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(54) Title: TRACKING ANTENNA SYSTEM

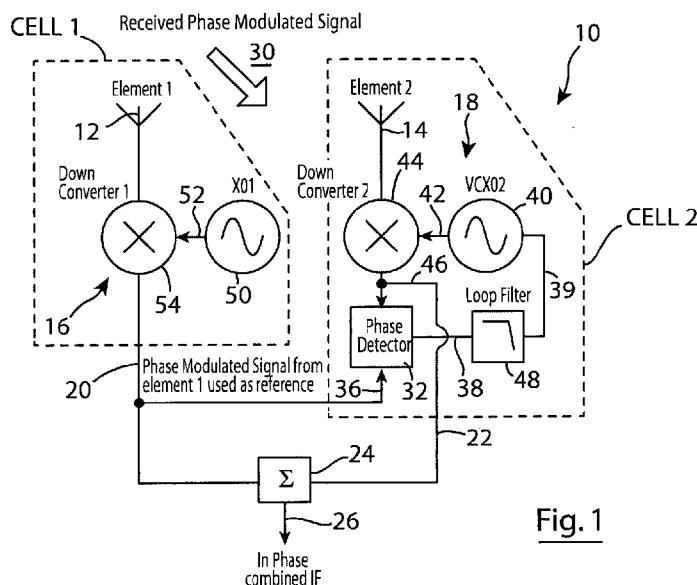


Fig. 1

(57) Abstract: An antenna system comprising a first antenna cell and at least one other antenna cell. Each antenna cell comprises a respective antenna element and generates, in use, a respective output signal from an input signal received during use. The other antenna cells include a phase locked loop (PLL) circuit for tracking changes in the phase of the received input signal. The PLL circuit includes an input for receiving a phase reference signal, the input being connected to the output of the first antenna cell to receive the output signal of said first antenna cell as its phase reference signal. The use of the phase modulated output signal as the reference input for the PLL allows the PLL to track phase changes as a result of relative movement between a source and a receiver, and to compensate for phase differences caused by the spacing between the respective antenna elements of the phased array.

Tracking Antenna System

Field of the Invention

- 5 The present invention relates to tracking antennas, especially retrodirective tracking antennas.

Background to the Invention

- A tracking antenna tracks incoming signals to accommodate relative movement between the
- 10 transmitter and the receiver. Tracking antennas are commonly retrodirective in that they transmit signals back in the direction from which the incoming signal is received, normally using phase conjugation of the received signal. When there is relative movement between the transmitter and the receiver, a retrodirective tracking antenna must track the incoming signal to ensure not only that the incoming signal is received but also that the retrodirected signal is correctly aligned.
- 15 Conventional tracking antennas may include a digital tracking system that requires directional information from GPS data in order to track, or may be provided on a movable support structure that is steered to track the signal. Such systems can suffer from various problems including being relatively complex, expensive, slow and large.
- 20 Relative movement between the transmitter and the receiver manifests as a change in phase of the incoming signal. Accordingly, analogue tracking antennas are known in which an analogue phase locked loop (PLL) is used to track the signal. However, such devices are reliant on the provision of a separate continuous wave (CW) pilot signal on a different frequency to the modulated signal. This is a major disadvantage since modern commercial communications systems tend to transmit only a
- 25 modulated signal at one frequency with no accompanying pilot signal. Using an analogue phase locked loop, it is very difficult to track the phase of such modulated signals, particularly if they contain phase modulation. This is because the phase detector in the phase locked loop does not produce a stable output signal from a phase modulated input and this prevents the phase locked loop from stably locking.
- 30 It would be desirable to provide an improved tracking antenna that mitigates some or all of the above problems.

Summary of the Invention

- 35 A first aspect of the invention provides an antenna system comprising: a first antenna cell; and at least one other antenna cell, wherein each antenna cell comprises a respective antenna element and generates, in use, a respective output signal from an input signal received by said respective antenna element, and wherein said at least one other antenna cell includes a phase locked loop
- 40 (PLL) circuit for tracking changes in the phase of said received input signal, said PLL circuit including

an input for receiving a phase reference signal, said input being connected to an output of said first antenna cell to receive the output signal of said first antenna cell as said phase reference signal.

. An antenna system as claimed in claim 1, including a plurality of said at least one other antenna cells, said phase reference input of each of said at least one other antenna cells being connected to
5 the output of said first antenna cell to receive the output signal of said first antenna cell as said phase reference signal.

Typically, the system further includes a combining device for combining the respective output signal from each antenna cell. The combining device may comprise a summation circuit.

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In preferred embodiments, said PLL circuit comprises a phase detector having a first input for receiving said phase reference signal and a second input for receiving a signal derived from said received input signal, and is configured to generate an output signal that is indicative of the phase difference between the respective signals received at said first and second inputs. Typically, said
15 PLL circuit further includes a variable frequency oscillator for generating an output signal having a frequency variable in response to a control signal, wherein the output signal of said phase detector provides said control signal. Usually, said PLL circuit further includes a signal mixing device for mixing the frequency oscillator output signal with said received input signal or a signal derived therefrom to produce a mixer output signal, said mixer output signal providing said signal for the
20 second input of said phase detector, and preferably also providing said output signal of the respective antenna cell. Said signal mixing device may comprise a frequency down converter.

In typical embodiments, said at least one other antenna cell includes receiver circuitry, said receiver circuitry including said PLL circuit. Said at least one other antenna cell typically includes transmitter
25 circuitry. Said receiver circuitry and said transmitter circuitry may each coupled to said respective antenna by a coupling device, for example a duplexer. Typically, said transmitter circuitry is configured to perform retrodirective retransmission in respect of said received input signal. Preferably, said transmitter circuitry includes phase conjugation circuitry for performing phase conjugation of said received input signal to effect retrodirective transmission.

30

In preferred embodiments, said first antenna cell includes receiver circuitry. Said receiver circuitry may include a fixed frequency oscillator and a signal mixing device for mixing the output signal from said oscillator with said received input signal, or a signal derived therefrom, to provide the output
signal of said first antenna cell. Said signal mixing device may comprise a frequency down converter.

35

In preferred embodiments, said first antenna cell includes transmitter circuitry. Said receiver circuitry and said transmitter circuitry may each coupled to said respective antenna element by a coupling device, for example a duplexer. Said transmitter circuitry may be configured to perform retrodirective retransmission in respect of said received input signal. Said transmitter circuitry typically includes
40 phase conjugation circuitry for performing phase conjugation of said received input signal to effect retrodirective transmission.

In typical embodiments, said antenna cells are comprised of analogue circuitry.

A second aspect of the invention provides a method of tracking an input signal received by an
5 antenna system, the method comprising: receiving said input signal at a respective antenna element
of a first antenna cell and at least one other antenna cell; generating, by said first antenna cell, an
output signal from said input signal received at said respective antenna element; tracking the phase
of said input signal received at the respective antenna element of said at least one other antenna cell
using a phase locked loop (PLL) circuit; and providing said output signal of said first antenna cell to
10 said PLL circuit as a phase reference signal.

Preferred embodiments of the invention may exhibit any one or more of the following aspects:
significantly reduced power consumption and complexity in comparison with conventional
alternatives; analogue implementation provides fast in tracking speed with no requirement for high
15 powered digital communications; constructive combination of received signals is provided; phase
offset correction for split frequency TX/RX beam pointing error is provided; can operate down to
extremely low RX signal levels (-130dBm); ability to regenerate high power retransmit signal;
analogue carrier recovery of QPSK/16QAM signals.

20 Moreover, preferred embodiments require lower power and are simpler than comparable digital
circuits. Preferred embodiments require no moving parts, and can be substantially flat in shape. The
preferred analogue construction has the inherent capability to track signals, unlike other solutions
which require directional information from GPS satellite navigation data.

25 Preferred features are recited in the dependent claims appended hereto.

Other advantageous features of the invention will become apparent to those ordinarily skilled in the
art upon review of the following description of a specific embodiment and with reference to the
accompanying drawings.

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Brief Description of the Drawings

An embodiment of the invention is now described by way of example and with reference to the
accompanying drawings in which like numerals are used to denote like parts and in which:

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Figure 1 is a schematic diagram of a tracking antenna system embodying one aspect of the
invention;

Figure 2 is a schematic diagram of an alternative embodiment of a tracking antenna system
40 incorporating a larger antenna array than the system of Figure 1; and

Figure 3 is a schematic diagram of a specific embodiment of a tracking antenna system.

Detailed Description of the Drawings

5 Referring now to Figure 1 of the drawings there is shown, generally indicated as 10, an antenna system embodying the invention. The antenna system 10 comprises first and second antenna cells, identified in Figure 1 as Cell 1 and Cell 2. Each antenna cell comprises a respective antenna element 12, 14 coupled to a respective signal processing unit 16, 18, the signal processing unit 16, 18 producing an output signal 20, 22 for the respective cell. The output signals 20, 22 are combined
10 with one another by a signal combining device 24 to produce a combined output signal 26 for the system 10. The antenna cells are configured such that the respective output signals 20, 22 are in phase with one another. The signal combining device 24 may take any suitable conventional form, e.g. comprising a summing circuit, and the combined output signal 26 comprises an in-phase combined signal, typically at an Intermediate Frequency (IF). The combined signal 26 may be
15 provided to any conventional circuitry (not shown) depending on the application, typically further receiver or transceiver circuitry, which is not necessary for understanding the present invention and so is not described further herein. Ideally, the antenna elements 12, 14 are omnidirectional although this is not essential. It is however preferred that the antenna elements 12, 14 are operable with a relatively wide field of view.

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The antenna cells are interconnected such that the system 10 comprises an antenna array. The preferred configuration is such that the antenna system 10 comprises a phased antenna array. As such, the phase of the signal to the antenna elements causes the elements to (optimally) transmit or receive constructively in a defined direction. The spacing between the antenna elements 12, 14 may
25 be selected to suit the application in conventional manner and creates a phase difference in a signal received by both antennas. Typically, inter-antenna element spacing is approximately half of one wavelength. In the example of Figure 1, only two antenna elements 12, 14 are provided although more generally antenna systems embodying the invention may comprise two or more antenna elements, each associated with a respective signal processing unit, as is illustrated by way of
30 example in Figure 2. Each antenna element 12, 14 is typically an active antenna element. The system 10 behaves as a directional antenna even though the individual antenna elements 12, 14 may be non-directional.

In Figure 1, only receiving components of the system 10 are shown and it is assumed that a signal
35 30 is received by each antenna element 12, 14. The received signal 30 is assumed to be a phase modulated signal and may emanate from any conventional source, for example a satellite transmitter, radio transmitter or television transmitter (not shown). The phase of the received signal is different for each antenna element 12, 14, as determined by the spacing of the antenna (this phase difference is separate from any phase modulation of the received signal). The signal
40 processing units 16, 18 comprise receiver circuitry for the respective received signals.

Advantageously, the circuitry comprises analogue components, or at least components that produce an analogue signal.

The signal processing unit 18 comprises a phase locked loop circuit (PLL), preferably an analogue PLL, or at least a PLL that produces an analogue output signal. The PLL comprises a phase detector 32 which may take any conventional form but is advantageously an analogue phase detector, or at least one that produces an analogue output signal. For example, an exclusive OR gate type phase detector may be used, which may be regarded as a digital component but which gives an analogue output after the loop filter. The PLL further includes an adjustable electronic oscillator 40 (commonly referred to as a local oscillator) that is operable to produce an output signal 42 of variable frequency. The oscillator 40 is conveniently a voltage controlled oscillator, more particularly a voltage controlled crystal oscillator (VCXO) in this example. It is preferred to use a narrow band VCXO since the phase noise of the signal is relatively low, allowing for a high quality signal for retransmission.

The PLL also includes a signal mixing device 44 which may take any suitable conventional form and in typical embodiments comprises a frequency converter, typically a down converter. The mixer 44 is coupled to the antenna 14 to receive the received signal 30, and to the output of the oscillator 40 to receive output signal 42. The mixer 44 performs a heterodyne operation on the received signal 30, 42 to produce an output signal 46, which in this example comprises the frequency (down) converted received signal 30. The mixer output signal 46 is provided to an input 34 of the phase detector 32. The phase detector 32 also receives a phase reference signal at input 36 and produces an output signal 38, depending on the phase difference between the signals provided at its inputs 34, 36, which controls the oscillator 40. A loop filter 48 is typically provided between the phase detector 32 and oscillator 40. The output signal 46 is the output of the PLL and, in the illustrated example, provides the output signal 22 of the signal processing unit 18.

In use, the output signal 46 is tracked to be in phase with the reference signal 36. The output signal 38 of the phase detector 32 adjusts the frequency of the oscillator output signal 42 to track changes in the phase of the signal 30 received by antenna 14. As a result, the output signal 46, 22 of the PLL / signal processing unit 18 tracks changes in phase of the received signal 30. Since these phase changes may be caused by relative movement between the source of the signal 30 and the system 10 (e.g. when the system 10 is in a moving vehicle), the operation of the PLL allows the system 10 to track the received signal 30 without the need for any corresponding physical movement of the system's components.

One option for the phase detector reference signal is to provide a continuous wave (CW) reference signal to input 36 and to provide a corresponding CW pilot signal with the received signal 30. However, this option is not suited to typical commercial applications where no such CW pilot signal is provided. In accordance with one aspect of the invention therefore, the output signal 20 from one antenna cell in the system 10 (Cell 1 in this example) provides the reference input signal for the

phase detector 32 of the other antenna cell (Cell 2 in this example). The output signal 20 comprises a phase modulated signal derived from the signal 30 received by antenna 12. Hence, the two inputs received by the phase detector 32 (i.e. at inputs 34 and 36) are identically phase modulated since they are each derived from the received signal 30. This facilitates stability of the filtered output
5 signal 39 of the phase detector 32 (typically comprising a DC voltage) and so allows the PLL to operate as desired irrespective of the modulation of the received signal 30. In this regard, it is noted that the phase modulation of the signal 30 relates to the information carried by the signal and is separate from any phase variations caused by relative movement between the system 10 and the signal source, or by the spacing between antennas 12, 14. In addition, the action of the PLL causes
10 the inputs to the phase detector 32, and therefore the output signals 20, 22, to be locked in phase (i.e. having the same phase or a fixed phase relationship, depending on the configuration of the phase detector). This facilitates combination of the output signals 20, 22.

In the embodiment of Figure 1, the signal processing unit 16 comprises an electronic oscillator 50
15 that is operable to produce an output signal 52 of fixed frequency. The oscillator 50 is typically a fixed frequency oscillator, for example a fixed frequency crystal oscillator (XO1) or other conventional local oscillator. The signal processing unit 16 also includes a signal mixing device 54 which may take any suitable conventional form and in typical embodiments comprises a frequency down converter (corresponding to the frequency down converter of the signal processing unit 18). The
20 mixer 54 is coupled to the antenna 12 to receive the received signal 30, and to the output of the oscillator 50 to receive output signal 52. The mixer 54 performs a heterodyne operation on the received signals 30, 52 to produce output signal 20, which in this example comprises the down converted received signal 30. In alternative embodiments, the mixers 44, 54 may be configured to perform frequency upconversion rather than downconversion, although downconversion is more
25 typical since phase detectors tend to be relatively low frequency components.

In operation, the phase modulated signal 30 received by one antenna 12 is used to provide a corresponding phase modulated reference signal 20 to the phase detector 32 of the other antenna 14. The phase detector 32 is therefore provided with two identically modulated input
30 signals. This allows the phase detector 32 to compare the phase difference between its input signals independently of the phase modulation of the signal 30. The output 38 of the phase detector 32 is therefore indicative of the phase difference between its input signals and is not affected by the modulation of the received signal 30. This allows for a constant DC voltage (or other stable output signal) to be available as the phase detector output 38. As a result, the PLL locks the phase of its
35 output signal 22 with the phase of the output signal 20. The system 10 is therefore capable of tracking phase changes in the received signal 30 independently of the modulation of the signal 30 and while keeping the output signals 20, 22 derived from the respective antenna 12, 14 in phase with one another. In addition, the respective output signals 20, 22 are in phase and can therefore be combined regardless of the phase of the signal 30 received at the respective antenna 12, 14.

In use, the respective signals 36 and 46 are applied to the phase detector 32, which controls the phase difference of the oscillators 50 and 40 until the mixer output signals 20 and 22 are in phase with one another, then the PLL is stably locked. The relative phase difference between the respective output signals generated by the oscillators 50 and 40 track the phase of the respective received signals 30. In particular, the output signals 20 and 22 are directly proportional in phase to the phase of the oscillators 50 and 40 respectively. Therefore the phase relationship between the fixed oscillator 50 and variable oscillator 40 is such that they compensate for the phase difference in the received signal 30 between cells, so that signals 20 and 22 are in phase, and thus can be optimally combined in the power combiner 24.

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Figure 2 shows an alternative antenna system 110 embodying the invention. The system 110 comprises a plurality of antenna cells, each cell comprising a respective antenna element 112, 114 (Element 1 to Element 9) and respective associated signal processing circuitry 116, 118. One of the cells (Cell 1 in Figure 2) serves as a reference cell to each of the other cells in that it produces a phase modulated output signal 120 that is provided as a phase reference signal to the respective phase detector (not shown in Figure 2) of each other cell. In the example of Figure 2 eight other cells are shown although more generally there may be one or more other cells in addition to the reference cell. The respective output signal of each antenna cell in the system 110 may be combined to provide a combined output for the system 110, for example using a combiner similar to that illustrated in Figure 1. In preferred embodiments, the respective cell output signals are in phase with one another and this facilitates this combination.

The signal processing circuitry 116, 118 may be the same as the signal processing circuitry 16, 18 respectively of Figure 1. However, typical systems embodying the invention are required to transmit signals as well as receive signals, and in particular to transmit signals retrodirectively. The signal processing circuitry 116, 118 therefore includes transmitter circuitry as well as receiver circuitry. For embodiments where the system 110 is retrodirective, the signal processing circuitry 116, 118 includes phase conjugation circuitry. Moreover, in typical embodiments the signal processing circuitry may include multi-stage, typically dual stage, frequency conversion circuitry since the single stage down conversion provided by the circuitry 16, 18 of Figure 1 may suffer from problems relating to the removal of image frequencies.

Figure 3 shows a specific example of an antenna system 210 embodying the invention, the system 210 being a retrodirective antenna system and including dual stage frequency conversion (down conversion in this example). The system 210 comprises two antenna cells: a reference cell (Cell 1) comprising antenna element 212 and signal processing circuitry 216; and a second cell (Cell 2) comprising antenna element 214 and signal processing circuitry 218. The cell output signals 220, 222 are in-phase and are combined at combining device 224. It will be understood that in alternative embodiments further instances of the second cell may be provided, as described with reference to Figure 2.

40

For each cell, the signal processing circuitry 216, 218 includes transmitter circuitry 216', 218' and receiver circuitry 216'', 218'' selectably coupled to the respective antenna 212, 214 by a respective coupling device 260, 262, e.g. a duplexer. The antenna cells, and in particular the respective transmitter circuitry 216', 218', are configured to perform phase conjugation in respect of the received signal 30 in order produce a retrodirective signal for transmission back to the source of the received signal 30. This may be achieved by providing a phase conjugating mixer in the transmission circuitry for performing up conversion of the signal to be transmitted, or in any convenient conventional manner. In this embodiment, the receiver circuitry 216'', 218'' includes two stages of frequency down conversion.

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The operation of the system 210 in respect of tracking a received signal is the same as described in relation to Figures 1 and 2 as would be apparent to a skilled person. More particularly, a phase modulated received signal 30 is detected by antenna 212 of Cell 1 and its frequency is separated to the RX port of the duplexer 260. It is typically amplified by an amplifier 202, preferably a low noise amplifier, and frequency (down) converted using a mixer 203 to an intermediate frequency (IF) signal of, in this example, 160 MHz. The IF signal is advantageously fed through a bandpass filter 204 to filter out image frequencies. The IF signal is fed to a second frequency (down) converter 254, which mixes the IF signal with a local oscillator (LO) signal, from PLL1 206 in this example, at a suitable frequency, e.g. 156 MHz. The LO signal is derived from a 26 MHz Temperature Compensated Crystal Oscillator 207. PLL1 206 is used to multiply the frequency of the 26 MHz TCXO 7 to 156 MHz. It may take the form of an off-the-shelf PLL clock generator IC. It is an optional component and not related to the PLL operation described above particularly in relation to Figure 1. The combination of the PLL1 206 and the 26 MHz TCXO 207 could be replaced by a single TCXO if one with a suitable frequency is available. Similar comments apply for the 26 MHz TCVCXO 240 and PLL2 211. The second down conversion produces a 4 MHz IF signal in this example. The IF signal is filtered, typically by a bandpass filter 208, preferably a high Q filter with a 1 KHz 3dB bandwidth. The purpose of the filter 208 is to filter unwanted mixing products and to reduce the noise floor according to $N=kTB$. The filtered IF signal from the filter 208 is typically amplified by an amplifier 209. The amplified IF signal is fed to an input of phase detector 232 as a phase reference signal. A second input of the phase detector 232 is fed with an IF signal which is derived from antenna 214 by the signal processing circuitry 218'' of Cell 2, preferably in the same manner as described in relation to Cell 1. The only difference between the respective receive circuitry 216'', 218'' of Cells 1 and 2 is that, for Cell 2 the LO signal used in the second down conversion is derived from a variable frequency oscillator 240, in this case a temperature compensated voltage controlled crystal oscillator, to allow adjustments in frequency/phase to be made by the PLL circuit of the Cell 2 when tracking the incoming signal 30 (in the manner described above with respect to Figure 1). To this end the frequency/phase of the TCVCXO 240 is controlled by the output of the phase detector 232, which is filtered by a low pass filter 248 to provide a DC voltage corresponding to the phase difference between the respective incoming signals picked up by antennas 212, 214.

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As a result of the operation of the PLL of Cell 2, the two inputs of the phase detector 232 are locked in phase with one another, regardless of the respective input phase of the received signal 30 at antennas 212, 214. Since the phase modulation of the respective signal provided to each input of the phase detector 232 is the same, the phase detector 232 is able to perform a like with like
5 comparison between the input signals regardless of their modulation, thereby allowing the system 210 to lock to, or track, incoming signals 30 at a relevant frequency regardless of the modulation of the incoming signal 30. In this connection, the system 210 may be configured to receive signals of a particular frequency, or in a particular frequency band, in conventional manner, e.g. by antenna selection and/or configuration and selection of oscillators and filters as appropriate.

10

Optimal phase combination in receive mode is possible, regardless of the phase difference between the signals received by antennas 212, 214, by feeding the cell output signals 220, 222 to the summer 224, thus providing an optimally combined received signal regardless of the angle of arrival of the signal at the antennas 212, 214.

15

Phase conjugated retransmission, at a different frequency to that received, is carried out via a frequency up converter 260 which is fed with the LO signal from PLL1 and a modulated LO signal F_{LOTX} . This conjugates the phase of the LO signal, by using a $F_{\text{TX}} = F_{\text{LOTX}} - F_{\text{PLL1}}$ relationship in this example. The desired resulting signal component is typically filtered by bandpass filter
20 262 and amplified by amplifier 264. The signal for transmission is fed to the antenna 212 via the duplexer 260. In the illustrated embodiment, it is assumed that the signal F_{LOTX} includes the data to be transmitted (e.g. by appropriate frequency modulation), and this may be achieved in any convenient conventional manner.

25 The conjugated retransmitted phase allows the retransmit signal to be sent back in the same direction as the received signal 30. The transmit circuitry 218' of Cell 2 may be the same as described for Cell 1, as would be apparent to a skilled person. It is possible to add additional antenna cells with the same or similar architecture as Cell 2, the phase reference signal provided to the respective phase detector of each additional cell being derived from the output of Cell 1. The
30 output signals from all cells can be combined using summer 224 or other suitable combining device.

In typical embodiments, the local oscillator (LO) frequencies are the same, or substantially the same and are conveniently selected so that the signal frequency of output signals 20 and 22 are of some practical IF frequency in respect of which there is ready availability of components such as phase
35 detectors and filters.

In preferred embodiments, use of the phase modulated output signal 20 as the reference input for the phase detectors of the other antenna cells in conjunction with the ability to adjust the phase of the antenna cells to obtain maximum gain in a defined direction allows the antenna system 10, 110,
40 210 to act as a phased array.

Advantageously, the use of the phase modulated output signal 20 as the reference input for the phase detector 32 not only allows the PLL to track phase changes as a result of relative movement between the source and the receiver, but also to compensate for phase differences caused by the spacing between the respective antenna elements of the phased array.

5

The invention is not limited to the embodiment(s) described herein but can be amended or modified without departing from the scope of the present invention.

CLAIMS:

1. An antenna system comprising:
 - a first antenna cell; and
 - 5 at least one other antenna cell,wherein each antenna cell comprises a respective antenna element and generates, in use, a respective output signal from an input signal received by said respective antenna element,
 - and wherein said at least one other antenna cell includes a phase locked loop (PLL) circuit
 - for tracking changes in the phase of said received input signal, said PLL circuit including an input for
 - 10 receiving a phase reference signal, said input being connected to an output of said first antenna cell
 - to receive the output signal of said first antenna cell as said phase reference signal.
2. An antenna system as claimed in claim 1, including a plurality of said at least one other antenna cells, said phase reference input of each of said at least one other antenna cells being connected to
- 15 the output of said first antenna cell to receive the output signal of said first antenna cell as said phase reference signal.
3. An antenna system as claimed in claim 1 or 2, further including a combining device for combining the respective output signal from each antenna cell.
- 20 4. An antenna system as claimed in claim 3, wherein said combining device comprises a summation circuit.
5. An antenna system as claimed in any preceding claim, wherein said PLL circuit comprises a
- 25 phase detector having a first input for receiving said phase reference signal and a second input for receiving a signal derived from said received input signal, and is configured to generate an output signal that is indicative of the phase difference between the respective signals received at said first and second inputs.
- 30 6. An antenna system as claimed in claim 5, wherein said PLL circuit further includes a variable frequency oscillator for generating an output signal having a frequency variable in response to a control signal, wherein the output signal of said phase detector provides said control signal.
7. An antenna system as claimed in claim 6, wherein said PLL circuit further includes a signal mixing
- 35 device for mixing the frequency oscillator output signal with said received input signal or a signal derived therefrom to produce a mixer output signal, said mixer output signal providing said signal for the second input of said phase detector, and preferably also providing said output signal of the respective antenna cell.
- 40 8. An antenna system as claimed in claim 7, wherein said signal mixing device comprises a frequency down converter.

9. An antenna system as claimed in any preceding claim, wherein said at least one other antenna cell includes receiver circuitry, said receiver circuitry including said PLL circuit.
- 5 10. An antenna system as claimed in claim 9, wherein said at least one other antenna cell includes transmitter circuitry.
11. An antenna system as claimed in claim 10, wherein said receiver circuitry and said transmitter circuitry are each coupled to said respective antenna by a coupling device, for example a duplexer.
- 10 12. An antenna system as claimed in claim 10 or 11, wherein said transmitter circuitry is configured to perform retrodirective retransmission in respect of said received input signal.
13. An antenna system as claimed in claim 12, wherein said transmitter circuitry includes phase
- 15 conjugation circuitry for performing phase conjugation of said received input signal to effect retrodirective transmission.
14. An antenna system as claimed in any preceding claim, wherein said first antenna cell includes receiver circuitry.
- 20 15. An antenna system as claimed in claim 14, wherein said receiver circuitry includes a fixed frequency oscillator and a signal mixing device for mixing the output signal from said oscillator with said received input signal, or a signal derived therefrom, to provide the output signal of said first antenna cell.
- 25 16. An antenna system as claimed in claim 15, wherein said signal mixing device comprises a frequency down converter.
17. An antenna system as claimed in any one of claims 14 to 16, wherein said first antenna cell
- 30 includes transmitter circuitry.
18. An antenna system as claimed in claim 17, wherein said receiver circuitry and said transmitter circuitry are each coupled to said respective antenna element by a coupling device, for example a duplexer.
- 35 19. An antenna system as claimed in claim 17 or 18, wherein said transmitter circuitry is configured to perform retrodirective retransmission in respect of said received input signal.
20. An antenna system as claimed in claim 19, wherein said transmitter circuitry includes phase
- 40 conjugation circuitry for performing phase conjugation of said received input signal to effect retrodirective transmission.

21. An antenna system as claimed in any preceding claim, wherein said antenna cells are comprised of analogue circuitry.

- 5 22. A method of tracking an input signal received by an antenna system, the method comprising:
- receiving said input signal at a respective antenna element of a first antenna cell and at least one other antenna cell;
 - generating, by said first antenna cell, an output signal from said input signal received at said respective antenna element;
 - 10 tracking the phase of said input signal received at the respective antenna element of said at least one other antenna cell using a phase locked loop (PLL) circuit; and
 - providing said output signal of said first antenna cell to said PLL circuit as a phase reference signal.

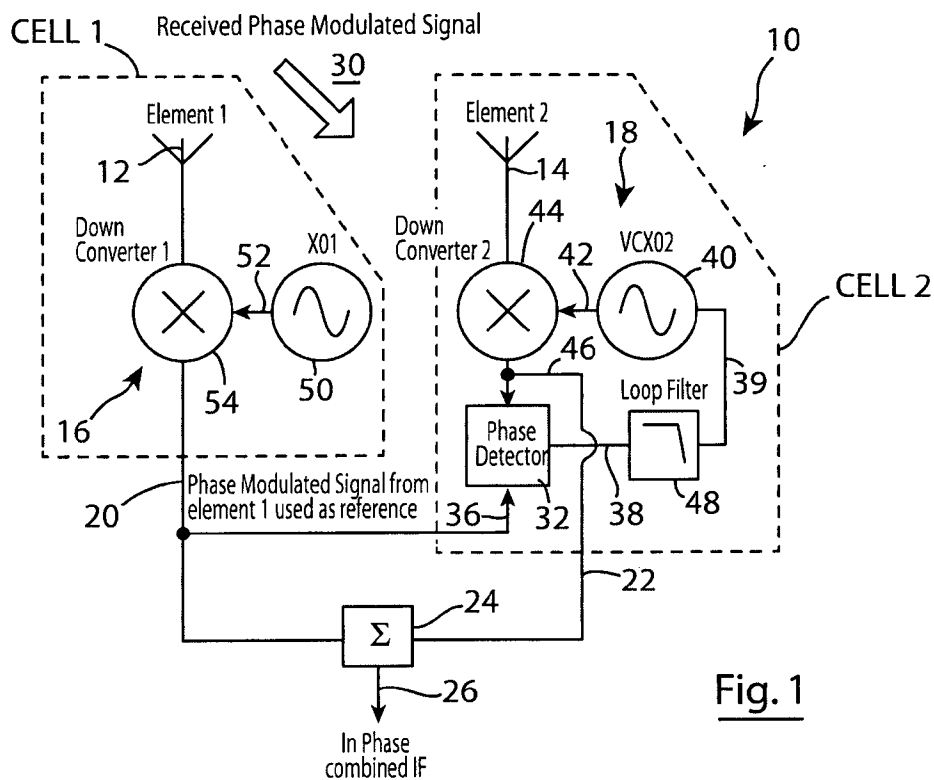


Fig. 1

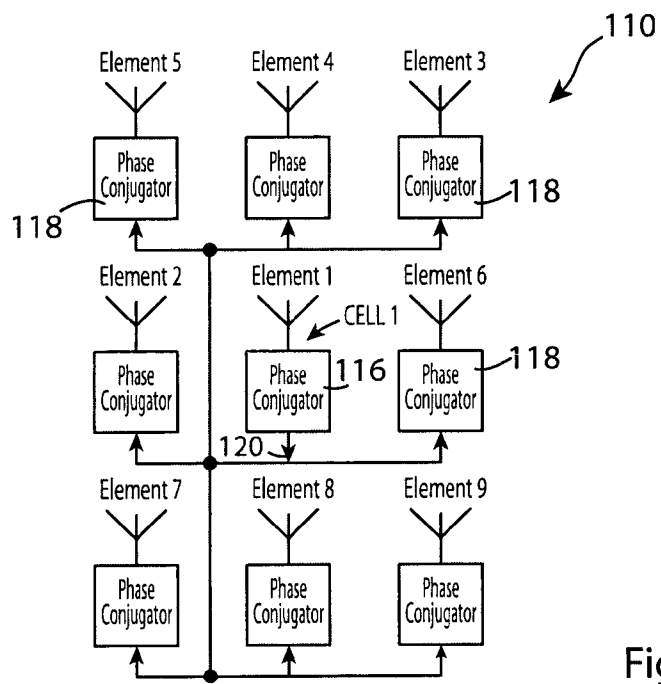


Fig. 2

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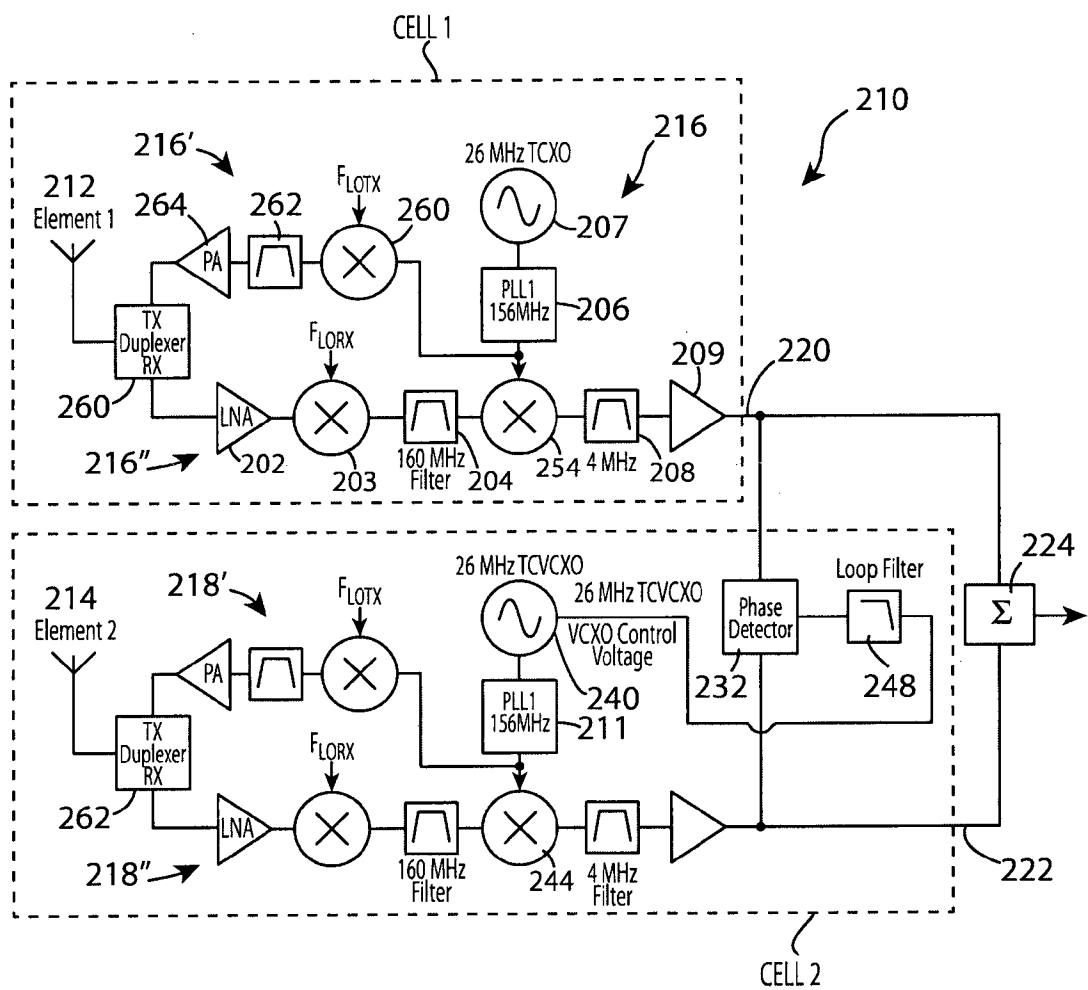


Fig. 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/056260

A. CLASSIFICATION OF SUBJECT MATTER INV. G01S3/46 G01S3/48 H01Q3/00 H04B7/08 G01S3/42 H01Q3/42 ADD. According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) G01S H01Q H04B Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EP0-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 1 274 181 A1 (ALPS ELECTRIC CO LTD [JP]) 8 January 2003 (2003-01-08) abstract paragraphs [0007] - [0011], [0013] - [0021]; claims 1-3; figure 1 -----	1-22
Y	GB 1 325 955 A (WESTERN ELECTRIC CO) 8 August 1973 (1973-08-08) page 1, lines 8-15, 33-41 page 3, lines 21-44 page 5, lines 32-40 figures 1,3 -----	1-22
Y	US 4 148 031 A (FLETCHER JAMES C ET AL) 3 April 1979 (1979-04-03) abstract column 1, line 15 - column 4, line 2 ----- -/-	12,13, 19,20
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 31 August 2015		Date of mailing of the international search report 07/09/2015
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Fernández Cuenca, B

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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