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(54) **Time modulated antenna array with optical switches**

(57) A method and system for driving a time modulated antenna array; comprising performing time switching of signals for one or more different elements (48, 50,... 52) of the antenna array (14) by optically switching the one or more signals. The signals may be time switched to perform pattern shaping and/or harmonic beam steering. Optical signals of different wavelengths may be optically switched, each wavelength being for a respective different antenna element, and in this event the optical signals may be wavelength division multiplexed and transmitted over an optical link (8) to the antenna elements (48, 50,...52), and the optical switching may be performed remotely from the vicinity of the antenna array (14). The antenna array may comprise a two-dimensional array of antenna elements, for example a cylindrical array (214), with rows or other groupings of the antenna elements being for time modulated switching using the time switched signals.

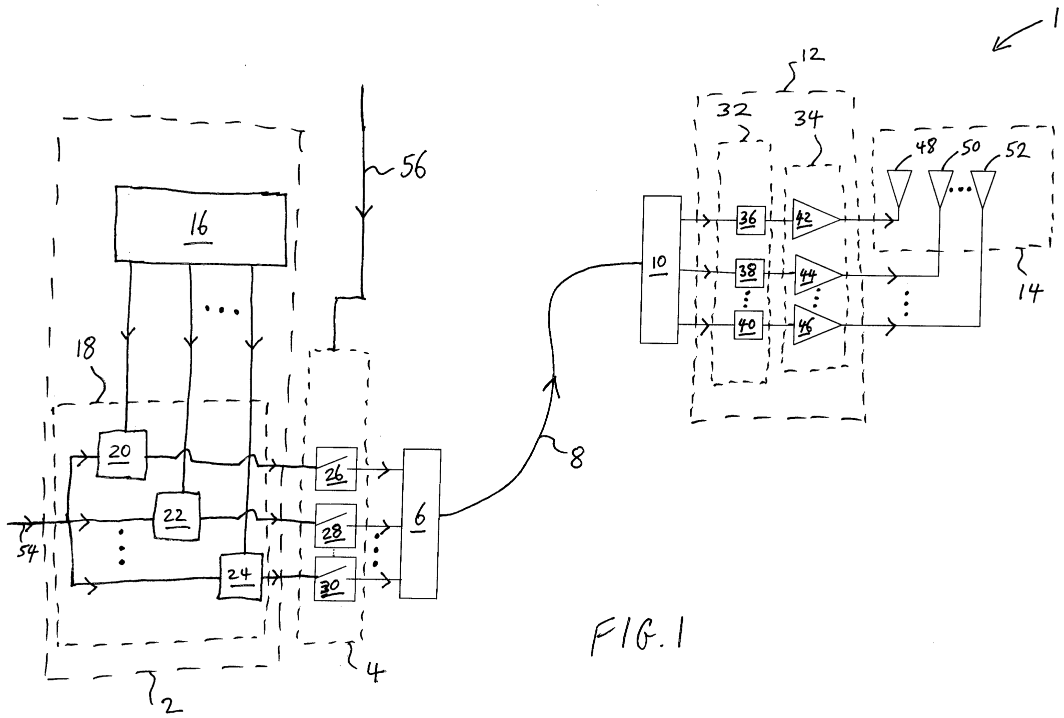

FIG. 1

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Description

FIELD OF THE INVENTION

[0001] The present invention relates to antenna arrays, antenna systems, and systems for driving and/or controlling antenna arrays. The present invention also relates to methods for operating such arrays and systems.

BACKGROUND

[0002] In relation to transmission of electromagnetic radiation, for example transmission of radio frequency (RF), it is well known to control the transmitted beam shape and direction by providing an array of antenna elements whose relative phase and/or amplitude is varied (phased array antennas).

[0003] A less well known possible alternative technology that has been researched, but not extensively developed, is known as time modulated arrays. In the case of time modulated arrays, the shape and direction of a beam output by an array of antenna elements is controlled by switching the different antenna elements on and off in a manner that provides outcomes similar to those provided by conventional phased array antennas. Time modulated arrays were first proposed in the 1950's, but conventionally are not considered as practicable compared to phased array antennas.

[0004] Further details of time modulated arrays are as follows (the indicated references [1]-[21] are listed after the following two paragraphs).

[0005] The concept of using time as an additional parameter, or a fourth dimension, in the design and control of array antennas was first proposed by Shanks and Bickmore in the late 1950s [1]. This work was then advanced both theoretically and experimentally by Kummer et al in the early 1960s [2]. The fundamental principle of time modulated or time switched, linear array is to periodically energize the elements of the array by switching each element on and off using high speed RF switches in such a way that the pattern radiated by the array conforms to a prescribed function. There are two basic functions that can be realized using time modulated linear arrays: pattern shaping and harmonic beam steering. To implement pattern shaping, or pattern synthesis, in a time modulated array the elements of the array are periodically energized in such a way that the time averaged effective-amplitude distribution across the array equates to that of a conventional array weighting function such as a low sidelobe Taylor distribution. Although this technique can be successfully used to provide low-sidelobe level radiation patterns at the fundamental operating frequency of the array, the process of periodic element switching also generates radiation at harmonics of the modulation frequency. In general such harmonics are undesirable as they reduce the efficiency of the array and may also interfere with other bands of the frequency spectrum [3]. Consequently, much of the recent research into time modulated arrays has addressed the problem of minimizing sideband levels and improving radiation efficiency using various adaptive optimization techniques. Yang et al addressed this issue by investigating the use of various adaptive optimization techniques, including Genetic Algorithms, to calculate the on-times of array elements required to reduce both the sidelobe and sideband levels [4]. The same authors also investigated the use of a differential evolution algorithm to optimize the interelement spacing of the array element in order to suppress sidelobe levels of a time modulated linear array [5]. Other approaches to sidebands reduction have been considered by various researchers and included the application of simulated annealing, particle swarm optimization, and element thinning via differential evolution and invasive weed optimization [6-14].

[0006] Although the harmonic patterns generated by a time modulated array are often undesirable, there are applications in which such harmonic beams can be exploited and this was also investigated by Shanks who described the process of harmonic beam steering in time modulated linear arrays [15]. In this application the elements along the length of the array are sequentially energized. This effectively introduces a linear time delay in the switching sequence across the face of the array, and generates harmonic radiation patterns which have a directional response at prescribed steering angles. Therefore a properly controlled time modulated array can be configured to replicate the properties of an electronically scanned array antenna. Crucially however, the time modulated array achieves this function without the use of expensive phase shifters. Recent work in this area has also demonstrated how a time modulated linear array can be configured to provide harmonic beam steering and simultaneous control of sidelobe levels by adjusting the switching time of the array elements [16]. Other recent papers have considered how time modulated linear array can be employed for null steering applications for direction finding [17-18], and their use in pulsed Doppler radar, direction of arrival estimation and phase switched screens [19-21].

[1] H. E. Shanks and R. W. Bickmore, "Four-dimensional electromagnetic radiators," Canadian Journal of Physics., vol.37, pp 263-275, 1959.

[2] W. H. Kummer, A. T. Villeneuve, T. S. Fong, and F. G. Terrio, "Ultra-low sidelobes from time-modulated arrays," IEEE Transactions on Antenna and Propagation, vol. 11, pp. 633-639, Nov, 1963.

[3] J. C. Bregains, J. Fondevila, G. Franceschetti, and F. Ares, "Signal radiation and power losses of time-modulated arrays," IEEE Transactions on Antenna and Propagation, vol. 56, no.6, pp. 1799-1804, Jun. 2008.

[4] S. Yang, Y. B. Gan, A. Qing, and P. K. Tan, "Design of uniform amplitude time modulated linear array with optimized time sequences," IEEE Transactions on Antenna and Propagation, vol. 53, no. 7, pp.

2337-2339, Jul. 2005.
[5] G. Li, S. Yang, M. Huang and Z. Nie, "Sidelobe Suppression in Time Modulated Linear Arrays with Unequal Element Spacing", Journal of Electromagnetic Waves and Applications, vol. 24, no. 5-6, pp. 775 - 783, 2010.
[6] J. Fondevila, J. C. Bregains, F. Ares and E. Moreno, "Optimising uniformly excited linear arrays through time modulation," IEEE Antennas Wireless Propagation Letters, vol. 3, pp 298-300, 2004.
[7] L. Manica, P. Rocca, L. Poli and A. Massa, "Almost time-independent performance in time-modulated linear arrays," IEEE Antennas Wireless Propagation Letter, vol. 8, pp. 843-846, Aug. 2009.
[8] L. Poli, P. Rocca, L. Manica, and A. Massa, "Handling sideband radiations in time-modulated arrays through particle swarm optimization," IEEE Transactions on Antennas and Propagation, vol. 58, no. 4, pp. 1408-1411, April 2010.
[9] P. Rocca, L. Poli, G. Oliveri and A. Massa, "Synthesis of time-modulated planar arrays with controlled harmonic radiations," Journal of Electromagnetic Waves and Applications, vol. 24, no. 5-6, pp. 827-838, 2010..
[10] P. Rocca, L. Manica, L. Poli and A. Massa, "Synthesis of compromise sum-difference arrays through time-modulation," IET Radar Sonar Navigation, vol. 3, pp. 630-637, Nov. 2009.
[11] L. Poli, P. Rocca, L. Manica and A. Massa, "Pattern synthesis in time-modulated linear arrays through pulse shifting," IET Microwaves, Antennas & Propagation, vol. 4, issue 9, pp. 1157-1164, Sep, 2010.
[12] L. Poli, P. Rocca, L. Manica and A. Massa, "Time modulated planar arrays - Analysis and optimisation of the sideband radiations," IET Microwaves, Antennas & Propagation, vol. 4, issue 9, pp. 1165 -1171, Sep, 2010.
[13] E. Aksoy and E. Afacan, "Thinned Nonuniform Amplitude Time-Modulated Linear Arrays," IEEE Antennas Wireless Propagation Letter, vol. 9, May, 2010, pp 514 -517.
[14] A. Basak, S. Pal, S. Das, A. Abraham and V. Snasel, "A modified Invasive Weed Optimization algorithm for time-modulated linear antenna array synthesis," IEEE Congress on Evolutionary Computation, pp 1- 8, July, 2010.
[15] H. E. Shanks, "A new technique for electronic scanning," IEEE Transactions on Antennas and Propagation, vol. 9, no. 2, pp. 162-166, Mar. 1961.
[16] Y. Tong and A. Tennant, "Simultaneous control of sidelobe level and harmonic beam steering in time-modulated linear arrays," IET Electronics Letters, vol. 46, no. 3, 2010, pp. 200-202.
[17] A. Tennant and B. Chambers, "A two-element time-modulated array with direction-finding properties," IEEE Antennas Wireless Propagation Letter, vol. 6, pp. 64-65, 2007.
[18] A. Tennant, "Experimental two-element time-modulated direction finding array," IEEE Transactions on Antennas and Propagation, vol. 58, no. 3, pp. 986-988, March 2010.
[19] G. Li, S. Yang and Z. Nie, "A study on the application of time modulated antenna arrays to airborne pulsed Doppler radar," IEEE Transactions on Antennas and Propagation, vol. 57, no. 5, pp. 1578-1582, May 2009.
[20] G. Li, S. Yang and Z. Nie, "Direction of arrival estimation in time modulated linear arrays with unidirectional phase center motion," IEEE Transactions on Antennas and Propagation, vol. 58, no. 4, pp. 1105-1111, April 2010.
[21] A. Tennant and B. Chambers, "Time-switched array analysis of phase switched screens," IEEE Transactions on Antennas and Propagation., vol. 57, no. 3, pp.808-812, Mar. 2009.

[0007] Further understanding of time modulated arrays may be gleaned from the description later below relating to Figures 2 and 3. It is however noted, for the avoidance of doubt, that the description later below with reference to Figures 2 and 3 includes, or possibly includes, aspects that have been derived by the present inventors, which aspects are not necessarily part of the state of the art and are also not essential for implementing the present invention.

SUMMARY OF THE INVENTION

[0008] The present inventors have realised that disadvantages presented by time modulated arrays include: switching times are required to be very quick and switching speed e.g. by a PIN diode is limited and switching harmonics may cause problems; losses will tend to occur due to inclusion of electric switches (e.g. PIN diodes); and the switching as performed to date will tend to be near the antenna element. The present inventors have further realised that such disadvantages, and/or conventional opinion that time modulated arrays are less practicable than conventional phased array antennas, may be overcome or at least alleviated by implementing some, or all, of the switching for a time modulated array optically rather than electrically.

[0009] In a first aspect, the present invention provides a method for driving a time modulated antenna array; the method comprising performing time switching of signals for one or more different elements of the antenna array by optically switching the one or more signals.

[0010] The signals for the different elements of the antenna array may be being time switched to perform pattern shaping.

[0011] The signals for the different elements of the antenna array may be being time switched to perform harmonic beam steering.

[0012] The signals for the different elements of the antenna array may be being time switched to perform pattern shaping and harmonic beam steering.

[0013] Plural optical signals of different wavelengths may be optically switched, each wavelength being for a respective different antenna element of an antenna array.

[0014] The plurality of optically switched signals may be wavelength division multiplexed for transmission toward the antenna elements over an optical link, and then wavelength division demultiplexed.

[0015] The optical link may be a single core optical fibre.

[0016] The time switching of the signals for all the elements of the antenna array may be performed by optical switching.

[0017] The optical switching may be performed remotely from the vicinity of the antenna array.

[0018] The method may further comprise driving plural elements of an antenna array with the time switched signals.

[0019] The antenna array may comprise a two-dimensional array of antenna elements, and rows or other groupings of the antenna elements with respect to one of the array's two dimensions are for time modulated switching using the time switched signals.

[0020] The antenna array may be a cylindrical array.

[0021] In a further aspect, the present invention provides a system for driving a time modulated antenna array; the system comprising one or more optical switches for performing time switching of signals for one or more different elements of the antenna array.

[0022] The system may further comprise an antenna array comprising a two-dimensional array of antenna elements.

[0023] The system may further comprise an optical link for provision between the one or more optical switches and the antenna array to position the one or more optical switches remote from the vicinity of the antenna array.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024]

Figure 1 is a schematic illustration (not to scale) of an antenna system;

Figure 2 is a schematic illustration (not to scale) showing an example of a driving scheme that is applied via a beam control signal;

Figure 3 is a schematic plot (not to scale) showing an example of beam output characteristics that may typically be provided by the driving scheme of Figure 2;

Figure 4 is a schematic illustration (not to scale) of an antenna array that may be used in the antenna system of Figure 1; and

Figure 5 shows a top view of a cylindrical form of an antenna array and an example beam shape and direction.

DETAILED DESCRIPTION

[0025] In this embodiment, the antenna system 1 comprises an electrical to optical (E/O) conversion module 2, an optical switch module 4, a wavelength division multiplexer (WDM) 6, an optical fibre 8, a wavelength division demultiplexer (WDDM) 10, and optical to electrical (O/E) conversion module, an antenna array 14.

[0026] The E/O conversion module 2 comprises an optical source module 16 and an optical modulator system 18. The optical modulator system 18 comprises sixteen optical modulators, of which for clarity only three are shown in Figure 1, namely a first optical modulator 20, a second optical modulator 22, and a sixteenth optical modulator 24.

[0027] The optical switch module 4 comprises sixteen optical switches corresponding respectively to the sixteen optical modules 20, 22,...24, of which for clarity only three are shown, namely a first optical switch 26, a second optical switch 28, and a sixteenth optical switch 30.

[0028] The O/E conversion module 12 comprises a photodetector system 32 and an amplifier module 34. The photodetector system 32 comprises sixteen photodetectors, of which for clarity only three are shown, namely a first photodetector 36, a second photodetector 38, and a sixteenth photodetector 40.

[0029] The amplifier module 34 comprises sixteen amplifiers corresponding respectively to the sixteen photodetectors 36, 38,...40, of which for clarity only three are shown, namely a first amplifier 42, a second amplifier 44, and a sixteenth amplifier 46.

[0030] The antenna array 14 comprises sixteen antenna elements corresponding respectively to the sixteen photodetector/amplifiers, of which for clarity only three are shown, namely a first antenna element 48, a second antenna element 50, and a sixteenth antenna element 52.

[0031] Figure 1 also shows two electrical signals that are involved in operation of the antenna system 1, namely an incoming RF signal 54 and a beam control signal 56.

[0032] The optical source module 16 is optically coupled to each of the optical modulators 20, 22,...24.

[0033] Each optical modulator 20, 22,...24 is further optically coupled to its corresponding respective optical switch 26, 28,...30. Each optical modulator 20, 22,...24 is further arranged to receive the electrical incoming RF signal 54.

[0034] Each optical switch 26, 28,...30 is further optically coupled to the WDM 6. The optical switch module 4 is arranged to receive the electrical beam control signal 56. In operation each optical switch 26, 28,...30 receives a respective switching control signal derived from the beam control signal 56, as will described in more detail later below.

[0035] The WDM 6 is optically coupled to the WDDM

10 via the optical fibre 8.

[0036] The WDDM 10 is further optically coupled to the respective inputs of each of the photodetectors 36, 38,...40.

[0037] The respective output of each photodetector 36, 38,...40 is electrically coupled to the input of its corresponding respective amplifier 42, 44,...46. The respective output of each amplifier 42, 44,...46 is coupled to its corresponding respective antenna element 48, 50,...52.

[0038] Further details of the above mentioned elements, and their operation, as employed in this embodiment, are as follows.

[0039] The optical source module 16 provides sixteen optical carrier signals, of different wavelengths. The wavelengths may include non-visible wavelengths, e.g. infra-red. In this embodiment the wavelengths employed are ones specified in the ITU-T Recommendation G694.2, which allocates specific wavelengths that are in the range 1270nm to 1611 nm and which have 20nm spacing between channels. In other embodiments, other wavelength values may be used in addition or instead.

[0040] The optical modulator system 18 modulates the incoming RF signal 54 on to the sixteen different wavelength carriers i.e. the first optical modulator 20 modulates the incoming RF signal 54 on to a first wavelength carrier, the second optical modulator 22 modulates the incoming RF signal 54 on to a second wavelength carrier, and so on up to the sixteenth optical modulator 24 that modulates the incoming RF signal 54 on to a sixteenth wavelength carrier.

[0041] Thus the E/O conversion module 2, comprising the optical modulator system 18 and the optical source module 16, performs electrical to optical conversion on the incoming RF signal 54, modulating it on to sixteen separate optical signals of differing wavelengths that are forwarded individually, each one to a respective different one of the optical switches 26, 28,...30.

[0042] The optical switch module individually switches the sixteen optical switches 26, 28,...30 on and off under control of the beam control signal 56, thereby individually switching the sixteen different wavelength optical signals on and off. In other words, each optical switch 26, 28,...30 receives a respective switching control signal derived from the beam control signal 56, as will described in more detail later below. In this embodiment the optical switches are Mach-Zender optical switches, but in other embodiments some or all of the optical switches 26, 28,...30 may be implemented using other types of optical switch.

[0043] At any instance, any of the optical switches 26, 28,...30 that is switched to its on state forwards its respective optical signal to the WDM 6.

[0044] The WDM 6 multiplexes the different wavelength signals so that they can all be passed via the optical fibre 8 to the WDDM 10. By virtue of this arrangement, the switching can be performed at significant distances away from the antenna elements, thereby tending to reduce interference and so on. For example, the optical fibre may be 100 metres long. However, this is not essential, and in other embodiments there may be no significant distances between the switching elements and the antenna elements.

[0045] The optical fibre 8 is a single core fibre, which can be accommodated by virtue of the use of different wavelength signals and the use of wavelength division multiplexing. By use of a single core fibre, if desired an optical rotating joint can also be employed. However, neither the use of a single core fibre nor an optical rotating joint is essential, and in other embodiments more than one core or fibre may be used, and the level of multiplexing may be reduced or totally omitted.

[0046] The WDDM 10 demultiplexes the different wavelength signals so that they can be passed individually to their respective corresponding photodetectors 36, 38,...40.

[0047] Each photodetector 36, 38,...40 of the photodetector system 32 detects its incoming optical signal and outputs a corresponding electrical signal, which is amplified by the respective amplifier 42, 44,...46 of the amplifier module 34. Thus the O/E conversion module 12, comprising the photodetector system 32 and the amplifier module 34, performs optical to electrical conversion on the sixteen individual optical signals received via the optical fibre 8.

[0048] The amplified output signals are each fed from the respective amplifier 42, 44,...46 to the corresponding respective antenna element 48, 50,...52 of the antenna array 14. (It will be appreciated that in other embodiments, the amplifiers 42, 44,...46 may be omitted, or other forms of processing may be performed on the signals output from the photodetectors in addition to or instead of amplification before being passed onwards to the antenna elements 48, 50,...52.)

[0049] The antenna elements 48, 50,...52, and indeed the whole antenna array 14, are conventional ones, as used for example in conventional phased array antenna systems.

[0050] Further details of the beam control signal and the modulation applied to each antenna element's respective signal in this embodiment will now be described with reference to Figures 2 and 3. However, it will be appreciated that any suitable time modulated array signals may be used, including, but not limited to, arrangements and schemes described in any of the references [1]-[21] mentioned earlier above in the Background section.

[0051] Figure 2 is a schematic illustration (not to scale) showing an example of a driving scheme that is applied via the beam control signal 56 in this embodiment. The x-axis 72 indicates the sixteen different antenna element channels. The y-axis is a time axis. The sixteen solid blocks 78 that constitute a first plot 76 each indicate the time period over which a respective antenna element is switched on. Thus, in this embodiment (although this need not be the case in other embodiments), the sixteen elements are each switched on sequentially, and at any given time only one (or none) of them is switched on, according to its position in the sequence, i.e. there are never two switched on at the same time. Also, as indicated schematically (although not to scale) in plot 76, the duration of the on-time varies between different elements, rising from the lowest duration for the outer elements numbered 1 and 16 up to the longest durations being for the central elements numbered 8 and 9. As is shown in Figure 3 (see later below), the above described modulation scheme provides for a relatively narrow main central beam profile of the transmitted radio beam. In this example, the ascending sequence provides a phase shift between each element so the pattern produced tends to steer the beam off-boresight. The relative on-times tends to adjust the side-lobes.

[0052] Also shown schematically in Figure 2 are five further examples of plots 78, 80, 82, 84, 86 that are applied at different times in this embodiment. For ease of viewing, these plots are represented by dotted lines, however it will be appreciated that each in fact consists of sixteen different "height" solid blocks with the same relative heights to each other as the sixteen solid blocks forming plot 76. In this embodiment, in each plot 78, 80, 82, 84, 86 the sixteen antenna elements have the same ratio of on-time to each other as in plot 76, however the timing of the sequence in which they are switched on is different to that of plot 76. In the case of plot 78, a small extent of temporal overlapping of the on times is provided, in the case of plot 80 a larger amount of temporal overlapping is provided, and so on, through to plot 86 where the on times of the sixteen elements are overlapped temporally to the maximum extent possible given that different elements have different lengths of on-time.

[0053] Figure 3 is a schematic plot (not to scale) showing an example of beam output characteristics that may typically be provided by the driving scheme described above with reference to Figure 2. The x-axis indicates the sine of the angle Θ of the beam, and the y-axis indicates the gain of the output signal at any given angle Θ. In Figure 3, plot 176 is the beam produced by the plot 76 of Figure 2, plot 178 is the beam produced by the plot 78 of Figure 2, plot 180 is the beam produced by the plot 80 of Figure 2, plot 182 is the beam produced by the plot 82 of Figure 2, plot 184 is the beam produced by the plot 84 of Figure 2, and plot 186 is the beam produced by the plot 86 of Figure 2. As also shown in Figure 3, each of plots 176, 178, 180, 182, 184, 186 has smaller side lobes in addition to its respective peak central beam shown.

[0054] As shown schematically in Figure 3, by varying between the plots 76, 78, 80, 82, 84, 86 of Figure 2, the central beam can be steered at different angles Θ as shown by the differing angular positions of the peaks of respective plots 176, 178, 180, 182, 184, 186.

[0055] As mentioned earlier above, in operation each optical switch 26, 28,...30 receives a respective switching control signal derived from the beam control signal 56. In this embodiment the switching signals are 'square wave' logic signals which operate the optical switches to control the optical signal. The switching signals are then driven be a processor (not shown), such as a microcontroller or other programmable logic device. If required or desired, conditioning of the signal from a controller may be performed so that the correct drive voltage and current are present to operate the switch.

[0056] Figure 4 is a schematic illustration (not to scale) of an embodiment of an antenna array 214 that may be used in the role of the antenna array 14 in the antenna system 1 described earlier above.

[0057] The antenna array 214 in this embodiment is a cylindrical array, although this need not be the case, and in other embodiments other shapes may be employed.

[0058] In this embodiment the antenna array 214 comprises three vertical antenna sub-arrays, namely a first vertical antenna sub-array 14a, a second vertical antenna sub-array 14b, and a third vertical antenna sub-array 14c. In other embodiments, there may be only two vertical antenna sub-arrays, or there may be more than three vertical antenna sub-arrays.

[0059] In this embodiment each vertical antenna sub-array 14a, 14b, 14c comprises sixteen antenna elements of which for clarity only three are shown for each in Figure 4, namely: a first antenna element 48a, a second antenna element 50a, and a sixteenth antenna element 52a of the first vertical antenna sub-array 14a; a first antenna element 48b, a second antenna element 50b, and a sixteenth antenna element 52b of the second vertical antenna sub-array 14b; and a first antenna element 48c, a second antenna element 50c, and a sixteenth antenna element 52c of the third vertical antenna sub-array 14c.

[0060] Equivalently, antenna array 214 may be considered as comprising sixteen horizontal antenna subarrays of which for clarity only three are shown in Figure 4, namely: a first horizontal antenna sub-array 248 comprising the three first antenna elements 48a, 48b, and 48c that are each the first antenna elements of their respective vertical antenna sub-arrays; a second horizontal antenna sub-array 250 comprising the three second antenna elements 50a, 50b, and 50c that are each the second antenna elements of their respective vertical antenna sub-arrays; and a sixteenth horizontal antenna sub-array 252 comprising the three sixteenth antenna elements 52a, 52b, and 52c that are each the sixteenth antenna elements of their respective vertical antenna sub-arrays. Not shown, but arranged in a corresponding manner, are the third to fifteenth horizontal antenna sub-arrays, where in each case where n = 3 to 15, the nth horizontal antenna sub-array 252 comprises the three nth antenna elements that are each the nth antenna elements of their respective vertical antenna sub-arrays.

[0061] In operation, the antenna array 214 of this embodiment is driven by the antenna system 1 in the same way as the first embodiment antenna array 14 described earlier above, except that in place of the single first antenna element 48 of the first embodiment antenna array 14 being switched on at any given "on time" of the time modulation, in this embodiment one or more of the plural first antenna elements 48a, 48b and 48c of the first horizontal antenna sub-array 248 may be turned on, and so on, for each of the second to sixteenth horizontal antenna sub-arrays. By controlling and varying which of the antenna elements are switched on at any time, three-dimensional control of the output beam direction and profile (i.e. pattern shape and harmonic beam steered direction) is achieved. This is shown schematically (not to scale) in Figure 5, which shows a top view of the cylindrical form of the antenna array 214 and an example beam shape and direction 270. The time modulation array driving (optically switched as described earlier) with respect to the sixteen different horizontal antenna sub-arrays 248, 250,...252 provides control of the beam shape and direction 270 (including side lobes) in or out of the page for the view shown in Figure 5. In combination with this, conventional electrical phase array type driving modulation is provided with respect to the three different vertical antenna sub-arrays 14a, 14b, 14c thereby providing control of beam shape and direction 270 (including side lobes) in the sense of emission from different points along the perimeter of the cylinder i.e. along the directional line indicated by reference numeral 280 in Figure 5. Thus the two simultaneous driving arrangements combined together (or in effect super-imposed on each other) provide in combination a three-dimensional control of the beam shape and direction 270.

[0062] It will be appreciated that the terms "horizontal" and "vertical" are used above merely for ease of reference to the Figures, and these terms are not limiting as such, and any two differing directions may be implemented rather than true horizontal and vertical as such, including two directions that are not perpendicular to each other.

[0063] In the above embodiments, the optical switching is performed after the incoming RF signal has been modulated onto the optical carriers. However, this need not be the case, and in other embodiments the optical switching may be performed elsewhere (i.e. at a different stage), for example the optical switching (i.e. in effect applying the beam control signal) may be performed on the optical carrier signals before the optical carrier signals have the incoming RF signal modulated on to them.

[0064] Although above the antenna array is included as part of the antenna system being described, it will be appreciated that the other elements of the described system alone or in combination represent embodiments of the present invention. In corresponding fashion, it will be appreciated that methods of preparing driving signals including optical switching for time modulation represent embodiments of the invention, without the final transmission to and by the antenna elements of those switched signals being necessary for embodiments to be implemented as such.

[0065] In the above embodiments, the signal channels for all of the antenna elements are switched optically. However, this need not be the case, and in other embodiments one or more of the channels may be electrically switched, and only one or some of the channels optically switched.

[0066] It will be appreciated that where specific numbers of elements, channels, etc. are described in the above embodiments these are merely by way of example, and in other embodiments other numbers of these elements may be included. For example, there may be other than sixteen channels/antenna elements, and in embodiments such as those of Figures 4 and 5, other than sixteen horizontal antenna sub-arrays and other than three vertical antenna sub-arrays, and so on.

[0067] The arrangement of different functionalities in the described modules, and the arrangement of given modules within other modules, in the above embodiments, is not essential, and in other embodiments such functionalities and modules may be arranged differently to how described above.

[0068] The above ways of performing the electrical to optical conversion, and the optical to electrical conversion, are not essential, and in other embodiments either or both of these may be implemented in other ways readily available to the skilled person.

[0069] Apparatus for implementing the above described modules and other processing entities may be provided by configuring or adapting any suitable apparatus, for example one or more computers or other processing apparatus or processors, and/or providing additional modules. The apparatus may comprise a computer, a network of computers, or one or more processors, for implementing instructions and using data, including instructions and data in the form of a computer program or plurality of computer programs stored in or on a machine readable storage medium such as computer memory, a computer disk, ROM, PROM etc., or any combination of these or other storage media.

Claims

1. A method for driving a time modulated antenna array; the method comprising performing time switching of signals for one or more different elements (48, 50,...52) of the antenna array (14) by optically switching the one or more signals.

2. A method according to claim 1, wherein the signals for the different elements (48, 50,...52) of the antenna array (14) are being time switched to perform pattern shaping.

3. A method according to claim 1, wherein the signals for the different elements (48, 50,...52) of the antenna array (14) are being time switched to perform harmonic beam steering.

4. A method according to claim 1, wherein the signals for the different elements (48, 50,...52) of the antenna array (14) are being time switched to perform pattern shaping and harmonic beam steering.

5. A method according to any of claims 1 to 4, wherein plural optical signals of different wavelengths are optically switched, each wavelength being for a respective different antenna elements (48, 50,...52) of the antenna array (14).

6. A method according to claim 5, wherein the plurality of optically switched signals are wavelength division multiplexed for transmission toward the antenna elements (48, 50,...52) over an optical link (8), and then wavelength division demultiplexed.

7. A method according to claim 7, wherein the optical link (8) is a single core optical fibre (8).

8. A method according to any of claims 1 to 7, wherein the time switching of the signals for all the elements (48, 50,...52) of the antenna array (14) is performed by optical switching.

9. A method according to any of claims 1 to 8, wherein the optical switching is performed remotely from the vicinity of the antenna array (14).

10. A method according to any of claims 1 to 9, further comprising driving plural elements (48, 50,...52) of the antenna array (14) with the time switched signals.

11. A method according to claim 10, wherein the antenna array comprises a two-dimensional array of antenna elements, and rows or other groupings of the antenna elements with respect to one of the array's two dimensions are for time modulated switching using the time switched signals.

12. A method according to claim 11, wherein the antenna array is a cylindrical array (214).

13. A system for driving a time modulated antenna array; the system comprising one or more optical switches (26, 28,...30) for performing time switching of signals for one or more different elements (48, 50,...52) of the antenna array (14).

14. A system according to claim 13, wherein the system further comprises an antenna array comprising a two-dimensional array of antenna elements.

15. A system according to claim 13 or 14, further comprising an optical link (8) for provision between the one or more optical switches (26, 28,...30) and the antenna array (14) to position the one or more optical switches (26, 28,...30) remote from the vicinity of the antenna array (14).

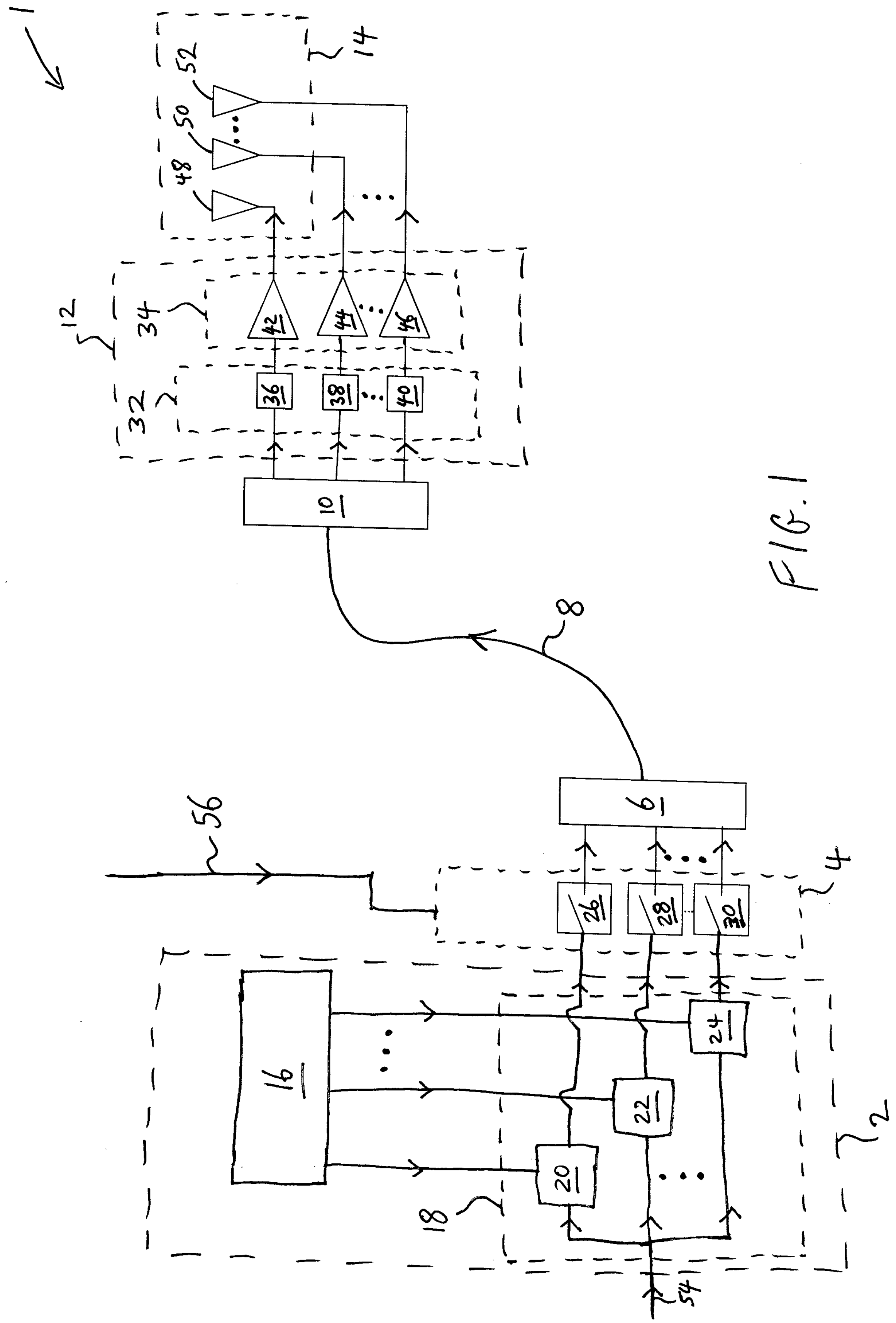
1
14
52
50
48
12
34
32
42
44
46
36
38
40
10
8
56
6
4
26
28
30
16
18
20
22
24
2
54

FIG. 1

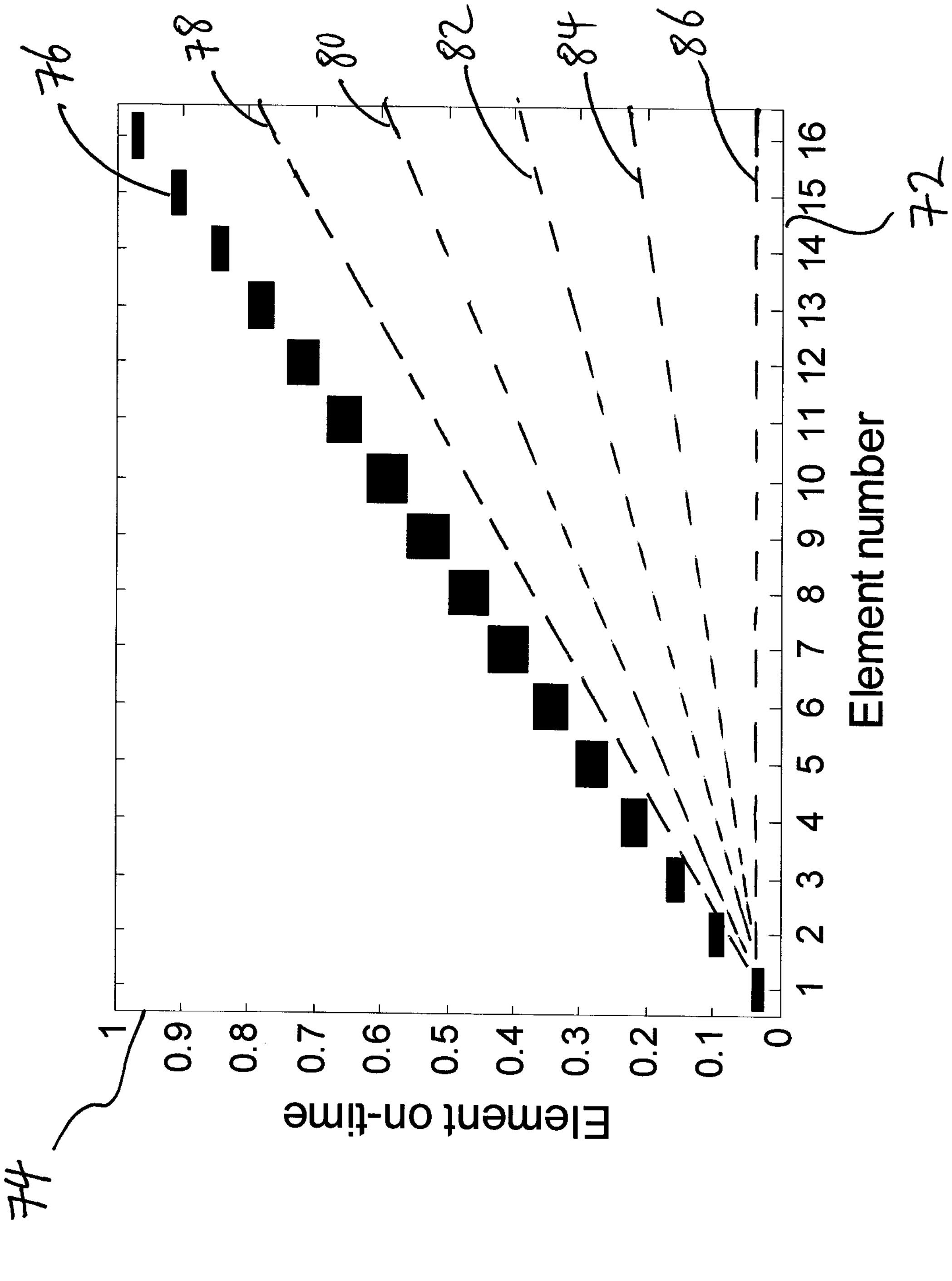

FIG. 2

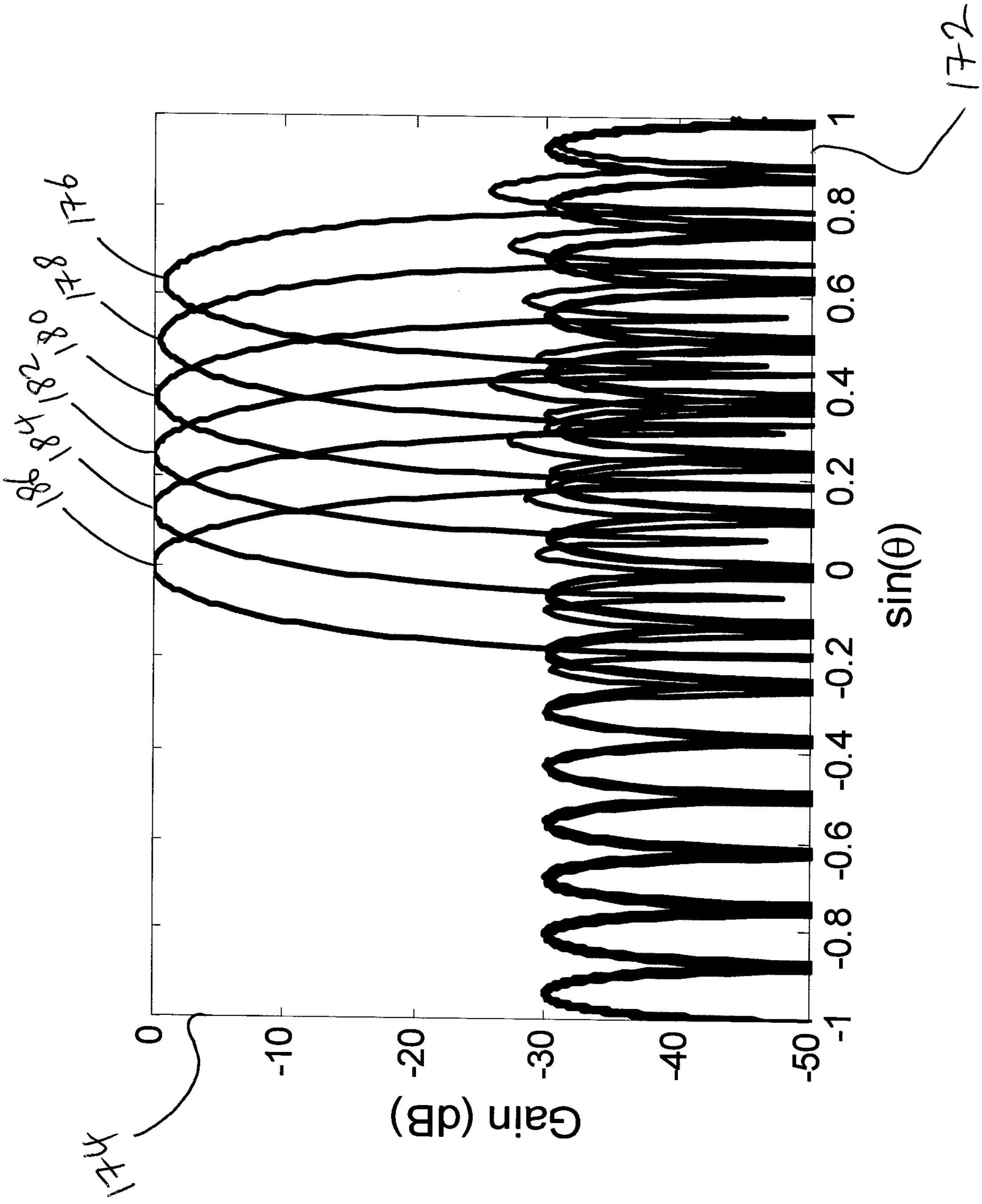
Gain (dB)
0
-10
-20
-30
-40
-50
sin(θ)
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
172
174
176
178
180
182
184
186

FIG. 3

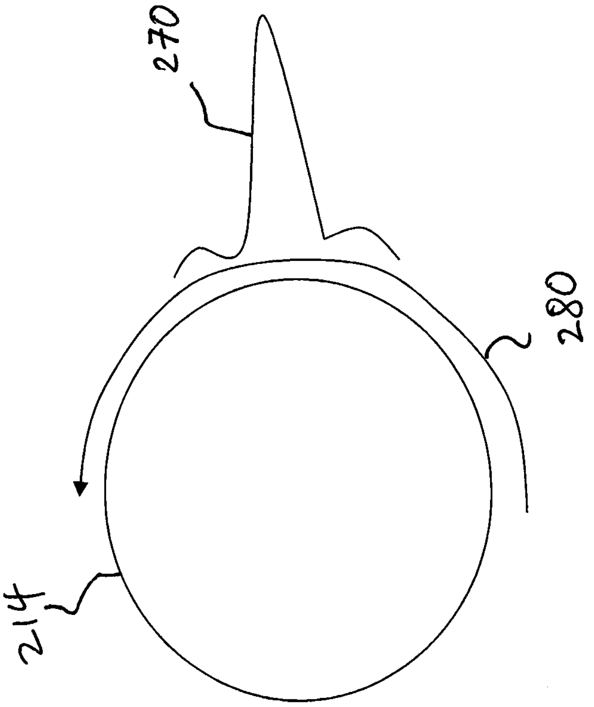
270
280
214

FIG. 5

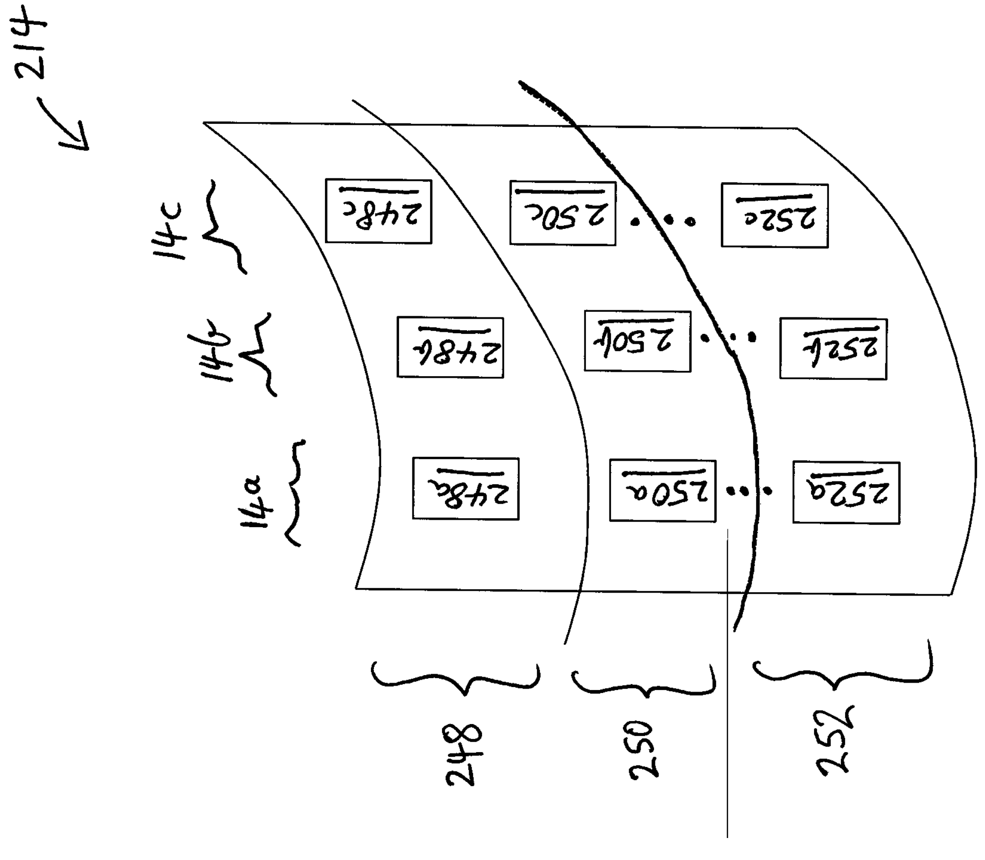
214
14a
14b
14c
248a
248b
248c
250a
250b
250c
252a
252b
252c
248
250
252

FIG. 4

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EUROPEAN SEARCH REPORT

Application Number
EP 12 27 5200

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	JP 2010 216885 A (MITSUBISHI ELECTRIC CORP) 30 September 2010 (2010-09-30) * the whole document * -----	1-15	INV. H01Q3/24 H01Q3/26
X	US 4 929 956 A (LEE JAR J [US] ET AL) 29 May 1990 (1990-05-29) * the whole document * -----	1-15	
A	JP 2001 177328 A (MITSUBISHI ELECTRIC CORP) 29 June 2001 (2001-06-29) * the whole document * -----	1-15	
A	US 5 640 678 A (ISHIKAWA HIROYASU [JP] ET AL) 17 June 1997 (1997-06-17) * the whole document * -----	1-15	
A	US 6 426 721 B1 (OBARA NORIAKI [JP]) 30 July 2002 (2002-07-30) * the whole document * -----	1-15	
A	EP 0 843 380 A2 (SUMITOMO ELECTRIC INDUSTRIES [JP]; COMMUNICATIONS RESEARCH LAB MI [JP]) 20 May 1998 (1998-05-20) * the whole document * -----	1-15	TECHNICAL FIELDS SEARCHED (IPC) H01Q

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	30 May 2013	Fredj, Aziz

CATEGORY OF CITED DOCUMENTS

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The members are as contained in the European Patent Office EDP file on
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30-05-2013

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 2010216885 A	30-09-2010	NONE	
US 4929956 A	29-05-1990	DE 68924590 D1	23-11-1995
		DE 68924590 T2	15-05-1996
		EP 0408676 A1	23-01-1991
		IL 91268 A	29-12-1994
		JP 2598541 B2	09-04-1997
		JP H03501436 A	28-03-1991
		US 4929956 A	29-05-1990
		WO 9003049 A1	22-03-1990
JP 2001177328 A	29-06-2001	NONE	
US 5640678 A	17-06-1997	JP 2777861 B2	23-07-1998
		JP H06178352 A	24-06-1994
		US 5640678 A	17-06-1997
US 6426721 B1	30-07-2002	JP 3564077 B2	08-09-2004
		JP 2002299942 A	11-10-2002
		US 6426721 B1	30-07-2002
EP 0843380 A2	20-05-1998	EP 0843380 A2	20-05-1998
		JP 3997294 B2	24-10-2007
		JP H10145286 A	29-05-1998

EPO FORM P0459

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

REFERENCES CITED IN THE DESCRIPTION

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Non-patent literature cited in the description

- **H. E. SHANKS ; R. W. BICKMORE.** Four-dimensional electromagnetic radiators. *Canadian Journal of Physics.,* 1959, vol. 37, 263-275 **[0006]**
- **W. H. KUMMER ; A. T. VILLENEUVE ; T. S. FONG ; F. G. TERRIO.** Ultra-low sidelobes from time-modulated arrays. *IEEE Transactions on Antenna and Propagation,* November 1963, vol. 11, 633-639 **[0006]**
- **J. C. BREGAINS ; J. FONDEVILA ; G. FRANCESCHETTI ; F. ARES.** Signal radiation and power losses of time-modulated arrays. *IEEE Transactions on Antenna and Propagation,* June 2008, vol. 56 (6), 1799-1804 **[0006]**
- **S. YANG ; Y. B. GAN ; A. QING ; P. K. TAN.** Design of uniform amplitude time modulated linear array with optimized time sequences. *IEEE Transactions on Antenna and Propagation,* July 2005, vol. 53 (7), 2337-2339 **[0006]**
- **G. LI ; S. YANG ; M. HUANG ; Z. NIE.** Sidelobe Suppression in Time Modulated Linear Arrays with Unequal Element Spacing. *Journal of Electromagnetic Waves and Applications,* 2010, vol. 24 (5-6), 775-783 **[0006]**
- **J. FONDEVILA ; J. C. BREGAINS ; F. ARES ; E. MORENO.** Optimising uniformly excited linear arrays through time modulation. *IEEE Antennas Wireless Propagation Letters,* 2004, vol. 3, 298-300 **[0006]**
- **L. MANICA ; P. ROCCA ; L. POLI ; A. MASSA.** Almost time-independent performance in time-modulated linear arrays. *IEEE Antennas Wireless Propagation Letter,* August 2009, vol. 8, 843-846 **[0006]**
- **L. POLI ; P. ROCCA ; L. MANICA ; A. MASSA.** Handling sideband radiations in time-modulated arrays through particle swarm optimization. *IEEE Transactions on Antennas and Propagation,* April 2010, vol. 58 (4), 1408-1411 **[0006]**
- **P. ROCCA ; L. POLI ; G. OLIVERI ; A. MASSA.** Synthesis of time-modulated planar arrays with controlled harmonic radiations. *Journal of Electromagnetic Waves and Applications,* 2010, vol. 24 (5-6), 827-838 **[0006]**
- **P. ROCCA ; L. MANICA ; L. POLI ; A. MASSA.** Synthesis of compromise sum-difference arrays through time-modulation. *IET Radar Sonar Navigation,* November 2009, vol. 3, 630-637 **[0006]**
- **L. POLI ; P. ROCCA ; L. MANICA ; A. MASSA.** Pattern synthesis in time-modulated linear arrays through pulse shifting. *IET Microwaves, Antennas & Propagation,* September 2010, vol. 4 (9), 1157-1164 **[0006]**
- **L. POLI ; P. ROCCA ; L. MANICA ; A. MASSA.** Time modulated planar arrays - Analysis and optimisation of the sideband radiations. *IET Microwaves, Antennas & Propagation,* September 2010, vol. 4 (9), 1165-1171 **[0006]**
- **E. AKSOY ; E. AFACAN.** Thinned Nonuniform Amplitude Time-Modulated Linear Arrays. *IEEE Antennas Wireless Propagation Letter,* May 2010, vol. 9, 514-517 **[0006]**
- **A. BASAK ; S. PAL ; S. DAS ; A. ABRAHAM ; V. SNASEL.** A modified Invasive Weed Optimization algorithm for time-modulated linear antenna array synthesis. *IEEE Congress on Evolutionary Computation,* July 2010, 1-8 **[0006]**
- **H. E. SHANKS.** A new technique for electronic scanning. *IEEE Transactions on Antennas and Propagation,* March 1961, vol. 9 (2), 162-166 **[0006]**
- **Y. TONG ; A. TENNANT.** Simultaneous control of sidelobe level and harmonic beam steering in time-modulated linear arrays. *IET Electronics Letters,* 2010, vol. 46 (3), 200-202 **[0006]**
- **A. TENNANT ; B. CHAMBERS.** A two-element time-modulated array with direction-finding properties. *IEEE Antennas Wireless Propagation Letter,* 2007, vol. 6, 64-65 **[0006]**
- **A. TENNANT.** Experimental two-element time-modulated direction finding array. *IEEE Transactions on Antennas and Propagation,* March 2010, vol. 58 (3), 986-988 **[0006]**
- **G. LI ; S. YANG ; Z. NIE.** A study on the application of time modulated antenna arrays to airborne pulsed Doppler radar. *IEEE Transactions on Antennas and Propagation,* May 2009, vol. 57 (5), 1578-1582 **[0006]**
- **G. LI ; S. YANG ; Z. NIE.** Direction of arrival estimation in time modulated linear arrays with unidirectional phase center motion. *IEEE Transactions on Antennas and Propagation,* April 2010, vol. 58 (4), 1105-1111 **[0006]**
- **A. TENNANT ; B. CHAMBERS.** Time-switched array analysis of phase switched screens. *IEEE Transactions on Antennas and Propagation.,* March 2009, vol. 57 (3), 808-812 **[0006]**