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ANTENNA ARRAY SYSTEM

Abstract

The disclosure provides an antenna array system, comprising: a printed circuit board; one or more radio-frequency circuits arranged on a surface of the printed circuit board; a plurality of optical-to-electrical converters electrically coupled to the one or more radio-frequency circuits; and an optical distribution layer arranged over the plurality of optical-to-electrical converters, for distributing one or more optical signals to the plurality of optical-to-electrical converters. The one or more radio-frequency circuits comprise an array of radiating antenna elements, and the optical distribution layer is arranged over a part of the surface of the printed circuit board such that the optical distribution layer does not cover the array of radiating antenna elements.

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Background/Summary

TECHNICAL FIELD

[0001] Embodiments of the present disclosure relate to antenna array systems, and particularly antenna array systems in which signals are distributed optically to the antenna array.

BACKGROUND

[0002] There is a vision that 6G connectivity may deliver peak data rates of hundreds of Gb per second, together with sub-millisecond latency. In order to deliver such high data rates, there is an interest in the potential use of frequencies in the sub-terahertz and terahertz ranges to provide the necessary bandwidth and enable intensive use of the available transmission spectrum within localized areas.

[0003] Additionally, sub-THz bands can be used as wireless backhaul for sites where fiber is either unavailable or too costly in solutions such as Integrated access and backhaul (IAB), e.g., to densify networks with multi-band radio sites at street level.

[0004] However, sub-THz/THz frequencies differ from those of bands typically used for wide-area, contiguous coverage in mobile networks today. Therefore, the use of sub-THz frequencies in next-generation networks raises fundamental questions regarding usage environments, use cases, network topologies, and devices.

[0005] The present disclosure focuses on the last of these technical areas. From the point of view of devices, high frequencies pose the problem of signal integrity, increased losses, integration and size, shortening the maximum length of electrical traces. Radio hardware in particular is faced with this problem, such as antenna systems including several radiating elements driven by a matrix of radio frequency integrated chips (RFICs).

[0006] In the current design of the next-generation antenna systems, the baseband reference clock is multiplied by a factor N to achieve radio frequency (RF) generation, e.g. in the W band of the electromagnetic spectrum (approx. 75 to 110 GHz). Clock references may be provided using phase-locked loops (PLLs) and multipliers, close to the RFICs that drive the antenna elements. However, the different multiplication stages may degrade the phase noise limiting the transmission performance, which requires complex compensation techniques. Further, while high-performance oscillators (such as GaN voltage-controlled oscillators) may provide excellent phase noise performance, many high-performance oscillators may increase cost, complexity, and power consumption. Electrical circuits operating at high frequency are likely to have non-ideal characteristics as the electrical lines may be affected by non-negligible parasitic resistance, capacitance, and inductance. Thus, the parasitic effects push the operating conditions far from the optimal or theoretical figures.

[0007] A further point to consider is the synchronization of the signal phase at each RFIC for the multiplied signals, which is critical for applications such as beamforming. As the wavelength is reduced, the impact of synchronization errors on the signal phase is expected to increase. The precision needed to synchronize this phase shifting is impacted by the non-idealities and the fabrication precision of the electrical lines dedicated to high RF signal distribution in the subparts of an array antenna system. Different electrical line lengths introduce a different phase added to the signals arriving at different radiating elements. In the mmWave range, the required precision of electrical line length is in the order of micrometres. The effective path length is given by the amount of time it takes the signal to travel along a wire, foil path, or interconnect metal. Then, the effective path length depends on the electrical properties of the lines that may vary due to factors such as the temperature. Accurate design and calibration may equalize the physical length of the wire; however, since each path may have a slightly different impedance, it is difficult to truly match electrical path length over time, introducing a skew that reduces the achievable phase precision. In addition, crosstalk and other RF noise may alter phase detection mechanisms.

[0008] As a result of these problems, a phase precision of 1° or lower is hard to achieve predictably with state of the art electronics, where the electrical line density on the antenna board is very high (e.g., tens of electrical lines per mm.sup.2).

[0009] In order to address these difficulties, various solutions have been proposed where optical carriers are used to deliver RF signals to the transmitting equipment. These solutions overcome the problem of signal integrity and are immune to electromagnetic interference. Additionally, the effect of temperature on the optical properties is very small in common optical waveguides (e.g. 10.sup.−5 K.sup.−1 in silica) and a temperature variation ΔT>100° K produces only a few nanometres of variation in the length of an optical waveguide which is a few centimetres long. Photonic solutions are therefore appealing to overcome the bottleneck of signal integrity, reduce power density and synchronize the RFICs.

[0010] However, an appropriate optical distribution system is necessary to apply these solutions in dense chip scenarios such as antenna array systems operating in the mm wavelength range (mmW). The critical point to address is the management of many optical waveguides that are required to reach photodiodes in positions near the integrated electronic chips. In an mmW antenna array, having, e.g., 1.5 cm.sup.2 in size for an 8×8 array of antenna elements at 100 GHz (depending on the wavelength, the number of antenna elements, and their spacing), the optical waveguide distribution needs to be extremely compact.

[0011] International patent application WO 2020/125946 discloses an optical interconnect for optically coupling a first optical integrated circuit and a second optical integrated circuit. The optical interconnect comprises at least two layers of optically transparent material. While this structure is useful for propagating optical signals between separate optical integrated circuits, it does not address the problem of distributing optical signals in the compact environment of an integrated circuit comprising an array of antenna elements. The presence of radiating elements in the solution has an effect on the positioning of the optical distribution device, which is immune from electromagnetic radiation but may cause radiation losses due to its dielectric constant (which is typically between 3.6 and 4 in quartz and standard glass types used in photonics).

[0012] Embodiments of the disclosure seek to address these and other problems.

SUMMARY

[0013] One aspect of the disclosure provides an antenna array system, comprising: a printed circuit board; one or more radio-frequency circuits arranged on a surface of the printed circuit board; a plurality of optical-to-electrical converters electrically coupled to the one or more radio-frequency circuits; and an optical distribution layer arranged over the plurality of optical-to-electrical converters, for distributing one or more optical signals to the plurality of optical-to-electrical converters. The one or more radio-frequency circuits comprise an array of radiating antenna elements, and the optical distribution layer is arranged over a part of the surface of the printed circuit board such that the optical distribution layer does not cover the array of radiating antenna elements.

[0014] The proposed solution solves the problems of existing solutions that prevent the use of the optical distribution in small antenna array systems, such as those configured to transmit/receive in the mmW range. The proposed solution is a compact optical distribution device that fits the size of a typical antenna array operating in the mm wavelength range (e.g., with dimensions of one or a few cm). Further, in some embodiments, by placing the optical distribution layer on ‘top’ of existing PCB-mounted devices, the fabrication processes typically used to realize antenna PCBs or packages can be left substantially unchanged. That is, the optical distribution layer may be fabricated and fitted in a separate step. Input fibers (from the optical source to the distribution device) can be attached to the optical distribution layer before the layer is mounted on the antenna package. This solution simplifies the antenna packaging/assembly operations.

[0015] In some embodiments of the disclosure, optical signals are delivered to the optical-to-electrical converters directly, without any fiber or optical connector between the optical distribution layer and the optical-to-electrical converter: this reduces the overall footprint of the solution and enables the distribution of optical signals to a dense set of receiving photodiodes (e.g. one per mm.sup.2).

[0016] Antenna array systems according to the present disclosure are stable to large temperature variations and immune from electromagnetic radiation noise that may cause skew in signal distribution over electrical lines.

[0017] The optical distribution layer may enable the remote calibration of the phase of the signal that is received at the antenna element since it would be possible to apply optical techniques to measure and control the difference in the optical path length to reach each optical-to-electrical converter.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] The present disclosure is described, by way of example only, with reference to the following figures, in which:

[0019] FIG. **1** is a plan view of an antenna array system according to embodiments of the disclosure;

[0020] FIG. **2** is a cross section view of an antenna array system according to embodiments of the disclosure;

[0021] FIG. **3** shows a mechanism for distributing optical signals through an optical distribution layer according to embodiments of the disclosure; and

[0022] FIG. **4** shows a mechanism for distributing optical signals through an optical distribution layer according to further embodiments of the disclosure.

DETAILED DESCRIPTION

[0023] For the purpose of explanation, details are set forth in the following description in order to provide a thorough understanding of the embodiments disclosed. It will be apparent, however, to those skilled in the art that the embodiments may be implemented without these specific details or with an equivalent arrangement.

[0024] According to embodiments of the disclosure, an antenna array system comprises: a printed circuit board; one or more radio-frequency circuits arranged on a surface of the printed circuit board; a plurality of optical-to-electrical converters electrically coupled to the one or more radio-frequency circuits; and an optical distribution layer arranged over the plurality of optical-to-electrical converters, for distributing one or more optical signals to the plurality of optical-to-electrical converters. The one or more radio-frequency circuits comprise an array of radiating antenna elements, and the optical distribution layer is arranged over a part of the surface of the printed circuit board such that the optical distribution layer does not cover the array of radiating antenna elements.

[0025] In certain embodiments, the optical distribution layer is provided in a layer above the printed circuit board, which makes manufacture of the antenna array system simpler and reduces wastage during the manufacturing process. The optical distribution layer may be clamped and/or glued on to the printed circuit board once other connections have been made, and this avoids substantial changes in the technology/method used for the fabrication of the antenna system. Further, by leaving the antenna array uncovered, optical signals can be distributed to the antenna array without interfering with the transmitted radio signals.

[0026] FIG. **1** is a plan view of an antenna array system **100** according to embodiments of the disclosure. FIG. **2** shows a cross-section view of an antenna array system **200**, which corresponds to the antenna array system **100** but comprises a different number of antenna elements.

[0027] The antenna array systems **100**, **200** comprise a printed circuit board (PCB) or other substrate **110**. An array of antenna elements **104**, **204** are positioned on one surface of the PCB **110**, which will be referred to herein as an "upper surface" of the PCB **110** for convenience. Each antenna element **104**, **204** is capable of radiating electromagnetic energy so as to transmit and/or receive radio signals. The antenna elements **104**, **204** may be particularly adapted to transmit and/or receive electromagnetic radiation having a wavelength in the order of millimetres (so-called mmW radiation), and/or a frequency in the sub-THz or THz range.

[0028] Each antenna element **104**, **204** is connected to processing circuitry, e.g. provided on a radio-frequency integrated circuit (RFIC) **116**, which is affixed to the upper surface of the PCB **110** through conventional mounting techniques. The systems **100**, **200** thus comprise one or more RFICs **116** which comprise the arrays of antenna elements **104**, **204**. The arrays of antenna elements **104**, **204** may be provided on a single RFIC, or distributed across multiple RFICs. Each RFIC **116** may therefore comprise one or multiple antenna elements **104**, **204**; in the illustrated embodiment, each RFIC **116** has at least four antenna elements **204** (as seen in FIG. **2**).

[0029] As used herein, the term "array" is used to describe a plurality of antenna elements arranged in a regular pattern and in close proximity to each other. The term does not imply any particular geometric shape. For example, while in some embodiments (e.g., as shown in FIG. **1**) the array of antenna elements is square, in other embodiments the array may have a rectangular, non-square shape or even a non-rectangular shape.

[0030] In the embodiment illustrated in FIG. **1**, the antenna array comprises an 8×8 array of antenna elements **104**; in the embodiment illustrated in FIG. **2**, the antenna array has at least one dimension of 16 antenna elements **204** (e.g., a 16×16 antenna array assuming a square array).

[0031] Referring to FIG. **2**, the antenna elements **204** transmit and/or receive radio signals to, and/or from, an upward direction, as shown. The upward direction may be considered as a direction away from the PCB **110** supporting the antenna elements **204**, and in particular, away from the plane of the PCB **110**. The upward direction, or radiating direction, may be in substantially the same direction as the multiple antenna elements **204** are mounted on the PCB **110**.

[0032] The antenna array systems **100**, **200** further comprise an optical distribution layer **102**, for distributing one or more optical signals to the RFICs **116**. The optical distribution layer **102** is manufactured from an optically transparent material, to allow the transmission of optical signals without significant attenuation, such as glass, quartz, silica etc. In some embodiments, the optical distribution layer **102** is a passive component.

[0033] According to some embodiments of the disclosure, the optical distribution layer **102** is provided in a layer which is above at least one of the PCB **110**, RFICs **116** and/or the antenna elements **104**, **204**. That is, the RFICs **116** are disposed at a level between the PCB **110** and the optical distribution layer **102**. Thus, the RFICs **116** are closer to the PCB **110** than the optical distribution layer **102**. In some aspects, the optical distribution layer is spaced away from the PCB **110**. In some aspects, the optical distribution layer **102** does not directly overlie the RFICs **116** connected to the antenna elements **104**, **204**. The optical distribution layer **102** may be attached to the PCB **110** via any suitable means, such as glue or other affixing substance or, as shown in FIG. **2**, one or more clamps **112** arranged at the periphery of the layer **102**.

[0034] The optical distribution layer **102** is further arranged over a part of the upper surface of the PCB **110** that does not cover the antenna elements **104**, **204**. In this way, the optical distribution layer **102** does not interfere with the radio signals transmitted by those elements **104**, **204**. In other words, the optical distribution layer **102** is arranged over a first part of the upper surface of the PCB **110**, whereas the array of antenna elements **104**, **204** is arranged over a second part of the upper surface of the PCB **110** that is different from the first part.

[0035] For example, the optical distribution layer **102** may be arranged around some or all of a periphery of the RFICs **116**. For example, where the PCB **110** does not extend significantly beyond the dimensions of the optical distribution layer **102**, the optical distribution layer **102** may be arranged towards some or all of a periphery of the PCB **110**, whereas the array of antenna elements **104**, **204** may be arranged towards a central region of the PCB **110**. In the illustrated embodiment, the optical distribution layer **102** is arranged around the entire periphery of the RFICs **116**. In this way, the optical distribution layer **102** substantially surrounds the array of antenna elements **104**, **204**. Note that, in this context, the term “surrounds” does not imply that the optical distribution layer **102** completely encases the array of antenna elements **104**, **204**, as this would interfere with radio transmissions from the antenna elements **104**, **204**. Instead, the optical distribution layer **102** surrounds the antenna elements **104**, **204** within a plane that is substantially parallel to the upper surface of the PCB **110**. The optical distribution layer **102** is extends around some or all of the periphery of the array of antenna elements **104**,**204**. The optical distribution layer **102** does not extend over (i.e. cover) the array of antenna elements **104**,**204**. The optical distribution layer **102** has an internal opening that substantially corresponds in shape and size to the array of antenna elements **104**, **204**. The optical distribution layer **102** thus forms a frame that lies outside the array of antenna elements **104**, **204**. In the illustrated embodiment, the array is square, and thus the internal opening is also square.

[0036] The antenna array system **100** further comprises a plurality of optical-to-electrical converters **114**, such as photodiodes (PDs), arranged underneath the optical distribution layer **102** on the upper surface of the PCB **110**. As noted above, the signal to be detected by the optical-to-electrical converter **114** may be in the 100 GHz range. For this reason, uni-travelling carrier (UTC) PDs may be a suitable choice. These are high-speed photodiodes capable of detecting signals up to the THz range. The response of a UTC-PD is determined by the electron transport in the whole structure. This aspect differs from conventional pin PDs, where both electrons and holes contribute to the device response, and low-velocity hole-transport may limit performance.

[0037] Note that the optical-to-electrical converters **114** are arranged beneath the optical distribution layer **102** in the illustrated embodiment. In other embodiments, the optical-to-electrical converters **114** may be arranged within (e.g., integrated with) the optical distribution layer **102**. In the latter case, an electrical connection may be provided from the optical distribution layer **102** (e.g., from the optical-to-electrical converter **114** in the optical distribution layer **102**) to a pad on the PCB **110**. If the optical-to-electrical converter **114** is arranged on the PCB **110** (as illustrated), the optical-to-electrical converter **114** may receive light from a vertical aperture in the optical distribution layer **102**. In either case, optical signals may be directed from the optical distribution layer **102** to the optical-to-electrical converters **114** without need of any further connectors.

[0038] The optical-to-electrical converters **114** are electrically coupled to the processing circuitry (e.g. RFICs **116**). The optical-to-electrical converters **114** are configured to receive optical signals via the optical distribution layer **102** and to extract a radio-frequency signal from those optical signals. Electrical signals corresponding to the radio-frequency signal are then forwarded to the RFICs **116** to implement the transmission of radio signals.

[0039] In the illustrated embodiment, the optical-to-electrical converters **114** are provided on mixer integrated circuits **118** arranged on the upper surface of the PCB **110**. The mixer integrated circuits **118** may also receive a baseband signal, which may be generated by other circuitry connected to the antenna system (not shown), comprising data for transmission by the radiating antenna elements. For example, the mixer integrated circuits **118** may comprise up-down converter circuits, designed to mix the baseband signal with the radio-frequency signal extracted by the optical-to-electrical converters **114** and upconvert the frequency of the baseband signal to radio frequency for transmission by the antenna elements **104**, **204**. Thus, the mixer integrated circuits **118** may be electrically coupled to the RFICs **116** (e.g., via a suitable conductive track on or in in the PCB **110**).

[0040] Note that the number of optical-to-electrical converters **114** may not be the same as the number of radiating elements **104**, **204** or the number of RFICs **116**. For example, in one embodiment, each optical-to-electrical converter **114** may have a corresponding RFIC **116**; that is, in such an embodiment, one optical signal may be used to drive the radiating antenna elements on one corresponding RFIC. The number of RFICs and optical-to-electrical converters **114** is the same. However, in other embodiments, the same optical signal may be used to drive the radiating antenna elements from multiple RFICs; in these embodiments, there may be more RFICs than optical-to-electrical converters **114**. Further, as noted previously, each RFIC may have one or multiple antenna elements; where an RFIC has multiple antenna elements, each antenna element may be driven by the same optical signal or by different optical signals.

[0041] In order to distribute the optical signals to the optical-to-electrical converters **114** with sufficient signal power, the optical distribution layer **102** comprises a set of optical waveguides **106**. Each waveguide receives an optical signal from a fibre attach unit **108** and provides the optical signal to a corresponding optical-to-electrical converter **114**. Note that, in alternative embodiments, a waveguide **106** may comprise one or more forks or splits, such that a single optical signal is provided to more than one optical-to-electrical converter **114**. Similarly, the optical fibre providing the optical signals to the waveguides **106** may be split so that the same optical signal is provided to more than one waveguide **106**.

[0042] The waveguides **106** may be formed using any suitable technique, such as chemical doping using Si:Ge or laser etching/scribing to change (increase) the refractive index in localized areas of the optical distribution layer **102** and so guide optical energy along a preferred path through the optical distribution layer **102**. The fibre attach unit **108** may comprise a plurality of optical fibres (not illustrated) bundled together, with each optical fibre physically coupled to one end of a corresponding waveguide **106** using one or more known techniques, such as V-groove or pigtail connections.

[0043] In order to reduce cross-coupling of optical signals between waveguides and increase the number of connections per unit surface, the waveguides **106** may be formed at a different depth in the optical distribution layer **102** (thus increasing the physical separation of each waveguide from other waveguides). That is, once the optical distribution layer **102** is attached to the PCB **110**, the waveguides **106** may be formed at different distances from the upper surface of the PCB **110**. This may be achieved via free-form laser induced waveguides, or multi-layer arrangements as described for example in WO 2020/125946, the contents of which are hereby incorporated by reference. Additionally or alternatively, the waveguides **106** may be formed at different lateral distances through the optical distribution layer **102** (e.g., different distances from the antenna array **104**, **204**).

[0044] As shown in FIG. **1**, the majority of the optical length of each waveguide **106** may be formed substantially parallel to the upper surface of the PCB **110**, directing optical energy from the fibre attach unit **108** towards an optical-to-electrical converter **114** elsewhere on the PCB **110**. However, it is also necessary for the optical energy to be directed downwards, towards the upper surface of the PCB **110** and the optical-to-electrical converters **114**.

[0045] FIG. **3** is a schematic diagram showing a first mechanism for distributing optical signals through the optical distribution layer **102** towards an optical-to-electrical converter **114** according to embodiments of the disclosure. The drawing shows an optical fibre **310** (e.g., as may be provided with the fibre attach unit **108**) providing an optical signal to a waveguide **106** in the optical distribution layer **102**. In this drawing, the optical-to-electrical converter **114** (e.g. photodiode) is not shown separately from the mixer circuits **118**.

[0046] In this embodiment, the optical distribution layer **102** comprises a micromirror **312**, which is positioned at the end of the waveguide **106** and angled to direct the optical signal downwards, towards the optical-to-electrical converter **114**. First and second micro-lenses **314** focus the optical energy towards the optical-to-electrical converter **114** to increase the signal power detected at the optical-to-electrical converter **114**. For example, the micro-lenses **314** may be formed by altering the refractive index of the material optical distribution layer **102**, or using elements of different refractive index.

[0047] The first mechanism has the advantage of minimizing the bending losses due to horizontal to vertical routing, maximizing received power at the optical-to-electrical converter **114**.

[0048] FIG. **4** is a schematic diagram showing a second mechanism for distributing optical signals through the optical distribution layer **102** towards an optical-to-electrical converter **114** according to further embodiments of the disclosure. The drawing shows an optical fibre **410** (e.g., as may be provided with the fibre attach unit **108**) providing an optical signal to a waveguide **106** in the optical distribution layer **102**. In this drawing, the optical-to-electrical converter **114** (e.g. photodiode) is not shown separately from the mixer circuits **118**.

[0049] In this embodiment, the waveguide **106** is formed to direct optical energy from the fibre **410** to the optical-to-electrical converter **114** directly. For example, the waveguide **106** is formed by altering the refractive index of the material optical distribution layer **102**, or using elements of different refractive index. Thus, the waveguide **106** is formed with a bend **402** which directs energy from the direction substantially parallel to the upper surface of the PCB **110** to a direction towards the optical-to-electrical converter **114**. The bend **402** may be formed substantially above the optical-to-electrical converter **114**. The second mechanism has the advantage of being easy to manufacture, with fewer parts requiring installation than the first mechanism. However, the radius of the bend **402** is limited, so as to avoid excessive loss of optical energy.

[0050] In both mechanisms shown in FIGS. **3** and **4**, the optical-to-electrical converter **114** receives energy vertically; that is, an input port of the optical-to-electrical converter **114** is configured to receive energy in a direction perpendicular to the upper surface of the PCB **110**. If the optical-to-electrical converter **114** is designed to have a horizontal input, a vertical coupler (such as a grating coupler) may be used to redirect optical energy from the vertical direction output by either the first or second mechanisms described above, to a substantial horizontal direction (parallel to the upper surface of the PCB **110**) to deliver light to the optical-to-electrical converter **114**.

[0051] As noted above, in some embodiments the optical signals may comprise a radio-frequency carrier signal used to carry an upconverted baseband signal. In other embodiments, the optical signals may comprise a clock reference signal used to drive the functioning of the mixer circuits **118** and/or the RFICs **116**. The radio-frequency signal carried by the optical signals may be generated using any suitable technique, such as amplitude or phase modulation of an optical carrier, or the use of a beat signal from two laser sources.

[0052] Embodiments of the disclosure thus provide an antenna array system in which an RF signal can be provided via an optical carrier to an antenna array in a scenario of high chip density. In particular, the solution addresses the case of an array of antenna elements operating in the high-frequency range (>90 GHz).

[0053] References in the present disclosure to “one embodiment”, “an embodiment” and so on, indicate that the embodiment described may include a particular feature, structure, or characteristic, but it is not necessary that every embodiment includes the particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is submitted that it is within the knowledge of one skilled in the art to implement such feature, structure, or characteristic in connection with other embodiments whether or not explicitly described.

[0054] It should be understood that, although the terms “first”, “second” and so on may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another. For example, a first element could be termed a second element, and similarly, a second element could be termed a first element, without departing from the scope of the disclosure. As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed terms.

[0055] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to limit the present disclosure. 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”, “has”, “having”, “includes” and/or “including”, when used herein, specify the presence of stated features, elements, and/or components, but do not preclude the presence or addition of one or more other features, elements, components and/or combinations thereof. The terms “connect”, “connects”, “connecting” and/or “connected” used herein cover the direct and/or indirect connection between two elements.

[0056] The present disclosure includes any novel feature or combination of features disclosed herein either explicitly or any generalization thereof. Various modifications and adaptations to the foregoing exemplary embodiments of this disclosure may become apparent to those skilled in the relevant arts in view of the foregoing description, when read in conjunction with the accompanying drawings. However, any and all modifications will still fall within the scope of the non-limiting and exemplary embodiments of this disclosure. For the avoidance of doubt, the scope of the disclosure is defined by the claims.

Claims

1. An antenna array system, comprising: a printed circuit board; one or more radio-frequency circuits arranged on a surface of the printed circuit board, the one or more radio-frequency circuits comprising an array of radiating antenna elements; a plurality of optical-to-electrical converters electrically coupled to the one or more radio-frequency circuits; and an optical distribution layer arranged over the plurality of optical-to-electrical converters, for distributing one or more optical signals to the plurality of optical-to-electrical converters, wherein the optical distribution layer is arranged over a part of the surface of the printed circuit board such that the optical distribution layer does not cover the array of radiating antenna elements.

2. The antenna array system according to claim 1, wherein the optical distribution layer is arranged at least partially around a periphery of the one or more radio-frequency circuits.

3. The antenna array system according to claim 1, wherein the one or more radio-frequency circuits are arranged in a layer between the printed circuit board and the optical distribution layer.

4. The antenna array system according to claim 1, wherein the array of radiating antenna elements are arranged in a layer between the printed circuit board and the optical distribution layer.

5. The antenna array system according to claim 1, wherein the one or more radio-frequency circuits and the array of radiating antenna elements are arranged in a central region of the surface.

6. The antenna array system according to claim 1, wherein the optical distribution layer distributes the one or more optical signals to the plurality of optical-to-electrical converters without the use of optical connectors between the optical distribution layer and the optical-to-electrical converters.

7. The antenna array system according to claim 1, wherein the optical distribution layer comprises a plurality of optical waveguides for directing the one or more optical signals towards the optical-to-electrical converters.

8. The antenna array system according to claim 7, wherein the optical waveguides are arranged at different distances from the surface of the printed circuit board.

9. The antenna array system according to claim 7, wherein the optical waveguides direct the one or more optical signals along a direction substantially parallel to the surface of the printed circuit board in a first part of the optical waveguide, and along a direction substantially perpendicular to the surface of the printed circuit board in a second part of the optical waveguide.

10. The antenna array system according to claim 9, wherein the first part of the optical waveguide is arranged around a periphery of the one or more radio-frequency circuits.

11. The antenna array system according to claim 7, wherein the optical waveguides comprise micro-lenses to focus the one or more optical signals at the optical-to-electrical converters.

12. The antenna array system according to claim 7, wherein the optical distribution layer comprises a respective optical waveguide for each optical-to-electrical converter.

13. The antenna array system according to claim 7, further comprising a fibre attach unit coupling a plurality of optical fibres to the plurality of optical waveguides.

14. The antenna array system according to claim 7, wherein the optical waveguides are formed by a localized variation in refractive index of the optical distribution layer.

15. The antenna array system according to claim 1, wherein the radiating antenna elements are configured to transmit radio signals having a frequency of at least 90 GHz.

16. The antenna array system according to claim 1, wherein the one or more optical signals comprise one or more of: a clock reference signal and a radio-frequency carrier signal.

17. The antenna array system according to claim 1, wherein the plurality of optical-to-electrical converters are electrically coupled to the one or more radio-frequency circuits via mixing devices, and wherein the mixing devices are further arranged to receive a baseband signal.

18. The antenna array system according to claim 1, comprising a plurality of radio-frequency circuits, and wherein each radio-frequency circuit comprises at least one radiating antenna element.

19. The antenna array system according to claim 1, wherein each optical-to-electrical converter is electrically coupled to a single radio-frequency circuit.