



Optical device for applying a real delay to a radio-
electric signal and application in the formation of
transmission and reception beams with an active
5 antenna.

The present invention relates to the solving of
technical problems posed by the application of pure
delays of given values to RF electromagnetic waves
10 whose frequency varies in a wide band of frequencies.
It relates more particularly to the use of optical
devices for generating such delays. It applies notably
to the field of active radar antennas and to the
formation of transmission and reception beams with such
15 antennas.

Optical architectures dedicated to the formation
of beams of network antennas, active antennas, have
formed the subject of a good number of developments.
Indeed these architectures make it possible to apply in
20 a relatively simple manner true delays of given value
to the signals sent in transmission to the radiating
elements constituting an active antenna, as well as to
the signals sent in reception by these same elements.

To produce these architectures, several optical
25 principles have thus been experimented with and are
briefly recalled hereinafter. However, in the state of
the art, no architecture seems to be perfectly suited
to the requirements, notably to carry out either a
transmission or a reception.

30 It is recalled first of all that an active
antenna, an electronic-scanning antenna in particular,
comprises a plurality of radiating elements which cater
at one and the same time for the transmission and the
reception of the RF waves. A transmission or reception
35 beam, oriented in a given direction, is formed from the
assembly of signals transmitted or received by each
element. The orientation of a beam in a given direction
 θ is obtained, as illustrated schematically by Figure
1, by applying appropriate time delays (τ_i) between the



signals transmitted or received by the various radiating elements constituting the antenna, the effect of this being to modify the orientation of the global equiphase plane 15 of the antenna with respect to the plane 14 of the antenna. Thus, for example, to orient the beam of an antenna comprising sources 11 spaced apart by a distance d , in a given direction 12 making an angle θ with the normal 13 to the plane 14 of the antenna, it is appropriate to apply to the waves received or transmitted by two consecutive sources 11 a delay τ whose value is given by the relation $\tau = (d \cdot \sin \theta) / c$ in which c represents the speed of light.

A first known solution much used to form a beam in a given direction consists in applying the desired delay directly to the RF waves which travel via the sources 11. More exactly, for greater convenience of construction, a phase shift $\phi = \omega \tau$ is applied to the signal received or transmitted by each of the sources, a signal of instantaneous angular frequency ω .

This solution is relatively simple to implement, insofar as it simply requires that each signal pathway, stated otherwise each source, be equipped with an RF phase shifter device whose construction is, nowadays, well mastered and economically affordable. Nonetheless this solution allows the desired delay to be obtained exactly only for a given frequency, the phase shift ϕ corresponding to the delay τ only for the frequency corresponding to a given value of angular frequency ω . So that, if it is conventionally used for signals whose instantaneous bandwidth remains small, that is to say limited a few % of the value of the central frequency propagated or received, it is hardly usable when the instantaneous band becomes consequent and the spreading of the beam by off-boresighting which results therefrom becomes too significant. This is why, for applications implementing instantaneous broadband transmissions such as high-resolution radars, radar imaging systems or else electronic warfare systems, a phase shift control can no longer substitute for a true-delay control, a

control which is difficult to achieve at RF frequencies the lengths of lines that are necessary being too significant having regard to the desired bulk.

5 The intrinsic characteristics and qualities of optical transmissions, such as for example low lineal losses and smaller bulk of the hardware components implemented, make it possible to contrive devices capable of creating these true delays. Accordingly, it suffices, in a known manner, to modulate a carrier
10 light wave with the RF signal transmitted or received to which it is desired to apply a given delay, and then to make this light wave journey a route corresponding to the desired delay. This route can moreover consist of a path in free space, on which are interposed
15 devices making it possible to deviate the light wave in such a way that the path is not necessarily journeyed in a straight line but may on the contrary be folded back in a space of small size. It may alternatively consist of a guided journey within an optical fiber
20 whose length determines the delay applied to the wave. This second way of proceeding is moreover the one most widely used since it is more easily industrializable.

Thus, in a known manner, by modulating a light wave, produced for example by a laser source, by a
25 radioelectric signal, and then by forming N identical modulated optical waves by means of a divider device and by applying a given specific delay to each of the N waves, it is possible to obtain, after demodulation, radioelectric signals exhibiting given delays with
30 respect to one another. These signals may for example be used to feed the radiating sources of an active antenna so as to transmit a wave of which an equiphase plane exhibits with the plane of the antenna a given angle θ .

35 Conversely, each of the signals received by the N radiating elements constituting an active antenna may be used separately to modulate a light wave. N modulated optical waves are thus formed, it being possible for each wave to be afforded a given specific

delay, making it possible after demodulation to produce a radioelectric signal corresponding to the signal received by the antenna in a given direction θ .

Moreover, according to the present state of the art, optical fibers and notably dispersive fibers constitute the simplest means of applying a delay of given value to an optical wave of given wavelength. This is why certain radioelectric transmission-reception systems requiring the formation of directional beams in transmission and/or in reception use means comprising optical fibers. As illustrated schematically by Figures 2 and 3, these systems employ optical structures comprising a light source and means for modulating this source with a radioelectric wave. The assembly is associated with an optical fiber making it possible to delay the modulated light wave by a given delay τ . Generally such an assembly is associated with each of the radioelectric sources constituting the antenna of the system, so that the delay applied to the signal relating to this source is independent of those applied to the signals relating to the other sources.

The advantage of employing such a structure is that it makes it possible to construct in a simple manner a transmission or reception system whose antenna exhibits a pattern consisting of a beam pointed in a direction making an angle θ with the normal to the plane of the antenna. Several known solutions using notably dispersive optical fibers moreover make it possible to give the angle θ several distinct values, the value of the delay afforded to each channel then being determined in a known manner by the length of the optical fiber, a fixed length which characterizes the channel, that is to say the position of the radiating source considered in the antenna, and by the wavelength of the light source, the latter possibly being a wavelength-controllable source. A beam of variable direction is thus advantageously formed.

Such a structure, moreover efficacious when the construction of a single-beam transmission or reception

system is involved, becomes more difficult to implement when it is desired to construct multibeam systems, capable at one and the same time of transmitting or of receiving on one and the same active antenna, transmission being for example carried out in accordance with a single variable beam and reception in accordance with several beams, the directions of the transmission beam and reception beams being furthermore separately controllable. The use of such an architecture leads to multiplying the number of variable-wavelength light sources (as many sources as beams to be formed), the consequence of this being to complicate the assembly thus formed and to substantially increase its manufacturing cost.

15 A solution for partially solving this problem and avoiding too significant an increase in the number of elements required, variable-wavelength sources and associated device for wavelength control, consists in implementing a structure such as that illustrated by Figure 3. This structure, based on the use of a light source of given wavelength for each reception channel, as well as its advantages are notably described in detail in the French patent application filed by the applicant and published on 12/09/2005 under the reference FR2871297. However, it relates only to multibeam reception and requires the addition of a complementary structure to carry out transmission in accordance with a variable direction beam. Furthermore, the beams formed in reception have given directions fixed by design.

30 An aim of the invention is to propose a solution for constructing a transmission-reception system comprising an active antenna whose transmission can be carried out in accordance with a variable direction beam and reception in accordance with several simultaneous beams, of likewise variable directions. Another aim of the invention is to propose an architecture which is simpler than those proposed by

the existing solutions and therefore easier to implement and less expensive.

For this purpose the subject of the invention is a delay-generating device, for applying a delay of given, quantified, value to a light wave, the value of the delay applied being dependent on the wavelength of this wave. It comprises an assembly of delay-generating cells and optical switches arranged so as to form a train of cells, linked to one another by optical switches, a train whose end cells are linked to terminal switches forming the input/output ports for the carrier light wave (63). Each delay-generating cell comprises a dispersive optical fiber segment and a non-dispersive optical fiber segment which are independent of one another. Each optical switch which interlinks two delay-generating cells is configured in such a way that as a function of the command applied to it, it links one of the two optical fiber segments constituting one of the cells considered to one or the other of the two optical fiber segments constituting the other cell.

According to the invention, each terminal optical switch is for its part configured in such a way that as a function of the command applied to it, it links one of the two optical fiber segments constituting one of the end cells to one of the input/output ports of the device.

According to a preferred embodiment of the invention the delay-generating cells are configured and arranged so as to be able to continuously vary the total delay applied to the carrier light wave.

According to a variant of this preferred embodiment, the delay-generating cells are configured to form delays whose values form a geometric progression.

According to a variant of this embodiment, the geometric progression is of ratio 2, the value of the delay applied to the carrier light wave forming the subject of a binary coding.

According to an alternative embodiment of the device according to the invention, each delay-generating cell comprises a dispersive optical fiber segment with positive dispersion coefficient, a
5 dispersive optical fiber segment with negative dispersion coefficient and a non-dispersive optical fiber segment, the three segments having identical lengths.

The subject of the invention is also an optical
10 system comprising a device according to the invention, associated with a light source producing a light wave comprising a plurality of spectral components forming a line spectrum.

According to a variant embodiment of the optical
15 system according to the invention the light source produces a light wave whose spectrum consists of regularly spaced lines.

The subject of the invention is also a system for single-beam transmission-reception of radioelectric
20 signals, for transmitting or receiving according to a beam directed in a given direction θ , the system comprising a delay-generating device according to the invention in the embodiment comprising delay-generating cells with a non-dispersive optical fiber segment and a
25 dispersive optical fiber segment.

The subject of the invention is also a system for single-beam transmission-reception of radioelectric signals, for transmitting or receiving according to a beam directed in a given direction θ , the system
30 comprising a delay-generating device according to the invention in the embodiment comprising delay-generating cells with a non-dispersive optical fiber segment and a dispersive optical fiber segment with positive dispersion and a dispersive optical fiber segment with
35 negative dispersion.

The subject of the invention is also a system for multibeam transmission-reception of radioelectric signals, for transmitting or receiving according to a plurality of beams directed in given directions θ_j , the

system comprising a plurality of delay-generating devices according to the invention.

The main advantage of the device according to the invention is that of allowing the easy application of a true delay to a radioelectric signal, the true delay being independent of the frequency of the radioelectric signal processed.

The characteristics and advantages of the invention will be better appreciated by virtue of the description which follows, which description sets forth the invention through nonlimiting examples of implementation and which is supported by the appended figures, which figures represent:

- Figure 1, an illustration of the physical principle on which the beam formation relies;

- Figure 2, the schematic illustration of a known structure making it possible to form a given direction beam in transmission;

- Figure 3, the schematic illustration of a known structure making it possible to form a given direction beam in reception;

- Figure 4, the schematic illustration of a known structure, alternative to the structure illustrated by Figure 3, making it possible to form a plurality of beams of given directions in reception;

- Figures 5a to 5c, illustrations relating to the structure and to the operating principle of the delay-generating device according to the invention;

- Figure 6, the schematic representation of an exemplary single-beam transmission-reception system implementing an optical architecture comprising a delay-generating device according to the invention;

- Figure 7, an illustration making it possible to justify the implementation of an invariable delay function in the case of systems which are similar in their manner of operation to the system of Figure 6;

- Figure 8, the schematic representation of an exemplary single-beam transmission and multibeam reception system implementing an optical architecture

comprising a plurality of delay-generating devices according to the invention;

- Figure 9, the schematic representation of an exemplary single-beam transmission-reception system implementing an optical architecture comprising a delay-generating device according to the invention, in a variant embodiment.

Turning firstly to Figure 1, which makes it possible to understand the principle of the electrical formation of a radiation pattern or beam in a given direction, in transmission or in reception, on the basis of an active antenna comprising a plurality of radiating sources disposed in a plane.

An active electronic-scanning antenna comprises a plurality of radiating elements 11, or sources, which ensure at one and the same time the transmission and the reception of an RF signal. A transmission or reception beam is formed by combining the signals transmitted or received by the various elements 11. It is known that, with such an antenna, it is possible to form a beam in a given direction 12, and therefore to give the antenna an orientation which makes it possible to have a maximum antenna gain in the direction considered, without it being necessary to rotate the plane 14 of the antenna. On the other hand, it is necessary to create time delays (τ_i) between the signals transmitted or received by the various radiating elements 11 constituting the antenna. These time delays make it possible to compensate for the fact that as a function of the direction considered, the equiphase planes 15 of the signals transmitted or received exhibit a variable inclination θ with respect to the plane 14 of the antenna, which plane 14 is moreover parallel to the equiphase planes of the signals transmitted or received in the direction pointed at by its normal 13.

Thus, if two neighboring sources 11 a distance d apart are considered, the expression for the delay to be applied to the signal received or transmitted by one

of the sources with respect to the signal received by the other source, to obtain an off-boresighting θ , is:

$$\tau = (d.\sin\theta)/c \quad [1]$$

In the field of radioelectric frequencies, the delay τ is often difficult to achieve on account of the electrical length required in order to apply a delay of the desired value. An analogous effect is obtained, for a given frequency, by applying phase shifts φ_i rather than the delays τ_i to the radioelectric signals. Nonetheless this solution is exact only for a given frequency f for which we have $\varphi_i = 2\pi f\tau_i$. It is, however, conventionally used for signals of low instantaneous bandwidths (a few % with respect to the central frequency propagated) but is affected by the phenomenon of beam spreading by off-boresighting as soon as the instantaneous band becomes consequent. For instantaneous broadband applications such as transmission-reception systems of high-resolution radars, radar imaging systems or else electronic warfare systems, this solution is no longer conceivable and the development of means for generating true delays exhibits a strategic benefit.

Turning now to Figures 2 and 3 which present in a schematic manner known optical structures making it possible to check the orientation of a radioelectric beam in transmission (Figure 2) and in reception (Figure 3).

The known optical structure, presented in Figure 2, comprises a light source 21 linked to an electro-optical modulator 22 itself driven by the signal 23 of frequency F_t to be transmitted. The output of the modulator delivers to an optical coupler 24 a light wave of wavelength λ modulated by the radioelectric signal to be transmitted. Each of the outputs of the coupler 24 is linked to an optical fiber 25 whose end is itself linked, by way of a photo-detector element (Pd) 26, to one of the sources 27 constituting the transmission antenna 28. In this structure, the length of each of the optical fibers 25 is defined so as to

apply, to the light wave which passes through it and consequently to the radioelectric signal that said wave carries, a given delay τ defined as a function of the position on the antenna of the source 27 to which it is
5 linked and of the direction θ of the beam according to which the radioelectric signal consisting of the radioelectric signals transmitted by each of the sources 27 must be transmitted.

Depending on whether the beam transmitted is a
10 beam pointed in a fixed or variable direction θ , the optical fibers 25 used are of different natures. To produce a beam with fixed pointing direction, non-dispersive optical fibers 25 associated with a laser source 21 of fixed wavelength are used. On the other
15 hand, to produce a beam with direction of pointing which is variable on command, dispersive optical fibers 25 associated with a laser source 21 of variable wavelength are used, the wavelength of which is for example controlled by control means 211. In this way,
20 the delay undergone by the light wave passing through a dispersive optical fiber being dependent on the wavelength of this wave, it is possible by varying the wavelength of the source 21 to transmit a radioelectric signal, in accordance with a single beam 29, in a
25 direction θ which is variable on command.

The optical structure presented in Figure 3 is a structure analogous to that of Figure 2. It comprises in the same manner a light source 31 of wavelength λ and an assembly of electro-optical modulators 32. Each
30 modulator is driven by the radioelectric signal 33 picked up by one of the sources 37 constituting the antenna 38. The output of each of the modulators 32 delivers to an optical fiber 35 a light wave modulated by the corresponding radioelectric signal, to which
35 wave it applies a given delay τ . Each optical fiber is linked to an input of an optical multiplexer 34 whose output 39 is demodulated by a photodetector device 36 which delivers a radioelectric signal corresponding to the sum, after applications of given delays, of the

radioelectric signals 33 provided by the sources 37 constituting the antenna 38. A global radioelectric signal 39 corresponding to a beam oriented in a direction θ determined by the length λ of the light wave produced by the light source 31 and by the lengths of the optical fibers 35 associated with each of the sources is thus advantageously obtained.

As previously, the direction θ of the beam thus formed in reception may be a fixed or variable direction. In the first case, the optical fibers 35 may be non-dispersive fibers and the source 31 a fixed wavelength source. In the second case, the optical fibers are dispersive fibers and the source 31 a source of variable wavelength λ controlled by control means 311.

The use of optical structures such as those previously described to generate delays in a radioelectric signal, structures known elsewhere, turns out to be particularly advantageous in a number of applications. Indeed, it should be noted here that unlike what happens when electronic devices are used to apply a delay to each of the radioelectric signals which feed the sources 25 constituting the antenna or which are provided by these sources 35, the delay applied is a true delay and not a delay resulting from a phase shift and therefore contingent on the frequency of the signal. Consequently the use of an optical structure, such as that schematically described here, advantageously makes it possible to process a radioelectric signal whatever the instantaneous bandwidth that it occupies. Furthermore the use of dispersive fibers advantageously makes it possible to construct in a simple manner a variable direction beam. On the other hand, the use of such structures turns out to be less advantageous as soon as one is dealing with simultaneously constructing several beams, in particular in reception. Indeed such a construction requires at the minimum several separately controllable light sources 31 (in fact one per beam to be formed) so

as to drive the various electro-optical modulators 32, as well as control means appropriate to the separate control of several light sources. Moreover, in addition to the fact that such sources are more complex to manufacture than sources of fixed wavelength, the switchover from one wavelength to another is far from being instantaneous, so the agility of the beams formed is sometimes insufficient having regard to the envisaged application. Such a structure is ultimately more suited to the simultaneous formation of several beams pointed in fixed directions.

Turning now to Figure 4 which presents a known alternative structure to the structure of Figure 3, which also makes it possible to carry out multibeam reception according to beams of fixed given directions.

As illustrated schematically by the figure, this structure comprises an assembly of light sources 41, laser sources, of fixed wavelengths, possibly being modulated by a radioelectric signal 42. The structure comprises here a number P of sources 41 equal to the number of radiating elements 47 which the antenna 48 comprises. Each of the light sources 41 is associated with a radiating element 47, the signal 42 issuing from each radiating element 47 being applied to the corresponding light source.

Each of the light sources 41 produces a light wave of different wavelength so that to a given wavelength λ_1 there corresponds a determined radiating element. The modulated light waves 43 issuing from each of the light sources 41 are applied to the inputs of an optical multiplexer 44 with P inputs, whose output produces a multiplexed wave 45 which is applied to the input of an optical coupler 46 comprising a number N of outputs equal to the number of beams formed. Each of the N outputs of the coupler 46 produces an identical optical wave 49 which is transported by a dispersive optical fiber 411 of given length to a photodetector 412 associated with the fiber considered. Each of the N optical fibers 411 being a dispersive fiber of

different length, the delay applied to the various components 49 of the optical wave which passes through it therefore depends at one and the same time on the length of the optical fiber 411 considered and the wavelength of the component 49 considered. Accordingly each photodetector 412 delivers a radioelectric signal 413 which corresponds to the sums of the signals 42 provided by each of the radiating elements 47, each signal 42 having been afforded a delay dependent on the position of the element 47 considered in the antenna and the direction θ of the beam by which the resulting signal 413 is received. N radioelectric signals corresponding to the signals received according to N beams oriented each in a fixed direction θ are thus obtained.

This alternative structure to that illustrated by Figure 3 advantageously makes it possible to carry out in a simultaneous manner, on the basis of simple optical sources 41, at fixed wavelength, a plurality of beams in reception oriented in determined fixed directions. However, this more advantageous structure, known elsewhere, does not make it possible to construct in a simple manner a system exhibiting a plurality of beams that can be oriented, independently of one another, in variable directions. At the very most it is possible, on the basis of this type of structure, by using wavelength-controllable light sources, to construct a system exhibiting a plurality of beams forming a cluster in which the orientation of the beams with respect to one another is fixed, it being possible for the cluster only to be oriented in variable directions.

Turning now to Figures 5a to 5c which present the structural and functional characteristics of the device 51 according to the invention.

As illustrated by Figure 5a, the device according to the invention 51 comprises an assembly of delay-generating cells 52, or delayer cells, as well as an assembly of optical switches 53, the delayer cells 52

being joined together by way of the optical switches 53 so as to constitute a delay-generating device comprising four input/output ports 54a to 54d.

Each of the delayer cells 52 consists mainly of a non-dispersive optical fiber segment 55 and at least one dispersive optical fiber segment 56. In a commonplace version each cell 52 comprises a non-dispersive optical fiber segment 55 and a single dispersive optical fiber segment 56. The non-dispersive optical fiber segment 55 causes, in a known manner, a given delay to the light wave which passes through it, which delay is independent of the wavelength of this wave. The dispersive optical fiber segment 56, for its part, causes this same wave a given delay dependent on its wavelength. More precisely, the dispersive optical fiber segment 56 causes the wave which passes through it a delay proportional to its length and to the gap $\Delta\lambda$ in wavelength existing between the wavelength λ of the wave considered and the nominal wavelength λ_0 characterizing the fiber.

The two segments 55 and 56 constituting one and the same cell 52 are not linked together and the ends of each segment form the points of connection of the cell with an external element, an optical switch 53 or an input/output port 54a to 54d.

According to the invention, the non-dispersive optical fiber segment 55 and the dispersive optical fiber segment 56 forming one and the same cell 52 preferably, but not necessarily, have equal lengths. Moreover, the length of the optical fiber segments 55 and 56 is preferably different from one delayer cell to the other.

Thus, in the exemplary application of Figure 5, the device according to the invention consists of an assembly of delayer cells 52 whose delays are defined so as to form a geometric progression, of ratio 2 for example. The device thus comprises M delayer cells among which one cell makes it possible to apply a

minimum delay equal to τ and one cell a maximum delay equal to $2^{(M-1)}\tau$.

Still according to the invention, the optical switches 53 are devices for switching optical signals, separately controllable by means of a command provided by an appropriate circuit, not represented in the figure. Each switch 53 comprises as many poles 57 as the delayer cells 52 comprise connection points. Thus, if the device comprises delayer cells with four connection points, the optical switches 53 integrated into the device are four-pole switches. Each switch 53 is moreover configured in such a way that, as a function of the command applied, each of its poles can be connected to any of its other poles.

Still according to the invention, the delayer cells 52 and the optical switches 53 are arranged so as to constitute a linear chain, a train, of delayer cells, each cell being connected at input and at output to an optical switch 53. A succession of delayer cells 52 linked together by optical switches 53 is thus obtained, the end switches, or terminal switches, 53a and 53b forming the input/output ports 54a to 54d of the device.

Each of the poles of a switch 53 linking together two cells 52 is linked to a connection point of one of the two cells considered. Stated otherwise, each optical switch 53 which interlinks two delay-generating cells 52 is configured in such a way that as a function of the command applied to it, it links one of the two optical fiber segments constituting one of the cells 52 considered to one or the other of the two optical fiber segments constituting the other cell.

Moreover, each of the terminal connectors 53a and 53b comprises two poles forming two of the input/output ports 54a to 54d of the device so that as a function of the command applied to it, it links one of the two optical fiber segments 55 or 56 constituting one of the end cells 52a or 52b to one of the input/output ports 54a to 54d of the device 51.

It should be noted that the optical switches 53 used are, just like the delayer cells 52, reciprocal devices. In this way, the device according to the invention is in itself an advantageously reciprocal
5 device in which the ports 54a and 54b on the one hand and the ports 54c and 54d on the other hand may be used as input or as output.

From a functional viewpoint, the device 51 according to the invention constitutes a device
10 advantageously capable of applying to a light wave a global delay T that can vary in a discrete manner, as a function of the commands applied to the switches 53. This delay can furthermore, as a function of the dispersive or non-dispersive nature of the optical
15 fiber segments through which the wave introduced into the device 51 passes, be independent of the wavelength of this wave or conversely be dependent on this wavelength.

Figure 5b illustrates for this purpose the case
20 where the switches 53 are controlled so as to apply to the light waves passing through the device 51 a delay T independent of the wavelength of the wave considered. It may be noted that, in this case, it is the non-dispersive optical fiber segments 55 which are used and
25 in their entirety, so that the delay applied is necessarily a delay T equal to the sum of the delays τ caused by these non-dispersive segments.

Figure 5c, for its part, illustrates the case
30 where the switches 53 are controlled so as to apply to the light waves passing through the device 51 a delay T which depends on the wavelength of the wave considered.

Thus, the light wave passing through the device according to the invention will be afforded a delay $T = T_1 + T_2$, T_1 being equal to the sum of the delays τ , which
35 are independent of the wavelength, caused by the non-dispersive optical fiber segments 55 through which the wave considered passes and T_2 to the sum of the delays $\tau(\lambda)$, which are dependent on the wavelength, caused by

the dispersive optical fiber segments 56 through which this same wave passes.

It should be noted that in the latter configuration, by virtue of the use of the dispersive optical fiber segments 56, a light wave consisting of a plurality of light waves of multiplexed different wavelengths will see each of its components afforded a different delay as a function of the wavelength of the component considered.

10 Stated otherwise, by associating in one and the same system the device according to the invention with a light source emitting a wave whose spectrum consists of lines of given wavelengths, a light wave whose spectral components are afforded delays is obtained at
15 the output of the system, the delay afforded to each spectral component being proportional to its wavelength. In the particular case where the spectrum of the wave produced by the light source consists of
20 spectral components of the wave produced at the output of the system are afforded delays defined as a function of wavelength by a law of ramp form.

 This result advantageously makes it possible to construct, by virtue of the device 51 according to the
25 invention, a device generating variable, controllable, delays, making it possible to afford various radioelectric signals carried by light waves having distinct wavelengths, mutually distinct true delays, the durations of which are dependent on the way in
30 which the delayer cells 52 are arranged with one another, the arrangement being produced by simply applying the appropriate commands to the optical switches 53.

 Turning now to Figure 6 which presents the basic
35 diagram of a first system integrating the device 51 according to the invention, which system is presented as exemplary nonlimiting application. This application consists of a system making it possible to carry out either a single-beam radioelectric transmission or

reception on the basis of the signals transmitted or received by the P radiating elements 621, or radiating sources, constituting an active antenna 62.

To carry out the formation of transmission and reception beams, the system considered implements an optical structure 61 making it possible to apply a true delay, of variable given value, to the radioelectric signals transmitted or received by each of the radiating elements 621 constituting the antenna 62, each element constituting an elementary reception or transmission pathway. The delay applied to each of the elementary pathways is different and determined so as to produce a beam whose equiphase plane makes an angle θ with the plane of the antenna. The value of the angle θ being determined by the values of the delays applied to the various elementary pathways. This architecture mainly comprises:

- P laser sources 611 with fixed wavelengths exhibiting an input allowing their modulation by means of a radioelectric signal. The wavelengths of the P laser sources, all different, are determined between a wavelength $\lambda_{\min}$ and a wavelength $\lambda_{\max}$ according to a law of linear variation, so that between two consecutive wavelengths there is a substantially constant gap $\delta\lambda$.

- a wavelength multiplexer 612 with P pathways producing as output a multiplexed light wave 63 taking the form of a comb of regularly spaced wavelengths.

- a delay-generating device 51 according to the invention, only three of whose four access ports A, B, C and D are connected. One of the poles of a terminal switch 53a or 53b is used as input, the pole corresponding to port A for example, while the two poles of the other terminal switch are used as outputs, the poles corresponding to ports C and D in this case. A device with one input (A) and two independent outputs (C and D) is thus produced, one output, the port C for example, being dedicated to the "transmission" pathway of the system, while the other, the port D in this case, is dedicated to the "reception" pathway.

- a control circuit 613 whose main function consists in determining, as a function of the direction θ in which the transmission or reception beam must be pointed, the value of the delay to be applied to the radioelectric signal transmitted or received by each of the P sources 621 and consequently the value of the delay to be applied to each of the corresponding modulated optical waves. The circuit 613 produces for this purpose the commands necessary to actuate in an appropriate manner the optical switches 53 which constitute the delays generator 51 according to the invention.

- a wavelength-separator demultiplexer device 614 with P pathways, inserted into the "transmission" pathway downstream of the device 51, whose input is connected to the output port dedicated to the "transmission" pathway, the port C for example. The demultiplexer 614 is charged with separating the P light waves constituting the multiplexed light wave having passed through the device 51 according to the invention and with restoring each of the P light waves 66 on a particular output.

The system described in this application is designed to operate alternately in "transmission" mode and in "reception" mode. Just like reception, transmission is here carried out according to a beam of controllable direction θ , the direction θ_t of the transmission beam possibly being different from that θ_r of the reception beam. The operation of the system according to the mode considered is described in what follows.

In transmission mode, the optical architecture previously described is driven by a radioelectric signal F_t generated by a signal synthesizing device 623. This signal simultaneously drives, via a power divider 624, the modulation inputs of the P laser light sources 611, which thus produce P light waves 64 modulated by the signal F_t . These P light waves are thereafter combined by means of the optical multiplexer 612 with P

pathways, so as to form a resulting wave 63 having the form of a comb of wavelengths.

The output from the optical multiplexer 612 is thereafter applied to the input of a delay-generating device 51 according to the invention, a device whose optical switches 53 are controlled by way of the control circuit 613. The multiplexed optical wave 63 thus traverses the various delayer cells 52 which constitute the device 51.

According to the value of the command C_i applied to the switch 53 which precedes the cell considered, the multiplexed optical wave passes through each cell 52 either via a dispersive optical fiber segment 56 or via a non-dispersive fiber segment 55. In this way, at the output of the device 51, the P components 64 of the multiplexed and delayed light wave produced by the multiplexer 612 are temporally shifted, the time shift τ between two waves issuing from two laser sources 611 of consecutive wavelengths being substantially constant. In "transmission" mode the multiplexed light wave 63 is directed, after having passed through the various delayer cells 52, onto the output port of the device 51 dedicated to the "transmission" pathway, port C for example. For this purpose the control circuit 613 delivers the appropriate command to the terminal switch 53b.

The light wave 65 produced by the delays generator 51 according to the invention is thereafter sent to the demultiplexer 614, charged with separating the P light waves of which it is composed and with restoring each of the P delayed light waves 66 on a particular output. This yields P light waves modulated by one and the same radioelectric signal exhibiting therebetween time delays of determined value. These P waves are then demodulated by photodetector elements 616 which restore for each light wave 66 the radioelectric signal 67 carried by this wave.

The P radioelectric signals thus obtained correspond to P replicas of the signal F_t , each replica

being afforded a specific delay corresponding to the delay applied by the device 51 according to the invention to the light wave having carried this replica. The delay afforded to each of the P signals 67
5 is moreover a multiple of a unit delay τ equal to the minimum delay that can separate two of the P light waves produced by the P laser sources 611, after their passage through the delay-generating device 51.

Each of the P radioelectric signals obtained is
10 ultimately applied, via a directional coupling device 622 of circulator type, to the radiating element 621 to which it corresponds by dint of its delay.

Accordingly the combination at the level of the antenna of these radioelectric signals afforded the
15 appropriate delays, which delays are here advantageously true delays and not delays produced by applying phase shifts, makes it possible to carry out the transmission of a signal with wide instantaneous bandwidth according to a beam pointed in a given single
20 direction θ .

In reception mode, the optical architecture previously described is driven by the P radioelectric signals picked up by the radiating elements 621 constituting the antenna 62. Each signal is applied to
25 the command for modulating one of the P laser light sources 611, which thus produces a light wave modulated by the signal considered. The P modulated light waves 64 thus produced are thereafter multiplexed and the resulting light wave 63 is thereafter applied to the
30 delay-generating device 51 so that, as in the transmission mode, each of the waves 64 of which the multiplexed wave is composed undergoes a delay which is dependent on the wavelength of this wave and the commands applied to the optical switches constituting
35 the device 51.

On output from the device 51, the multiplexed light wave 63 is directed, after having passed through the various delayer cells 52, toward the output port dedicated to the "reception" pathway, port D for

example. For this purpose the control circuit 613 delivers the appropriate command to the terminal switch 53b. The light wave 68 then undergoes a demodulation through a photodetector element 615 and the resulting radioelectric signal 69, which represents the sum of the radioelectric signals carried by the P light waves constituting the multiplexed wave 68 and afforded the corresponding delays, is utilized after reception 625 by the system processing means 626. The processing applied makes it possible to form, in a conventional manner, a reception beam according to the direction defined by the delays applied to the signals received by the various sources 621 constituting the antenna 62.

As may be noted through this first application, the use of a delay-generating device 51 according to the invention therefore advantageously makes it possible to construct optical structures 61 that can be integrated into a transmission reception system with active antenna comprising radiating sources, so as to render this system capable of carrying out either a broadband transmission or reception in accordance with a beam of variable direction θ that can be controlled in a simple manner.

It should be noted here that, as each laser light source 611 generally comprises only a single modulation control, the corresponding input of each light source 611 is associated with a switch 627 controlled by the control circuit 613. This switch makes it possible to hook up to the modulation control of each of the laser light sources 611, as a function of the mode of operation considered, either the radioelectric signal 628 issuing from the corresponding source 621 (reception mode), or the radioelectric signal 629 replicating the signal F_t (transmission mode).

It should also be noted that, in the application considered, the delay-generating device 51 used is a device in which each delayer cell comprises only two optical fiber segments, a non-dispersive optical fiber segment 55 and a dispersive optical fiber segment 56,

this segment being a dispersive fiber segment with positive or negative dispersion. It is recalled here that the sign of the dispersion characterizes, in a known manner, the fact that for the optical fiber considered, the delay applied to a light wave which passes through it increases (positive dispersion) or decreases (negative dispersion) as a function of the wavelength of this wave.

In this configuration, the device 51 is therefore able to apply only a delay which increases or decreases as a function of wavelength to the waves which pass through it. The known result of this is that the direction θ of the beam thus formed can only vary in a single sense with respect to the nominal direction of pointing corresponding to the normal to the plane of the antenna. This is why, in this first application, the use of the delay-generating device according to the invention in this form generally requires, as illustrated by Figure 7, the production of a constant prior delay which makes it possible to apply an angular offset Θ_0 to the antenna beam pointing direction. The effect of this offset is to modify the nominal direction of pointing from a direction 13a perpendicular to the plane 14 of the antenna to a direction 13b making an angle Θ_0 with 13a. This offset is obtained by affording each of the radiating elements of the antenna an identical delay T_0 .

In this way, the direction θ , in which a formed beam is directed, is referenced on the basis of this direction Θ_0 of prior off-boresighting in a single (constant) direction of rotation with respect to the direction 13b of the nominal beam afforded the offset Θ_0 . Figures 7a and 7b illustrate respectively the effects of the implementation of this correction for the production of a beam 12 making an angle θ reckoned positively with respect to the initial nominal direction of pointing 13a and for the production of a beam 12 making an angle θ reckoned negatively with respect to this same direction.

It is thus noted that by applying a constant delay Θ_0 and by referencing the direction θ of the beam to be formed with respect to the direction 13b it is possible to label any beam by an angle θ_a or θ_b reckoned in an invariant manner, positively or negatively, for all the directions pointed at. Accordingly the corresponding delays to be applied to the radioelectric signals transmitted or received by the radiating elements 621 of the antenna may be produced by using a single type of dispersive optical fiber 56, a fiber with negative dispersion or a fiber with positive dispersion according to case.

This angular offset may be produced in a simple manner, as illustrated by Figure 6, by inserting into each of the optical pathways which convey the light waves 64 produced by the light sources 611 to the optical multiplexer 612 segments of optical fiber 617 of appropriate lengths. The lengths of these non-dispersive optical fiber segments 617 are defined in a known manner so as to induce on the optical waves 63 produced by the P light sources 611, and therefore on the radioelectric signals carried by these waves, delays which, in the absence of any differential delay applied by the device 51, lead to the formation of a beam whose direction 13_b is off-boresighted by an angle Θ_0 with respect to the initial direction 13_a corresponding to the normal to the plane 15 of the antenna 62. A preorientation of the beam pointing direction is thus performed.

Turning now to Figure 8 which presents the basic diagram of a second system integrating the device 51 according to the invention, which system is also presented as exemplary nonlimiting application. This application deduced from the previous application consists of a system making it possible to carry out a single-beam radioelectric transmission or a multibeam radioelectric reception on the basis of the signals transmitted or received by the P radiating elements 621, or radiating sources, constituting an active

antenna 62. The system considered implements an optical structure 81 similar to that described.

As may be noted in the figure, this structure 81 is distinguished from the structure 61 in that, rather than a single delay-generating device 51, it now integrates an assembly of N generators of delays 51 operating in an independent manner to form N beams in reception. In this application, each delays generator 51 receives an identical light wave delivered by an optical coupler 81 on the basis of the multiplexed light wave 63 provided by the multiplexer 612. Furthermore, a particular delays generator 51 is dedicated to the formation of the transmission beam, while the other N-1 devices 51 are used exclusively for beam formation in reception, the lone output port dedicated to the "reception" pathway considered, port D for example, then being used.

In this application, the radioelectric signal, obtained on each reception pathway after demodulation of the corresponding light wave 811 provided by the associated delay-generating device 51, is thereafter processed separately from the others so that independent signals each corresponding to a beam whose direction may be fixed independently of that of the other beams formed are available at the output of the multipathway receiver 83. For this purpose the control circuit 82, whose functions are similar to those of the control circuit 613 of the previous application, is nonetheless dimensioned so as to produce the commands necessary for the implementation of the N delay-generating devices 51 embraced by the optical structure 81.

In regard to modes of operation, this second application does not exhibit any difference with respect to the previous application, if only that in reception mode the system advantageously makes it possible, by simple simultaneous implementation of several devices 51 according to the invention, to simultaneously form a plurality of independent beams.

This second application highlights the particularly advantageous character of the device according to the invention, which device makes it possible to produce a simple, generic, optical structure and, depending on the desired degree of sophistication, a system for forming pathways for a single-beam transmission and a single- or multi-beam reception, the number of beams that can be formed depending mainly on the number of delay-generating devices 51 integrated into this optical structure 81.

Turning finally to Figure 9 which presents the basic diagram of a system integrating the delay-generating device 51 according to the invention, which system is also presented as exemplary nonlimiting application. This application, like that illustrated by Figure 6, consists of a system making it possible to carry out a single-beam radioelectric transmission or reception on the basis of the signals transmitted or received by the P radiating elements 621, or radiating sources, constituting an active antenna 62.

As in the case of application of Figure 6 the system presented comprises an optical structure 91 making it possible to apply a true delay on each of the radioelectric signals delivered by the radiating elements 621 constituting the antenna 62 of the system (reception) or applied to these elements (transmission), each source 621 constituting an elementary reception or transmission pathway. Also as previously, the delay applied to each of the elementary pathways is different and determined so as to produce a beam whose equiphase plane makes a given angle θ with the plane of the antenna 15. The value of the angle θ is determined by the values of the delays applied to the various pathways.

On the other hand, the architecture of the optical structure 91, implemented in this application, differs somewhat from that of the structure 61 illustrated by Figure 6, in that it comprises a variant embodiment 911

of the delay-generating device according to the invention.

In this variant embodiment 911, whose structure and principle of operation are substantially the same as those of the simpler variant 51, described previously, the device according to the invention consists of delayer cells 912 comprising three segments of optical fiber rather than two; a non-dispersive optical fiber segment 915, a segment 916 of optical fiber with negative dispersion and a segment 917 of optical fiber with positive dispersion. In this way, this variant embodiment, the delay-generating device according to the invention is capable of applying to a light wave resulting from the multiplexing of light waves of different wavelengths a delay law, a linear law for example, whose variation as a function of wavelength is either positive, or negative.

Accordingly the optical structure produced on the basis of the delays generator 911 makes it possible to form, in transmission or in reception, a beam whose equiphase planes exhibit an acute angle (θ_a in Figure 7a) or obtuse angle (θ_b in Figure 7b) with the plane of the antenna. Stated otherwise, it makes it possible to form a beam pointed in a direction 12 which makes with the normal 13_a to the plane of the antenna a positive or negative angle θ , that is to say corresponding to a rotation of this normal in the clockwise direction or in the trigonometric direction.

The use of this variant embodiment of the device according to the invention advantageously makes it possible to circumvent the necessity to apply as in the application of Figure 6 a constant pointing bias θ_0 , a systematic bias a consequence of which may be to alter the general characteristics of the antenna pattern and therefore of the beams constructed. The use of optical links of various lengths between the light sources and the optical multiplexer is therefore no longer necessary and it is thus advantageously possible to use linking segments 92 of an identical length, preferably

the shortest possible. However, it requires the implementation of a variant 911 of the device according to the invention which is slightly more complex and therefore slightly more expensive to produce in particular due to the fact that the optical switches 913 used comprise six poles rather than four. Neither of the two alternative solutions presented in these two applications therefore renders the other unconditionally obsolete.

CLAIMS

1. A delay-generating device (911), for applying a
5 delay of given, quantified, value to a light wave (63),
the value of the delay applied being dependent on the
wavelength of this wave, the device comprising an
assembly of delay-generating cells (912) and optical
switches (913) arranged so as to form a train of cells,
10 linked to one another by optical switches, a train
whose end cells are linked to terminal switches (913a,
913b) forming the input/output ports (1 to 6) for the
carrier light wave (63);

characterized in that each delay-generating cell
15 (912) comprises three independent segments of optical
fiber, a dispersive optical fiber segment (917) with
positive dispersion coefficient, a dispersive optical
fiber segment (916) with negative dispersion
coefficient and a non-dispersive optical fiber segment
20 (915), the three segments having identical lengths,
each optical switch (913) which interlinks two delay-
generating cells (912) being configured in such a way
that as a function of the command applied to it, it
links one of the three optical fiber segments
25 constituting one of the cells (912) considered to one
or the other of the three optical fiber segments
constituting the other cell.

2. The device as claimed in claim 1, characterized
30 in that each terminal optical switch (913a, 913b) is
configured in such a way that as a function of the
command applied to it, it links one of the three
optical fiber segments (915, 916, 917) constituting one
of the end cells to one of the input/output ports (1 to
35 6) of the device (911).

3. The device as claimed in one of claims 1 or 2,
characterized in that the delay-generating cells (912)
are configured and arranged so as to be able to

continuously vary the total delay applied to the carrier light wave (63).

4. The device as claimed in claim 3, characterized
5 in that the delay-generating cells (912) are configured to form delays whose values form a geometric progression.

5. The device as claimed in claim 4, characterized
10 in that the geometric progression is of ratio 2, the value of the delay applied to the carrier light wave forming the subject of a binary coding.

6. An optical system comprising a device (911) as
15 claimed in any one of claims 1 to 5, associated with a light source producing a light wave (63) comprising a plurality of spectral components forming a line spectrum.

20 7. The optical system as claimed in claim 6, characterized in that the light source produces a light wave (63) whose spectrum consists of regularly spaced lines.

25 8. A system for single-beam transmission-reception of radioelectric signals, for transmitting or receiving according to a beam directed in a given direction θ , characterized in that it comprises:

- an antenna (62) with a plurality of
30 radioelectric sources (621);

- a plurality of light sources (611) equal in number to the number of radioelectric sources (621), each of the light sources being associated with a radioelectric source and producing a light wave (64)
35 having a specific wavelength λ_i , modulated by a radioelectric signal (628, 629) applied to a modulation input;

- a multiplexer of light waves (612) producing a light wave (63) combining the light waves (64) produced

by said light sources (611), each of the light waves (64) being applied directly to an input of the multiplexer;

- a delay-generating device (911) as claimed in
5 any one of claims 1 to 5 whose input (2) is linked to the output of the multiplexer (612);

the wavelength λ_i of each of the light sources (611) being determined as a function of the radioelectric source (621) with which it is associated
10 so as to obtain for each of the sources, after demodulation of the light wave (65, 68) provided by the delay-generating device (911), a radioelectric signal equal to the radioelectric signal (628, 629) applied to the input for modulating the light source and afforded
15 a given delay; defined in such a way that the combination of the radioelectric signals thus obtained constitutes the signal transmitted or received in the direction of pointing θ of the beam considered.

20 9. A system for multibeam transmission-reception of radioelectric signals, for transmitting or receiving according to a plurality of beams directed in given directions θ_j , characterized in that it comprises:

- an antenna (62) with a plurality of
25 radioelectric sources (621);

- a plurality of light sources (611) equal in number to the number of radioelectric sources (621), each of the light sources being associated with a radioelectric source and producing a light wave (64)
30 having a specific wavelength λ_i modulated by a radioelectric signal (628, 629) applied to a modulation input;

- a multiplexer of light waves (612) producing a light wave (63) combining the light waves (64) produced
35 by said light sources (611);

- a plurality of delay-generating devices (911) as claimed in any one of claims 1 to 5, the number of delay-generating devices being equal to the number of beams to be formed, the input (A) of each delay-

generating device being linked to an output of an optical coupler (81) whose input is linked to the output of the multiplexer of light waves (612);

the wavelength λ_i of each of the light sources
5 (611) being determined as a function of the radioelectric source (621) with which it is associated so as to obtain for each of the sources, after demodulation of the light wave (65, 811) provided by each delay-generating device (911), a plurality of
10 radioelectric signals, each signal being equal to the radioelectric signal (628, 629) applied to the input for modulating the light source and afforded a given delay; defined in such a way that the combination of the radioelectric signals thus obtained constitutes the
15 signal transmitted or received in one of the beam pointing directions θ considered.

10. A system for single-beam transmission-reception of radioelectric signals, for transmitting or
20 receiving according to a beam directed in a given direction θ , characterized in that it comprises:

- an antenna (62) with a plurality of radioelectric sources (621);
- a plurality of light sources (611) equal in
25 number to the number of radioelectric sources (621), each of the light sources being associated with a radioelectric source and producing a light wave (64) having a specific wavelength λ_i modulated by a radioelectric signal (628, 629) applied to a modulation
30 input;
- a multiplexer of light waves (612) producing a light wave (63) combining the light waves (64) produced by said light sources (611), each of the light waves being conveyed toward an input of the multiplexer by a
35 non-dispersive optical fiber segment (617) of a given length differing from one wave to another;
- a delay-generating device (51) whose input (A) is linked to the output of the multiplexer (612), producing as output a delayed light wave;

the wavelength λ_i of each of the light sources (611) being determined as a function of the radioelectric source (621) with which it is associated so as to obtain for each of the sources, after
5 demodulation of the light wave (65, 68) provided by the delay-generating device (51), a radioelectric signal equal to the radioelectric signal (628, 629) applied to the input for modulating the light source and afforded a given delay; defined in such a way that the
10 combination of the radioelectric signals thus obtained constitutes the signal transmitted or received in the direction θ of the beam considered; the respective lengths of the dispersive optical fiber segments (617) conveying the light waves (64) produced by the light
15 sources (611) being defined so as to preorient the beam in a given direction of pointing;

the delay generator (51) comprising an assembly of delay-generating cells (52) and optical switches (53) arranged so as to form a train of cells, linked to one
20 another by optical switches, a train whose end cells are linked to terminal switches (53a, 53b) forming the input/output ports (54a to 54d) for the carrier light wave (63), each delay-generating cell (52) comprising a dispersive optical fiber segment (56) and a non-
25 dispersive optical fiber segment (55) which are independent of one another, each optical switch (53) which interlinks two delay-generating cells (52) being configured in such a way that as a function of the command applied to it, it links one of the two optical
30 fiber segments constituting one of the cells (52) considered to one or the other of the two optical fiber segments constituting the other cell.