiner
The Hague	3 April 2023	El-Shaarawy, Heba

CATEGORY OF CITED DOCUMENTS

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EP 22 20 9721

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03-04-2023

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KR 102089545 B1	16-03-2020	NONE	
EP 2808941 A1	03-12-2014	NONE	

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82