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# ELECTRONIC SCANNING ANTENNA FORMED OF A TWO-DIMENSIONAL ARRAY OF RADIATING NANOELEMENTS.

The invention pertains to electronic scanning antennas, in particular antennas formed of radiating elements of very small size, of the order of a few tens of nanometres. These antennas are formed of an array of controlled radiating nanoelements, distributed in two dimensions.

These antennas are conventionally employed in two types of configurations.

A first configuration pertains to antennas that can transmit and receive signals at very high frequencies, up to a TeraHertz. These are for example commonly used in:

- high-resolution imaging systems,
- the detection of the presence of cables or of wire-like objects in the environment of helicopters,
- systems for protecting sensitive sites, or else
- arrays of miniaturized sensors communicating among themselves or with other systems.

A second configuration pertains to radiofrequency antennas that can transmit and receive signals of wavelength of the order of a centimetre or millimetre, whose radiating elements may be spatially oversampled. These antennas are often used within imaging systems allowing the detection and/or location of threats, in airports for example.

In either of the two configurations, the gap between two radiating elements may be reduced down to a few tens of nanometres. Consequently the interconnection between the control of the radiating elements and the radiating elements themselves must be adapted to suit such dimensions.

Accordingly, an existing solution proposes the production of electrical connections linking each radiating element and the control device for these elements. Now, for an antenna operating at 1 THz for example, the

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associated wavelength in air is 300 µm and the distance between two adjacent elements of the antenna array is 150 µm. Thus, for an antenna 1 cm by 1 cm, the number of radiating elements is about four thousand (66*66). It is therefore necessary to employ four thousand electrical connectors to control this antenna. This is very difficult or indeed impossible to produce such an antenna without mutual disturbance between two adjacent wires.

An aim of the invention is notably to solve the problems stated hereinabove.

Accordingly, there is proposed an electronic scanning antenna comprising a two-dimensional array of radiating elements, formed with the aid of nanocomponents.

According to a general characteristic, the antenna comprises:

- an optical source able to illuminate the said array of radiating elements so as to drive their operation, and

- a two-dimensional spatial light modulator, placed between the optical source and the array of radiating elements, the said modulator comprising as many activatable transparent wafers as radiating elements, so as optionally to let through the radiation of the optical source to the corresponding radiating element.

Stated otherwise, the invention proposes a driving of the radiating elements with the aid of an optical source, the activation of such and such radiating elements being possible by virtue of the incorporation of a spatial light modulator, able optionally to digest the light signal from the optical source towards the corresponding radiating element.

The invention thus makes it possible to drive radiating elements that may be spaced apart by a few hundred nanometres without any disturbance.

According to a first embodiment, the array of radiating elements is of active reflector type.

In this case, the optical source may be a continuous laser.

According to a second embodiment, the optical source is a laser of dual-frequency type. It is recalled that a dual-frequency laser is a laser source capable of simultaneously emitting two wavelengths that are spectrally distant by a value corresponding to a frequency. In this case, each radiating element of the array is then associated with a nanophotodiode able to demodulate the beating of the wavelengths of the said laser.

According to an embodiment, the nanocomponents may be carbon nanotubes.

As a variant, the nanocomponents may be of III-V semi-conductor type, in particular silicon nanowires.

In this case, the antenna may be of integrated type.

Other advantages and characteristics of the invention will be apparent on examining the detailed description of wholly non-limiting embodiments of the invention and the appended drawings in which:

- Figures 1 and 2 illustrate in a simplified manner an embodiment of the invention according to two different angles of view, and
- Figures 3 and 4 illustrate in a simplified manner another embodiment of the invention according to two different angles of view.

Referring to Figure 1, the latter represents an embodiment of an antenna ANT viewed from above. Figure 2 represents this same antenna ANT viewed from the side, and exploded.

The common elements in the two figures are designated with the aid of the same references.

In this embodiment, the antenna considered is of "Reflect array" type. Stated otherwise, the antenna ANT receives a beam FR from an external source SE and reflects another beam FRF in a given direction.

The antenna ANT is formed of an optical source, here a laser LSR of continuous type. Stated otherwise, the laser LSR continuously illuminates

the elements arranged facing it. The light beam emitted by the laser LSR is shaped by a lens LTL and directed towards radiating elements ELT.

Depending on the way in which each radiating element ELT is controlled, the illumination law of the antenna ANT is modified.

These radiating elements ELT are arranged on a mechanical support SM, made of a transparent material so as to let through the light signal originating from the laser LSR. For example, the mechanical support SM may be made of glass or any other material transparent at the operating wavelength ($TiO_2$, etc.).

For example, the radiating elements ELT may be produced with the aid of semi-conducting nanowires, of semi-conducting carbon nanotubes or else with the aid of structures termed Carbon NanoTube (CNT) "mushrooms", as in the embodiment of Figures 1 and 2.

The use of semi-conducting nanowires is particularly suited to the case where the antenna ANT is produced in an integrated manner.

The illumination by the light of the laser LSR of the radiating element ELT of semi-conducting material makes it possible to make it toggle from an insulating state to a conducting state.

Each radiating element ELT is conventionally inserted into a phase shift circuit (not represented for the sake of simplification) making it possible to produce a zero phase shift if the radiating element is not illuminated by the light signal of the laser, or a 180° phase shift if conversely it is illuminated.

So that a radiating element ELT is or is not illuminated, a spatial light modulator MSL is arranged between the lens LTL and the mechanical support SM. This spatial light modulator MSL is formed of as many wafers PST as radiating elements ELT. These wafers PST, also called pixels, are here rectangular but can adopt any other shape. They are made of a transparent material, for example a film serving to fabricate the screens of portable computers, but in transmission. A wafer PST then corresponds to a screen pixel.

Each wafer PST is matched with a corresponding radiating element ELT as illustrated in Figure 2. These wafers PST are controlled with the aid of a two-dimensional electronic control CMD. This control CMD optionally darkens the designated wafer PST, so that the latter optionally lets through the light emitted by the laser LSR. Depending on whether the light signal originating from the laser does or does not arrive at the input of the corresponding radiating element ELT, the radiating element is insulating or conducting. Consequently, it reflects in a signal called FRF, with or without phase shift, the signal FR originating from the exterior source SE.

The interconnection produced by the spatial light modulator MSL makes it possible to use nanocomponents in order to produce the radiating elements and to arrange them with a very considerable density so that the antenna ANT can reflect very high frequency signals.

For example, to reach frequencies of 300 GHz, the radiating elements ELT must be spaced apart by a distance equal to $\lambda/2$, i.e. 0.5 mm. The spatial light modulator MSL makes it possible, through its design, to control the radiating elements ELT thus placed, and therefore to produce very high frequency yet compact electronic scanning antennas.

Figures 3 and 4 which illustrate another embodiment are now referred to. Figure 3 represents this other embodiment of the antenna ANT viewed from above. Figure 4 represents this same antenna ANT viewed from the side, and exploded. For the sake of simplification, these two figures relate to the "Transmit" mode of the antenna ANT. The person skilled in the art can deduce the "Receive" mode therefrom without difficulty.

In these figures, the antenna ANT represented is of "transmit/receive" type. Stated otherwise, the signal transmitted by the antenna ANT originates from the optical source LSR and then undergoes transmission through the environment. Accordingly, the optical source LSR is a laser of dual-frequency type. This type of laser (also called dual-mode) emits two optical spectral lines shifted by a desired frequency value.

The light of the laser LSR is, as for the previous embodiment, focused by a lens LTL, and then transmitted towards the radiating elements ELT by way of the wafers PST optionally letting through the light according to the control CMD.

In the solution intended for so-called "Transmit/Receive" antennas, the signal to be radiated arises from the beating of the two optical wavelengths whose spectral gap is equal to the frequency of this signal to be radiated.

The signal of optical carrier-based radiofrequency type is formed by the beating of the two wavelengths. When the two wavelengths arrive at a photodetector, here nanophotodiodes NPD coupled to the radiating elements ELT, it effects the beating between the two wavelengths, this being a quadratic element. Each photodetector NPD then generates a photocurrent whose frequency is equal to the spectral distance between the two wavelengths. This mode of operation requires that the photodetector NPD have a sufficiently high passband to be able to generate photocurrents of possibly as much as a TeraHertz.

In this case, the optical carrier-based radio-frequency signal (RF) generated by the laser LSR is addressed, collectively and individually via the spatial light modulator MSL operating between a passing state and a non-passing state as a function of the electronic control applied. The optical signal thereafter arrives at the photodetector NPD (here a nanophotodiode) arranged between the spatial light modulator MSL and the mechanical support SM (not represented for the sake of simplification) whose RF passband is compatible with the frequency to be radiated.

Under one nanophotodiode NPD out of two is arranged a spacer ESP. The function of these is to phase shift the optical signal received from the spatial light modulator MSL. The phase shift is dependent on the thickness of each spacer ESP. They may be produced for example within the mechanical support SM.

Preferably, the thickness of the spacers ESP is equal to half the wavelength associated with the frequency of the signal to be transmitted by the radiating elements.

So that the nanophotodiodes NPD are illuminated by the rear face, the mechanical support SM is made of a material serving at one and the same time:

- as substrate for the growth of the nanophotodiodes NPD during the design of the antenna ANT, and
- as support transparent to the optical signal of the laser LSR.

For example, this material may be Gallium Arsenide (GaAs) or Indium Phosphide (InP) for the case of a photodiode operating at 1.5 µm. More generally, this material may be any other glass or $TiO_2$ type transparent material.

In this embodiment, the light passing through the wafers PST are transmitted towards the radiating elements ELT via nanophotodiodes NPD. The latter, when they are illuminated by the optical signal emitted by the laser (corresponding wafer passing), generates a photocurrent of the frequency of the signal that the radiating element will transmit.

It is noted that in the case where the antenna ANT operates in reception, the nanophotodiode NPD is mounted in mixer mode. The signal arising from laser LSR is then used as local oscillator in relation to the signal received by each radiating element ELT. Each nanophotodiode performs the mixing of the signal received and of the beat signal of the laser LSR used as oscillator.

The radiating elements ELT may be produced with the aid of carbon nanotubes (as for the embodiment of Figures 3 and 4) or from semi-conducting nanowires, this second material being preferred in the case of an antenna ANT of integrated type.

The use of nanocomponents (therefore of very small size) for the radiating elements ELT makes it possible to produce antennas comprising an oversampling of these radiating elements.

For example, for this type of antenna the radiating elements are spaced apart by a distance equal to λ/20, λ being the wavelength of the signal transmitted by the antenna. It is possible to place elements at as small a distance if they have dimensions that are much lower than this wavelength λ. This is possible by virtue of the use of nanocomponents (such as those cited hereinabove for example).

The use and the driving by the laser of these radiating elements, placed so small a distance apart, is made possible by virtue of the interconnection produced by the spatial light modulator according to the invention.

## CLAIMS

1. Electronic scanning antenna (ANT) comprising a two-dimensional array of radiating elements (ELT), formed with the aid of nanocomponents, the antenna being characterized by the fact that it comprises:

- an optical source (LSR) able to illuminate the said array of radiating elements so as to drive their operation, and

- a two-dimensional spatial light modulator (MSL), placed between the optical source and the array of radiating elements, the said modulator comprising as many activatable transparent wafers (PST) as radiating elements, so as optionally to let through the radiation of the optical source to the corresponding radiating element.

2. Antenna according to the preceding claim, in which the array of radiating elements is of active reflector type.

3. Antenna according to the preceding claim, in which the optical source is a continuous laser.

4. Antenna according to Claim 1, in which the optical source is a laser of dual-frequency type, each radiating element of the array being associated with a nanophotodiode able to demodulate the beating of the wavelengths of the said laser.

5. Antenna according to one of Claims 1 to 3, in which the nanocomponents are carbon nanotubes.

6. Antenna according to one of Claims 1 to 4, in which the nanocomponents are of III-V semi-conductor type, in particular silicon nanowires.

7. Antenna according to the preceding claim, of integrated type.