



Method to close an electronically-scanned antenna, setting method and dephaser for this type of antenna

5 This invention concerns a method to close an electronically-scanned antenna, a setting method for this type an antenna and a dephaser associated with a radiating element. It applies for example to the setting of active electronically-scanned antennae, especially to the setting of its transmission and reception modules.

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 Modern multifunction radars which must in particular perform both a multi-target tracking function and a search function, comprise an electronically-scanned antenna which can scan in elevation and bearing. Electronically-scanned antennae usually consist of a set of radiating
15 elements transmitting a microwave whose phase can be controlled electronically, independently for each element or group of elements, in order to obtain an antenna beam scanning space. Consequently, the plane of this type of antenna is layered with dephasers, one dephaser being associated with one radiating element. An antenna whose beam can scan space in two
20 directions requires a large number of radiating elements. Diode dephasers are generally used, due to cost considerations.

 An active antenna also comprises the transmission sources, especially power amplifiers designed to amplify a microwave signal supplied by a local oscillator. An elementary oscillator can be associated with one or
25 more dephasers. This could be for example a module comprising both the transmission function, amplification of a microwave signal, and the reception function. Since the antenna beam depends on the dephasing applied to the signals of the radiating elements, the phase at the origin of each transmission module is important. The transmission modules must in fact transmit with the
30 same phase in order to optimise the antenna diagrams. For an antenna manufacturer, an *a priori* simple solution consists of obtaining modules of identical phase to equip a given antenna. However, this is a costly solution since their phases are dispersed during manufacture. If we consider for example an antenna where the radiating elements and their associated
35 dephasers are grouped in lines, with one transmission and reception module per line, this type of architecture may in fact require several dozen modules.



Lastly, not only are the initial phases of the transmission modules dispersed, but the same applies for the numerous dephasers required in the antenna.

An economical solution therefore consists of using modules and dephasers whose initial phases are dispersed and therefore less expensive, and setting or calibrating the phases output from the dephasers, once the antenna is equipped. Traditional methods use a calibration signal transiting in each transmission module. The signal parameters are then set so as to obtain a phase determined according to the calibration signal. These methods have several disadvantages. A first disadvantage is that the calibration function may be disturbed by the external environment, especially in the event of jamming. A second disadvantage lies in the fact that the calibration signal transmitted by an antenna may represent a signal of relatively high power which could be detected and therefore be a problem in a context where discretion is necessary.

The solutions which consist of measuring the environment or of repeating the calibration measurements as long as jammed measurements are obtained quickly reveal their limitations in a severe jamming environment or when there are several radars, on a ship for example. In addition, since it is difficult to meet the discretion requirement in space, one solution would be to privilege one particular bearing for the transmission of the calibration signals. This method also has its limitations and imposes system constraints on the radar.

An objective of the invention is to overcome the above-mentioned disadvantages. Consequently, the invention concerns a method to close an electronically-scanned antenna comprising radiating elements each connected upstream to a microwave dephaser. Since the dephaser comprises diode dephasing cells in cascade, the last cell being composed of two branches each leading to the radiating element and comprising at least one diode, the closure of the antenna is obtained by setting the cell diodes to on-state.

Advantageously, the degree of isolation of the closure is increased due to the fact the last but one cell being composed of two branches each comprising at least one diode and meeting in the input of the second branch, the diodes of the two branches are set to on-state.

Advantageously, in order to control the phase of a signal reflected by the last but one dephasing cell, this cell comprises two diodes D6, D7 separated by a distance equal to $\lambda/4$ where λ is the average wavelength of the signals transmitted by the antenna, diode D6, the more upstream, being
 5 set to on-state whereas diode D7, located downstream, is set to off-state so as to create a dephasing of π with respect to the off-state of diode D6.

The invention also concerns a method to set an electronically-scanned antenna and a microwave dephaser comprising diode dephasing
 10 cells in cascade.

The main advantages of the invention are the reliable and discrete setting of an electronically-scanned antenna, its ease of implementation and
 15 its low cost.

Other advantages and features of the invention will be clearer on reading the following description, illustrated by the attached drawings representing in:

- figure 1, an example of the architecture of an electronically-scanned antenna;
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- figure 2, a diagram showing the operating principle of a diode dephaser according to the invention;
- figure 3, an example of realisation of the above-mentioned dephaser.

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Figure 1 illustrates an example of the architecture of an electronically-scanned antenna. This antenna comprises N groups of radiating elements 1, each radiating element being associated with a dephaser 2 located upstream. A radiating element, positioned at the output of its dephaser, is for example a dipole. The radiating elements and their dephasers are for example grouped in lines or in columns. As an example, N lines will be considered. Each line is connected to a transmission and reception module 3. A low level microwave signal f_0 attacks the modules 3 which amplify this signal to supply an amplified signal to each group of
 30 dephasers 2. This signal is distributed in each dephaser by a tree structure of

microwave lines 4, in the shape of a chandelier for example, the main point being that the signal is distributed in equiphase on the dephasers. In addition, if a group comprises m dephasers and the signal has a power P , the power received by a dephaser is P/m . These microwave lines are, for example, three-plate type. They are for example connected to a transmission and reception module 3 by a divider 5, for example a hybrid ring, so that a first input/output is connected by a microwave line to module 3. Another output is connected to a first combiner 6.

The output of the reception channel of each module 3 is connected to a divider 7 whose output is connected to a second combiner 8 and the other output is connected to a third combiner 9. Traditionally, the output of the third combiner 9 represents the sum channel and the outputs of the first and second combiners 6, 8 represent the difference channels, in elevation and in bearing, especially for angle error measurements.

A calibration signal f_E is sent by a coupler 10 onto each group of dephasers 2. This calibration signal has a reference phase φ_0 .

Figure 2 illustrates a block diagram of a diode dephaser 2 according to the invention. This dephaser comprises four diode dephasing cells 21, 22, 23, 24. Quantified dephasing is carried out by these cells. Each cell corresponds to a given dephasing weight. Thus, the first, second, third and fourth cells 21, 22, 23, 24 carry out for example respectively dephasing by $\pi/8$, $\pi/4$, $\pi/2$ or π depending on the state of their control bits. The microwave signal enters on an input E before passing successively in the first 21, second 22, third 23 and fourth 24 cells. In output from the last cell, the dephased signal attacks the radiating element 1, for example a dipole.

The invention makes special use of this diode dephaser by using some of its features to advantage.

The first cell 21, the $\pi/8$ bit cell, is composed traditionally, for example, of two microwave line stubs of length $\lambda/4$. This cell acts by disturbance. Afterwards, λ corresponds to the average wavelength, i.e. the frequency at the centre of the operating band. The second cell 22, the $\pi/4$ bit cell, is also composed for example of stubs. Other types of cell could be considered. The construction of the last two dephasing cells 23, 24, before the radiating element 1, is defined below.

The last but one dephasing cell 23, the $\pi/2$ bit cell, acts by path difference. It is therefore composed of two branches 231, 232 which meet at its output. The two branches have different lengths, the second branch being $\lambda/4$ longer than the first 231. The first branch is a microwave line comprising a diode D8. The second branch is a microwave line comprising two diodes D6, D7. The distance between these two diodes is $\lambda/4$. The last cell 24, the π bit cell associated with the dipole 1, acts by inverting the electromagnetic field. It comprises two branches 241, 242 each leading to one branch of the dipole. The first branch 241 comprises a diode D10 and the second branch comprises a diode D9. The use of this type of dephaser during antenna operation therefore sets the two branches of the $\pi/2$ cell to on-state and off-state respectively. This is equivalent in particular to controlling the diodes D6, D7, D8 of the $\pi/2$ bit cell in order to direct the microwave signal into one branch or the other, i.e. to block the diode D8 when the diodes D6 and D7 are in conduct, and vice versa. Similarly, for the π bit cell 24, the diode D9 is blocked when the diode D10 conducts to obtain the field vector in one direction and the field is switched into phase opposition when the diode controls are inverted, resulting in dephasing by π .

In setting phase, according to the invention the dephaser shown on figure 2 can be used advantageously to perform at least two functions. A first function closes the antenna. The antenna is then isolated from the exterior. In particular, a calibration signal injected in the dephaser is then likely to be reflected to the source or to a calibration coupler. The second function protects these circuits by enabling a user to control the path of the reflected signal, so that it is directed in particular away from the source or the calibration coupler which contains fragile circuits, such as the limiters for example.

The invention can therefore be used to close the antenna. We have seen above that it may be necessary to calibrate or set transmission or reception modules associated with a radiating element and its dephaser or more generally with a group of radiating elements and their dephasers formed, for example, from lines or columns. In this case, the phase and amplitude of the transmitted signal must be accurately controlled. A calibration signal f_E is therefore injected. This signal is for example injected,

for each group of radiating elements associated with a transmission / reception module, in input x of the three-plate type circuit comprising the power supply lines 4 of the dephasers. This can be used in particular to inject a reception signal or to make a power transmission, the two operations being temporarily decorrelated, and to collect a measurement signal. In calibration during reception, any signal from the exterior can jam the calibration signal. In calibration during transmission, the radar radiates its frequencies which are therefore likely to be detected. The invention therefore provides a simple means of isolating the transmission and reception circuits up to and including the dephasers, in both directions.

The use of the dephaser is therefore non conform, in particular as regards its last two cells 23, 24. This use according to the invention stops a signal passing.. For the last cell 24, producing dephasing by π , the two diodes D9 and D10 are set to on-state resulting in an open circuit in the dipole 1 and in input of this cell 24. Experimental measurements taken by the Applicant demonstrate that 30 dB isolation can be obtained between the dipole 1 and the input of the last cell 24. For the last but one cell 23, producing dephasing of $\pi/2$, the diodes D6, D7 and D8 are also set to on-state, resulting in an open circuit at the output of this cell 23. Experimental measurements taken by the Applicant have demonstrated that an additional isolation of 20dB could be obtained in this way.

An injected calibration signal which enters a dephaser will therefore be reflected in the last but one cell 23. A second function provided by the invention is dephasing in reflection. It concerns the control of cells 21, 22, 23, i.e. cell 23 where reflection of the calibration signal starts and cells 21, 22 preceding it. The control concerns in particular the diode D6 of one of the branches 232 in the last but one cell, located most upstream. The second diode of the branch, located downstream, is the diode D7.

Between the two states, on and off, of the diode D6, a dephasing of π is obtained on a signal injected in the dephaser and reflected on the diode D7. In addition, the first two cells 21, 22, producing dephasing of $\pi/8$ and $\pi/4$ in direct path, provide double dephasing, of values $\pi/4$ and $\pi/2$ respectively, with respect to a signal reflected in the dephaser. On the reflected signal, we therefore obtain the equivalent of a dephaser with three bits, of weight $\pi/4$, $\pi/2$ and π . The reflected signal can therefore be controlled,

especially in order to minimise the return power in the measurement channel, for example by:

- either focusing at a point other than the measurement channel;
- or creating a jamming law, in order to minimise the return signal in the measurement channel;
- or focusing in a difference channel designed to absorb the return signal.

Figure 3 describes, as an example, a possible mode of realisation of a dephaser according to the invention corresponding to the block diagram of figure 2. It is for example equipped with control means that can be used in particular to apply the previously described controls concerning the method to close an antenna. The dephaser is for example produced on a microstrip type structure 32. Figure 3 is a plan view of the dephaser circuits. This microstrip structure comprises for example the dipole 1 forming the radiating element placed at the output of the dephaser.

The circuit therefore comprises a microwave line 33 starting from input E of the dephaser up to the last but one cell composed of its two branches 231, 232. These branches each comprise at least one diode D6, D7, D8 and meet up at the output of the cell. One of the two branches 232 comprises two successive diodes D6, D7 separated by a distance of $\lambda/4$ where λ is the average wavelength of the signals transmitted by the antenna. This path difference of $\lambda/4$ between the two branches 231, 232 results in dephasing of $\pi/2$ depending on which of the two branches is taken, and can be used in addition to produce a dephasing of π for the reflected signal, due in particular to the fact that the diodes D6 and D8 are equidistant from the point of separation A of the two branches.

The last dephasing cell placed at the output of the previous one is composed of two branches 241, 242 of equal length leading to the dipole 1. Each branch comprises at least one diode D9, D10 located at equal distances from the point of separation B of the two branches.

The dephaser on figure 3 is a dephaser with four control bits capable of producing sixteen dephasing values distributed evenly over the interval between 0 and 2π . Obviously, the number of dephasing cells is not restricted to four. The two previous cells 23, 24 produce dephasing of $\pi/2$ and

π respectively. The first two cells of the cascade 21, 22 producing dephasing of $\pi/8$ and $\pi/4$, are located along the microwave line 33 connecting the dephaser input to the input point A of the last but one cell 23. The first cell is composed for example traditionally of two stub lines 34, 35 each connecting
 5 the microwave line 33 to a diode D34, D35. The first cell comprises for example three stub lines 36, 37, 38 each connecting the microwave line 33 to a diode D36, D37, D38. The control signals of the diodes, supplied by the control means 31, pass by one or more printed circuit type layers associated with the three-plate circuit. The control signals arrive on the front panel which
 10 comprises the diodes, via metallised holes and are then routed to the diodes along low frequency conductors, these traditional elements not being shown on figure 3.

By blocking the last two cells 23, 24, which produce the dephasing of $\pi/2$ and π , the isolation obtained between the input point A of the last but
 15 one cell and the dephaser output, at the radiating element 1, can reach approximately 50 dB, which provides good protection with respect to the exterior. This function corresponds advantageously to closing an antenna composed of the radiating elements 1 associated with the dephasers 2. This function obviously provides protection in both signal propagation directions. It
 20 therefore provides excellent attenuation of the calibration signals to the exterior transiting in the antenna.

By controlling the two input cells 21, 22 and the diode D6, the reflection of the calibration signal can be directed advantageously away from its source and/or a coupler, in particular to protect fragile elements such as
 25 power limiters and also to minimise the calibration errors.

The method to close an antenna according to the invention can be implemented easily and at low cost, since it mainly consists of acting on the controls. If the control means 31 are programmable, the hardware cost is then virtually zero.

30 Advantageously, the antenna closure as described previously can be applied in a method to set an electronically-scanned antenna, if calibration signals need to transit in the antenna, whether in its transmission and/or reception modules or in its other circuits. These calibration signals therefore transit in the antenna circuits, for example the above-mentioned modules, up
 35 to and including in the dephasers. These signals are therefore protected,

more especially isolated, from the exterior. The setting can therefore be carried out in complete safety and in complete discretion.

The invention has been described with a dephaser comprising diode dephasing cells. These diodes can nevertheless be replaced by any
5 other component which can act as a switch between the short circuit state and the open circuit state, and vice versa.

CLAIMS

1. Method to close an electronically-scanned antenna comprising radiating elements (1) each connected upstream to a microwave dephaser (2) wherein the dephaser (2) comprising switch dephasing cells (21, 22, 23, 24) in cascade, the last cell being composed of two branches (241, 242) each leading to the radiating element and comprising at least one switch (D9, D10), the closure of the antenna is obtained by setting the switches of the cell (24) to on-state.

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2. Method according to claim 1, wherein the last dephasing cell (24) produces dephasing of π when one of its branches is conducting and the other blocked.

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3. Method according to any of the previous claims, wherein the last but one cell (23) being composed of two branches (231, 232) each comprising at least one switch (D6, D7, D8) and meeting in the input of the last branch, the switches of the two branches are set to on-state.

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4. Method according to claim 3, wherein one of the branches (232) of the last but one dephasing cell (23) comprising two switches D6, D7 separated by a distance equal to $\lambda/4$ where λ is the average wavelength of the signals transmitted by the antenna, the switch D6, the more upstream, being set to on-state whereas the switch D7, located downstream, is set to off-state so as to create a dephasing of π with respect to the off-state of the switch D6.

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5. Method according to claim 4, wherein the last but one cell (23) and the previous dephasing cells (21, 22) are organised so as to control a signal reflected by this last but one cell (23), control being carried out by the application or not of successive dephasing weights, the dephasing weight of the other cells (21, 22) being doubled with respect to the direct path.

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6. Method according to claim 5, wherein the successive weights are at least π , $\pi/2$ and $\pi/4$.

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7. Method according to any of the previous claims, wherein the antenna comprises transmission and reception modules (3) associated with a radiating element (1) or a group of radiating elements (1), a dephaser (2) being placed between each radiating element and its associated transmission and reception module.

8. Method for setting an electronically-scanned antenna comprising radiating elements (1) each connected upstream to a microwave dephaser (2) where a calibration signal transits in the antenna circuits including in the dephasers, wherein it closes the antenna according to any of the previous claims.

9. Method according to any of the previous claims, wherein the switches are diodes.

10. Microwave dephaser comprising switch dephasing cells (21, 22, 23, 24) in cascade and means (31) to set the switches to on-state or off-state, wherein it comprises at least one dephasing cell (23) composed of two branches (231, 232) each comprising at least one switch (D6, D7, D8) and meeting up in output, one of the two branches (232) comprising two successive switches D6, D7 separated by a distance equal to $\lambda/4$ where λ is the average wavelength of the signals transmitted by the antenna, the distance from the switch D6 to the point of separation A of the two branches being equal to the distance from the switch D8 of the other branch (231) to this point A, the dephaser comprising a dephasing cell (24) downstream composed of two branches (241, 242) each comprising at least one switch D9, D10 and forming the last cell of the cascade likely to lead to an antenna radiating element (1), the control means (31) closing the dephaser output by setting at least the switches D9, D10 of the last cell (24) to on-state.

11. Dephaser according to claim 10, wherein the last cell (24) and the last but one cell (23) produce dephasing of π and $\pi/2$ respectively.

12. Dephaser according to claim 10 or 11, wherein the control means (31) close the output by setting in addition the switches D6, D7, D8 of the last but one cell to on-state.

5 13. Dephaser according to any of claims 10 to 12, wherein a dephasing of π is obtained on a reflected signal by the last but one cell (23) by setting the most upstream switch D6 to on-state and the downstream switch D7 to off-state, to form a dephaser of $N - 1$ control bits for the reflected signal, N being the number of dephasing cells (21, 22, 23, 24).

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14. Dephaser according to any of claims 10 to 13, wherein the switches are diodes.