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(54) **ISOLATION OF POLARIZATIONS IN MULTI-POLARIZED SCANNING PHASED ARRAY ANTENNAS**

(57) A multi-polarized phased array antenna includes an element, a first feed line, a second feed line, a first phase shifter, and a second phase shifter. The element is fed with a first polarization signal at first and third angles, and a second polarization signal at second and fourth angles. One of the first polarization signal and second polarization signal is cancelled at a feed point in at least one of a first feed line and second feed line by

operation of the first phase shifter, second phase shifter, first angle, second angle, third angle, and fourth angle. The first phase shifter provides a first 180° phase shift between the first and third angles, and the second phase shifter provides a second 180° phase shift between the second and fourth angles. A corresponding method of increasing isolation between polarizations in the multi-polarized phased array antenna is also provided.

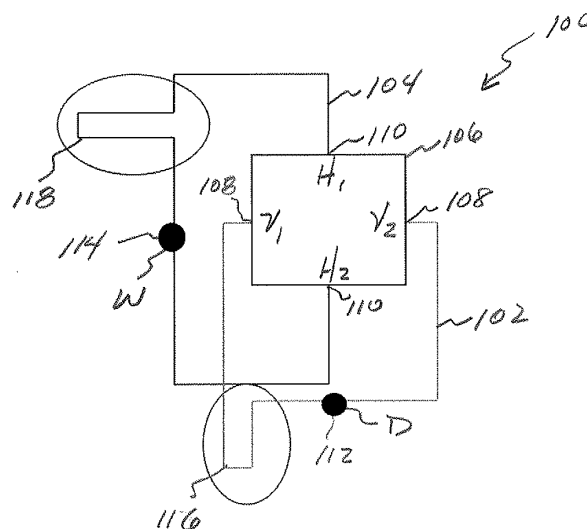


FIGURE 5

Description

BACKGROUND

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is a continuation-in-part application of United States Application No. 13/479,928, filed May 24, 2012, which claims the benefit of United States Provisional Application No. 61/609,619, filed March 12, 2012, the disclosures of which are incorporated by reference herein in their entireties

Field

[0002] Embodiments of the invention generally relate to antennas and, more particularly, relate to devices and methods which increase isolation between polarizations associated with phased array antennas.

Related Art

[0003] One of the major challenges in antenna design is to provide the highest gain in the smallest possible area.

SUMMARY

[0004] Various embodiments of the invention relate to a device, method, and system to increase isolation between different polarizations associated with a phased array antenna. A multi-polarized scanning phased array antenna includes a plurality of elements, a horizontal feed line operatively coupled to the plurality of elements, and a vertical feed line operatively coupled to the plurality of elements.

[0005] A multi-polarized scanning phased array antenna is provided, which includes a plurality of elements, a first feed line operatively coupling the plurality of elements, a second feed line operatively coupling the plurality of elements, and a phase delay operatively coupled in at least one of the first feed line and the second feed line. The phase delay is configured to cancel a polarized signal associated with the multi-polarized scanning phased array antenna.

[0006] The plurality of elements may include a first element, second element, third element, and fourth element. A first set of elements may include the first and second elements, a second set of elements may include the third and fourth elements, a third set of elements may include the first and third elements, and a fourth set of elements may include the second and fourth elements. The phase delay may include a first phase delay operatively coupled in the first feed line between the third and fourth sets of elements, and a second phase delay operatively coupled in the second feed line between the first and second sets of elements. At least one of the first and second phase delays may include a 180° phase shift.

The first, second, third, and fourth elements may be operatively coupled by the second feed line and the first feed line.

[0007] The phase delay may include a first phase delay operatively coupled in the first feed line between the third and fourth sets of elements, a second phase delay operatively coupled in the second feed line between the first and second elements, and a third phase delay operatively coupled in the second feed line between the third and fourth elements. The first phase delay may include a 180° phase shift, the second phase delay may include a 180° phase shift, and the third phase delay may include a 180° phase shift and at least one θ° phase shift, wherein θ° represents an angle of elevation scanning.

[0008] The phase delay may include a first phase delay operatively coupled in the second feed line between the first and second sets of elements, a second phase delay operatively coupled in the first feed line between the first and third elements, and a third phase delay operatively coupled in the first feed line between the second and fourth elements. The first phase delay may include a 180° phase shift, the second phase delay may include a 180° phase shift, and the third phase delay may include a 180° phase shift and at least one θ° phase shift, wherein θ° represents an angle of azimuth scanning.

[0009] The phase delay may include a first phase delay operatively coupled in the first feed line between the first and third elements, a second phase delay operatively coupled in the first feed line between the second and fourth elements, a third phase delay operatively coupled in the second feed line between the first and second elements, and a fourth phase delay operatively coupled in the second feed line between the third and fourth elements. The first phase delay may include a 180° phase shift, the second phase delay may include a 180° phase shift and at least one θ_2° phase shift, the third phase delay may include a 180° phase shift, and the fourth phase delay may include a 180° phase shift and at least one θ_1° phase shift, wherein θ_1° represents an angle of elevation scanning and θ_2° represents an angle of azimuth scanning.

[0010] The plurality of elements may include a patch antenna. The first feed line may be configured to at least one of transmit and receive at least one of a vertically polarized signal, horizontally polarized signal, right-hand clockwise circularly polarized signal, and left-hand counterclockwise circularly polarized signal. The second feed line may be configured to at least one of transmit and receive at least one of a vertically polarized signal, horizontally polarized signal, right-hand clockwise circularly polarized signal, and left-hand counterclockwise circularly polarized signal. The first feed line may be configured to be a horizontal feed line, and the second feed line may be configured to be a vertical feed line.

[0011] A method of increasing isolation between polarizations in a multi-polarized scanning phased array antenna is provided, which includes coupling a plurality of elements operatively with a first feed line, coupling the

plurality of elements operatively with a second feed line, and coupling a phase delay operatively in at least one of the first feed line and the second feed line such that a polarized signal associated with the multi-polarized scanning phased array antenna is cancelled.

[0012] Coupling the phase delay may include coupling a first phase delay operatively in the first feed line between the third and fourth sets of elements, and coupling a second phase delay operatively in the second feed line between the first and second sets of elements. At least one of the first and second phase delays may include a 180° phase shift.

[0013] Coupling the phase delay may include coupling a first phase delay operatively in the first feed line between the third and fourth sets of elements, coupling a second phase delay operatively in the second feed line between the first and second elements, and coupling a third phase delay operatively in the second feed line between the third and fourth elements. The first phase delay may include a 180° phase shift, the second phase delay may include a 180° phase shift, and the third phase delay may include a 180° phase shift and at least one θ° phase shift, wherein θ° represents an angle of elevation scanning. The method may include coupling the first, second, third, and fourth elements operatively by the second feed line, and coupling the first, second, third, and fourth elements operatively by the first feed line.

[0014] Coupling the phase delay may include coupling a first phase delay operatively in the second feed line between the first and second sets of elements, coupling a second phase delay operatively in the first feed line between the first and third elements, and coupling a third phase delay operatively in the first feed line between the second and fourth elements. The first phase delay may include a 180° phase shift, the second phase delay may include a 180° phase shift, and the third phase delay may include a 180° phase shift and at least one θ° phase shift, wherein θ° represents an angle of azimuth scanning.

[0015] Coupling the phase delay may include coupling a first phase delay operatively in the first feed line between the first and third elements, coupling a second phase delay operatively in the first feed line between the second and fourth elements, coupling a third phase delay operatively in the second feed line between the first and second elements, and coupling a fourth phase delay operatively in the second feed line between the third and fourth elements. The first phase delay may include a 180° phase shift, the second phase delay may include a 180° phase shift and at least one θ_2° phase shift, the third phase delay may include a 180° phase shift, and the fourth phase delay may include a 180° phase shift and at least one θ_1° phase shift, wherein θ_1° represents an angle of elevation scanning and θ_2° represents an angle of azimuth scanning.

[0016] The method may include configuring the first feed line to at least one of transmit and receive at least one of a vertically polarized signal, horizontally polarized signal, right-hand clockwise circularly polarized signal,

and left-hand counterclockwise circularly polarized signal. The method may include configuring the second feed line to at least one of transmit and receive at least one of a vertically polarized signal, horizontally polarized signal, right-hand clockwise circularly polarized signal, and left-hand counterclockwise circularly polarized signal. The method may include configuring the first feed line to be a horizontal feed line, and configuring the second feed line to be a vertical feed line.

[0017] A multi-polarized phased array antenna is provided, which includes an element, a first feed line, a second feed line, a first phase shifter, and a second phase shifter. The element is fed with a first polarization signal at a first angle, a second polarization signal at a second angle, the first polarization signal at a third angle, and the second polarization signal at a fourth angle. The first polarization signal includes a first polarization, and the second polarization signal includes a second polarization. The first polarization is different from the second polarization. The first feed line operatively couples the first polarization signal to the element, and the first feed line is associated with the first polarization. The second feed line operatively couples the second polarization signal to the element, and the second feed line is associated with the second polarization. The first phase shifter is operatively coupled in the first feed line, and the second phase shifter is operatively coupled in the second feed line. One of the first polarization signal and the second polarization signal is cancelled at a feed point in at least one of the first feed line and the second feed line by operation of the first phase shifter, second phase shifter, first angle, second angle, third angle, and fourth angle. At least one of the first phase shifter and the second phase shifter includes at least one of a digital phase shifter and analog phase shifter. The analog phase shifter includes at least one length of conductor in addition to that required to couple at least one of (1) the first feed line across the first phase shifter and (2) the second feed line across the second phase shifter using a straight conductor. The first phase shifter provides a first 180° phase shift between the first and third angles, and the second phase shifter provides a second 180° phase shift between the second and fourth angles.

[0018] The first feed line may be bent in only right angles, and the second feed line may be bent in only right angles. The element may be a patch antenna. The first feed line may at least one of transmit and receive at least one of a vertically polarized signal, horizontally polarized signal, right-hand clockwise circularly polarized signal, and left-hand counterclockwise circularly polarized signal. The second feed line may at least one of transmit and receive at least one of a vertically polarized signal, horizontally polarized signal, right-hand clockwise circularly polarized signal, and left-hand counterclockwise circularly polarized signal. The first feed line may be a horizontally polarized feed line, and the second feed line may be a vertically polarized feed line.

[0019] A method of increasing isolation between po-

larizations in a multi-polarized phased array antenna includes coupling an element operatively to a first polarization signal using a first feed line, coupling the element operatively to the second polarization signal using a second feed line, coupling a first phase shifter operatively in the first feed line, and coupling a second phase shifter operatively in the second feed line. The element is fed with the first polarization signal at a first angle, a second polarization signal at a second angle, the first polarization signal at a third angle, and the second polarization signal at a fourth angle. The first polarization signal includes a first polarization, and the second polarization signal comprising a second polarization. The first polarization is different from the second polarization. The first feed line is associated with the first polarization, and the second feed line is associated with the second polarization. At least one of the first phase shifter and the second phase shifter includes at least one of a digital phase shifter and an analog phase shifter. The analog phase shifter includes at least one length of conductor in addition to that required to couple at least one of (1) the first feed line across the first phase shifter using a straight conductor 1 and (2) the second feed line across the second phase shifter using a straight conductor. The at least one length of conductor provides a phase shift. The first phase shifter provides a first 180° phase shift between (1) the first and third angles, and the second phase shifter provides a second 180° phase shift between the second and fourth angles.

[0020] The first feed line may be bent in only right angles, and the second feed line may be bent in only right angles. The method may include configuring the first feed line to at least one of transmit and receive at least one of a vertically polarized signal, horizontally polarized signal, right-hand clockwise circularly polarized signal, and left-hand counterclockwise circularly polarized signal. The method may include configuring the second feed line to at least one of transmit and receive at least one of a vertically polarized signal, horizontally polarized signal, right-hand clockwise circularly polarized signal, and left-hand counterclockwise circularly polarized signal. The method may include configuring the first feed line to be a horizontally polarized feed line, and configuring the second feed line to be a vertically polarized feed line.

[0021] Other embodiments of the invention will become apparent from the following detailed description considered in conjunction with the accompanying drawings. It is to be understood, however, that the drawings are designed as an illustration only and not as a definition of the limits of any embodiments of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] The following drawings are provided by way of example only and without limitation, wherein like reference numerals (when used) indicate corresponding elements throughout the several views, and wherein:

Figure 1 shows an antenna having vertical and horizontal polarization feed lines without azimuth or elevation scanning in accordance with a first embodiment of the invention;

Figure 2 shows an antenna having vertical and horizontal polarization feed lines with elevation scanning in accordance with a second embodiment of the invention;

Figure 3 shows an antenna having vertical and horizontal polarization feed lines with azimuth scanning in accordance with a third embodiment of the invention;

Figure 4 shows an antenna having vertical and horizontal polarization feed lines with azimuth and elevation scanning in accordance with a fourth embodiment of the invention; and

Figure 5 shows an antenna having vertical and horizontal polarization feed lines without azimuth or elevation scanning in accordance with a fifth embodiment of the invention.

[0023] It is to be appreciated that elements in the figures are illustrated for simplicity and clarity. Common but well-understood elements that are useful or necessary in a commercially feasible embodiment are not shown in order to facilitate a less hindered view of the illustrated embodiments.

DETAILED DESCRIPTION

[0024] In the case of dual polarized antennas, such as antennas utilizing linear and circular polarization, reductions in area are achieved by introducing both polarizations in a plurality of single elements associated with the phased array or, in the case of two separate elements each having a single polarization, by providing dual polarizations that occupy the same area. To do this, the polarizations (such as vertical and horizontal) are provided by the same antenna element. However, proximity between phased array elements creates additional challenges, such as maintaining isolation between polarizations. Accordingly, embodiments of the invention improve isolation between different polarizations in multi-polarized phased array antennas. Embodiments of the invention also cancel a polarization signal while another polarization signal is active.

[0025] Figure 1 shows an antenna 10 having vertical and horizontal polarization feed lines without azimuth or elevation scanning. The antenna 10 transmits and receives in two polarizations, such as two linear polarizations, such as vertical and horizontal polarizations. However, embodiments of the invention are equally applicable to circular polarizations. Line 12 represents a vertical polarization feed line, line 14 represents a horizontal po-

larization feed line, and squares represent antenna elements 16. Feed points V1, V2, V3, V4 represent vertical polarization feed points 18, and feed points H1, H2, H3, H4 represent horizontal polarization feed points 20. Connection points A, B, C represent connection points 22 for the vertical polarization feed line 12, and connection points X, Y, Z represent connection points 24 for the horizontal polarization feed line 14.

[0026] Figure 1 shows an embodiment of the invention including a single element for dual linear polarization, which is equally applicable to all types of antennas. Signals arriving from connection point A to connection point C and connection point X to connection point Z experience an additional 180-degree phase shift 26, 28, respectively, either due to an additional length of conductor 26, 28 for a narrowband signal or a phase shifter with a 180° hybrid (not shown) for a wideband signal. That is, if the application is narrowband, such as rates up to 1.544 Mbps, the additional length of conductor is used, and if the application is wideband, such as 64 Kbps to 2 Mbps, the 180° hybrid is used. In broadband applications, the 180° phase shift can be added by using hybrids, digital phase shifters, and/or analog phase shifters.

[0027] In a first example implementation of the embodiment shown in Figure 1, horizontal polarization is received by the vertical feed line 12. Specifically, signal V1 is fed at vertical polarization feed point V1 20 at an angle of 0°, signal V2 is fed at vertical polarization feed point V2 20 at an angle of 0°, signal V3 is fed at vertical polarization feed point V3 20 at an angle of 0°, and signal V4 is fed at vertical polarization feed point V4 20 at an angle of 0°. For normalized feed signals, $V1=V2=V3=V4=1$. The signal at connection point A equals $V1$ at $0^\circ+V2$ at 0° , and the signal at connection point B equals $V3$ at $0^\circ+V4$ at 0° . All four signals add at connection point C to equal $V1$ at $180^\circ+V2$ at $180^\circ+V3$ at $0^\circ+V4$ at 0° . Therefore, the signal at connection point C is equal to $-V1$ at $0^\circ-V2$ at $0^\circ+V3$ at $0^\circ+V4$ at 0° , which equals 0. Since the magnitudes of the signals are equal, the signals cancel each other, which indicate that undesirable horizontal polarization signal magnitudes become zero at connection point C. Connection point C is the output of the vertical polarization feed line while the antenna 10 is receiving. As indicated above, no horizontal polarization signal is received at connection point C. Thus, isolation is increased to infinity, which shows that one element can be used for both polarizations simultaneously without any isolation issues.

[0028] In a second example implementation of the embodiment shown in Figure 1, vertical polarization is received by the vertical feed line 12. Specifically, signal V1 is fed at vertical polarization feed point V1 at an angle of 180°, signal V2 is fed at vertical polarization feed point V2 20 at an angle of 180°, signal V3 is fed at vertical polarization feed point V3 20 at an angle of 0°, and signal V4 is fed at vertical polarization feed point V4 20 at an angle of 0°. For normalized feed signals, $V1=V2=V3=V4=1$. The signal at connection point A

equals $V1$ at $180^\circ+V2$ at 180° , and the signal at connection point B equals $V3$ at $0^\circ+V4$ at 0° . All four signals add at connection point C to equal $V1$ at $360^\circ+V2$ at $360^\circ+V3$ at $0^\circ+V4$ at 0° . Since a 360° degree phase shift is equivalent to a 0° degree phase shift, the signal at connection point C can be rewritten as $V1$ at $0^\circ+V2$ at $0^\circ+V3$ at $0^\circ+V4$ at 0° . This result indicates that a vertical polarization signal can be received and transmitted from the vertical feed line 12 without cancellation or degradation. Connection point C is the output of the vertical polarization feed line 12 while the antenna 10 is receiving. As indicated above, at connection point C, the vertical signal is received without cancellation or attenuation as desired while no horizontal polarization signal is received. This shows that one element can be used for both polarizations simultaneously without cancellation or attenuation issues.

[0029] In a third example implementation of the embodiment shown in Figure 1, vertical polarization is received by the horizontal feed line 14. Specifically, signal H1 is fed at horizontal polarization feed point H1 18 at an angle of 0°, signal H2 is fed at horizontal polarization feed point H2 18 at an angle of 0°, signal H3 is fed at horizontal polarization feed point H3 18 at an angle of 0°, and signal H4 is fed at horizontal polarization feed point H4 18 at an angle of 0°. For normalized feed signals, $H1=H2=H3=H4=1$. The signal at connection point X equals $H1$ at $0^\circ+H2$ at 0° , and the signal at connection point Y equals $H3$ at $0^\circ+H4$ at 0° . All four signals add at connection point Z to equal $H1$ at $180^\circ+H2$ at $0^\circ+H3$ at $180^\circ+H4$ at 0° . Therefore, the signal at connection point Z is equal to $-H1$ at $0^\circ+H2$ at $0^\circ-H3$ at $0^\circ+H4$ at 0° , which equals 0. Since the magnitudes of the signals are equal, the signals cancel each other, which indicate that the magnitude of undesirable vertical polarization signals becomes zero at point Z, which is the horizontal polarization feed point. Therefore, complete isolation between polarizations is achieved in this configuration. Connection point Z is the output of the horizontal polarization feed line 14 while the antenna 10 is receiving. As indicated above, no vertical polarization signal is received at connection point Z. The isolation is increased to infinity, which indicates that one element can be used for both polarizations simultaneously without isolation issues.

[0030] In a fourth example implementation of the embodiment shown in Figure 1, horizontal polarization is received by the horizontal feed line 14. Specifically, signal H1 is fed at horizontal polarization feed point H1 at an angle of 180°, signal H2 is fed at horizontal polarization feed point H2 at an angle of 0°, signal H3 is fed at horizontal polarization feed point H3 at an angle of 180°, and signal H4 is fed at horizontal polarization feed point H4 at an angle of 0°. For normalized feed signals, $H1=H2=H3=H4=1$. The signal at connection point X equals $H1$ at $180^\circ+H3$ at 180° , and the signal at connection point Y equals $H2$ at $0^\circ+H4$ at 0° . All four signals add at connection point Z to equal $H1$ at $360^\circ+H2$ at $0^\circ+H3$ at $360^\circ+H4$ at 0° . Since a 360° degree phase shift is equivalent to a 0° degree phase shift, the signal at point

Z can be rewritten as $H1$ at $0^\circ + H2$ at $0^\circ + H3$ at $0^\circ + H4$ at 0° . This result indicates that a horizontal polarization signal can be received and transmitted from the horizontal feed line without cancellation or degradation. Point Z is the output of the horizontal polarization feed line 14 while the antenna 10 is receiving. As indicated above, at point Z, the horizontal signal is received without cancellation or attenuation as desired while no vertical polarization signal is received, which indicates that one element can be used for both polarizations simultaneously without cancellation or attenuation issues.

[0031] Figure 2 shows an antenna 40 having vertical and horizontal polarization feed lines with elevation scanning. The antenna 40 transmits and receives in two polarizations, such as in two linear polarizations, such as vertical and horizontal polarizations. However, embodiments of the invention are equally applicable to circular polarization as well. Line 42 represents a vertical polarization feed line, line 44 represents a horizontal polarization feed line, and squares represent antenna elements 46. Feed points H1, H2, H3, H4 represent horizontal polarization feed points 50, and feed points V1, V2, V3, V4 represent vertical polarization feed points 48. A, B and C represent connection points 52 for the vertical polarization feed line 42, and X, Y and Z represent connection points 54 for the horizontal polarization feed line 44.

[0032] Figure 2 shows an embodiment of the invention including a single element for dual linear polarization, which is equally applicable to all types of antennas. Signals arriving from connection point V1 to connection point A, connection point V3 to connection point B, and connection point X to connection point Z experience an additional 180-degree phase shift either due to an additional length of conductor 56 for a narrowband signal or a phase shifter with a 180° hybrid (not shown) for wideband applications. That is, if the application is narrowband, an additional length of conductor is used, and if the application is wideband, a 180° hybrid is used. In broadband applications, the 180° phase shift can be added by using hybrids, digital phase shifters, and/or analog phase shifters. Elevation scanning is implemented by applying a θ° phase shift 51 in the vertical polarization feed line 42.

[0033] In a first example implementation of the embodiment shown in Figure 2, horizontal polarization is received by the vertical polarization feed line 42. Specifically, signal V1 is fed at vertical polarization feed point V1 at an angle of 0° , signal V2 is fed at vertical polarization feed point V2 at an angle of 0° , signal V3 is fed at vertical polarization feed point V3 at an angle of 0° , and signal V4 is fed at vertical polarization feed point V4 at an angle of 0° . For normalized feed signals, $V1=V2=V3=V4=1$. The signal at connection point A equals $V1$ at $180^\circ + V2$ at 0° or $-V$ at $0^\circ + V2$ at 0° , which is equal to 0, and the signal at connection point B equals $V3$ at $(180+0)^\circ + V4$ at 0° or $-V3$ at $0^\circ + V4$ at 0° , which equals 0. Therefore, the signal at connection point C is equal to $-V1$ at $0^\circ + V2$ at $0^\circ - V3$ at $\theta^\circ + V4$ at θ° , which equals 0. Since the mag-

nitudes of the signals are equal, the signals cancel each other, which indicate that undesirable horizontal polarization signal magnitudes are not received by the vertical polarization feed line. Point C is the output of the vertical polarization feed line 42 while the antenna 40 is receiving. As indicated above, no horizontal polarization signal is received at connection point C. The isolation is increased to infinity, which indicates that one element can be used for both polarizations simultaneously without isolation issues.

[0034] In a second example implementation of the embodiment shown in Figure 2, vertical polarization is received by the vertical polarization feed line 42. Specifically, signal V1 is fed at vertical polarization feed point V1 at an angle of 180° , signal V2 is fed at vertical polarization feed point V2 at an angle of 0° , signal V3 is fed at vertical polarization feed point V3 at an angle of 180° , and signal V4 is fed at vertical polarization feed point V4 at an angle of 0° . For normalized feed signals, $V1=V2=V3=V4=1$. The signal at connection point A equals $V1$ at $360^\circ + V2$ at 0° or $V1$ at $0^\circ + V2$ at 0° , and the signal at connection point B equals $V3$ at $(360+0)^\circ + V4$ at 0° or $V3$ at $0^\circ + V4$ at 0° . All four signals add at connection point C to equal $V1$ at $0^\circ + V2$ at $0^\circ + V3$ at $0^\circ + V4$ at 0° . This result indicates that a vertical polarization signal can be received and transmitted from the vertical polarization feed line 42 without cancellation or degradation. Point C is the output of the vertical polarization feed line 42 while the antenna 40 is receiving. As shown above at point C, the vertical signal is received without cancellation or attenuation as desired while no horizontal polarization signal is received, which indicates that one element can be used for both polarizations simultaneously without cancellation or attenuation issues.

[0035] In a third example implementation of the embodiment shown in Figure 2, vertical polarization is received by the horizontal polarization feed line 44. Specifically, signal H1 is fed at horizontal polarization feed point H1 at an angle of 0° , signal H2 is fed at horizontal polarization feed point H2 at an angle of 0° , signal H3 is fed at horizontal polarization feed point H3 at an angle of θ° , and signal H4 is fed at horizontal polarization feed point H4 at an angle of θ° . For normalized feed signals, $H1=H2=H3=H4=1$. The signal at connection point X equals $H1$ at $0^\circ + H3$ at θ° , and the signal at connection point Y equals $H2$ at $0^\circ + H4$ at 0° . All four signals add at connection point Z to equal $H1$ at $180^\circ + H2$ at $0^\circ + H3$ at $(180+0)^\circ + H4$ at $(180+0)^\circ$. Therefore, the signal at connection point Z is equal to $-H1$ at $0^\circ + H2$ at $0^\circ - H3$ at $\theta^\circ + H4$ at θ° , which equals 0. Since the magnitudes of the signals are equal, the signals cancel each other, which indicates that the magnitude of undesirable vertical polarization signals become zero at connection point Z, which is the horizontal polarization feed point. Connection point Z is the output of the horizontal polarization feed line 44 while the antenna 40 is receiving. As indicated above, no vertical polarization signal is received at point Z. The isolation is increased to infinity, which shows that one element

can be used for both polarizations simultaneously without isolation issues.

[0036] In a fourth example implementation of the embodiment shown in Figure 2, horizontal polarization is received by the horizontal polarization feed line 44. Specifically, signal H1 is fed at horizontal polarization feed point H1 at an angle of 180° , signal H2 is fed at horizontal polarization feed point H2 at an angle of 0° , signal H3 is fed at horizontal polarization feed point H3 at an angle of 180° , and signal H4 is fed at horizontal polarization feed point H4 at an angle of 0° . For normalized feed signals, $H1=H2=H3=H4=1$. The signal at connection point X equals $H1$ at $180^\circ+H3$ at 180° , and the signal at connection point Y equals $H2$ at $0^\circ+H4$ at 0° . All four signals add at connection point Z to equal $H1$ at $360^\circ+H2$ at $0^\circ+H3$ at $360^\circ+H4$ at 0° . Since a 360° degree phase shift is equivalent to a 0° degree phase shift, the signal at point Z can be rewritten as $H1$ at $0^\circ+H2$ at $0^\circ+H3$ at $0^\circ+H4$ at 0° . This result indicates that a horizontal polarization signal can be received and transmitted from the horizontal polarization feed line 44 without cancellation or degradation. Point Z is the output of the horizontal polarization feed line 44 while the antenna 40 is receiving. As discussed above, at connection point Z, the horizontal signal is received without cancellation or attenuation as desired while no vertical polarization signal is received, which indicates that one element can be used for both polarizations simultaneously without cancellation or attenuation issues.

[0037] Figure 3 shows an antenna 60 having vertical and horizontal polarization feed lines with azimuth scanning. The antenna 60 transmits and receives in two polarizations, such as in two linear polarizations, such as vertical and horizontal polarizations. However, embodiments of the invention are equally applicable to circular polarizations as well. Line 62 represents a vertical polarization feed line, line 64 represents a horizontal polarization feed line, and squares represent antenna elements 66. Feed points H1, H2, H3, H4 represent horizontal polarization feed points 68, and feed points V1, V2, V3, V4 represent vertical polarization feed points 70. A, B and C represent connection points 72 for the vertical polarization feed line 62, and X, Y and Z represent connection points 74 for the horizontal polarization feed line 64.

[0038] Figure 3 shows an embodiment of the invention including a single element for dual linear polarization, which is equally applicable to all types of antennas. Signals arriving from connection point A to connection point C, connection point H1 to connection point X, and connection point H2 to connection point Y experience an additional 180° -degree phase shift either due to an additional length of conductor 76 for a narrowband signal or a phase shifter with a 180° hybrid (not shown) for a wideband signal. That is, if the application is narrowband, an additional length of conductor is used, and if the application is wideband, a 180° hybrid is used. In broadband applications, the 180° phase shift can be added by using

hybrids, digital phase shifters, and/or analog phase shifters. Elevation scanning is implemented by applying a θ° phase shift 77 in the horizontal polarization feed line 64.

[0039] In a first example implementation of the embodiment shown in Figure 3, vertical polarization is received by the horizontal polarization feed line 64. Specifically, signal H1 is fed at horizontal polarization feed point H1 at an angle of 0° , signal H2 is fed at horizontal polarization feed point H2 at an angle of 0° , signal H3 is fed at horizontal polarization feed point H3 at an angle of 0° , and signal H4 is fed at horizontal polarization feed point H4 at an angle of 0° . For normalized feed signals, $H1=H2=H3=H4=1$. The signal at connection point X equals $H1$ at $180^\circ+H3$ at 0° , and the signal at connection point Y equals $H2$ at $(180+\theta)^\circ+H4$ at θ° . Therefore, since the signals differ by 180° and have the same magnitude, the signals cancel each other, which indicates that undesirable vertical polarization signal magnitudes are not received by the horizontal polarization feed line 64. Therefore, complete isolation between polarizations is achieved. Connection point Z is the output of the horizontal polarization feed line 64 while the antenna 60 is receiving. As discussed above, no vertical polarization signal is received at point Z. The isolation is increased to infinity, which indicates that one element can be used for both polarizations simultaneously without isolation issues.

[0040] In a second example implementation of the embodiment shown in Figure 3, horizontal polarization is received by the horizontal polarization feed line 64. Specifically, signal H1 is fed at horizontal polarization feed point H1 at an angle of 180° , signal H2 is fed at horizontal polarization feed point H2 at an angle of 180° , signal H3 is fed at horizontal polarization feed point H3 at an angle of 0° , and signal H4 is fed at horizontal polarization feed point H4 at an angle of 0° . For normalized feed signals, $H1=H2=H3=H4=1$. The signal at connection point X equals $H1$ at $360^\circ+H3$ at 0° or $H1$ at $0^\circ+H3$ at 0° , and the signal at connection point Y equals $H2$ at $(360+\theta)^\circ+H4$ at θ° or $H2$ at $\theta^\circ+H4$ at θ° . All four signals add at connection point Z to equal $H1$ at $0^\circ+H2$ at $0^\circ+H3$ at $\theta^\circ+H4$ at θ° . This result indicates that a horizontal polarization signal can be received and transmitted from the horizontal polarization feed line 64 without any cancellation or degradation. Point Z is the output of the horizontal polarization feed line 64 while the antenna 60 is receiving. As discussed above, at point Z, the horizontal signal is received without cancellation or attenuation as desired while no vertical polarization signal is received, which shows that one element can be used for both polarizations simultaneously without cancellation or attenuation issues.

[0041] In a third example implementation of the embodiment shown in Figure 3, horizontal polarization is received by the vertical polarization feed line 62. Specifically, signal V1 is fed at vertical polarization feed point V1 at an angle of 0° , signal V2 is fed at vertical polarization feed point V2 at an angle of θ° , signal V3 is fed at vertical

polarization feed point V3 at an angle of 0° , and signal V4 is fed at vertical polarization feed point V4 at an angle of θ° . For normalized feed signals, $V1=V2=V3=V4=1$. The signal at connection point A equals $V1$ at $0^\circ+V2$ at θ° , and the signal at connection point B equals $V3$ at $0^\circ+V4$ at θ° . All four signals add at connection point C to equal $V1$ at $180^\circ+V2$ at $(180+\theta)^\circ+V3$ at $0^\circ+V4$ at θ° . Therefore, the signal at connection point C is equal to $-V1$ at $0^\circ-V2$ at $\theta^\circ+V3$ at $\theta^\circ+V4$ at θ° , which equals 0. Since the magnitudes of the signals are equal, the signals cancel each other, which indicates that the magnitude of undesirable horizontal polarization signals become zero at point C, which is the vertical polarization feed point. Point C is the output of the vertical polarization feed line 64 while the antenna 60 is receiving. As shown above, no horizontal polarization signal is received at point C. The isolation is increased to infinity, which shows that one element can be used for both polarizations simultaneously without isolation issues.

[0042] In a fourth example implementation of the embodiment shown in Figure 3, vertical polarization is received by the vertical polarization feed line 62. Specifically, signal V1 is fed at vertical polarization feed point V1 at an angle of 180° , signal V2 is fed at vertical polarization feed point V2 at an angle of 180° , signal V3 is fed at vertical polarization feed point V3 at an angle of 0° , and signal V4 is fed at vertical polarization feed point V4 at an angle of 0° . For normalized feed signals, $V1=V2=V3=V4=1$. The signal at connection point A equals $V1$ at $180^\circ+V2$ at 180° , and the signal at connection point B equals $V3$ at $0^\circ+V4$ at 180° . All four signals add up at connection point C to equal $V1$ at $360^\circ+V2$ at $360^\circ+V3$ at $0^\circ+V4$ at 0° . Since a 360° degree phase shift is equivalent to a 0° degree phase shift, the signal at connection point C can be rewritten as $V1$ at $0^\circ+V2$ at $0^\circ+V3$ at $0^\circ+V4$ at 0° . This result indicates that the vertical polarization signal can be received and transmitted from the vertical polarization feed line 62 without cancellation or degradation. Point C is the output of the vertical polarization feed line 62 while the antenna 60 is receiving. As indicated above, at point C, the vertical signal is received without any cancellation or attenuation as desired while no horizontal polarization signal is received, which indicates that one element can be used for both polarizations simultaneously without cancellation or attenuation issues.

[0043] Figure 4 shows an antenna 80 having vertical and horizontal polarization feed lines 82, 84 with azimuth and elevation scanning. The antenna 80 transmits and receives in two polarizations, such as in two linear polarizations, such as vertical and horizontal polarizations. However, embodiments of the invention are equally applicable to circular polarizations as well. Line 82 represents a vertical polarization feed line, line 84 represents a horizontal polarization feed line, and squares represent antenna elements 86. Feed points H1, H2, H3, H4 represent horizontal polarization feed points 88, and feed points V1, V2, V3, V4 represent vertical polarization feed

points 90. A, B and C represent connection points 92 for the vertical polarization feed line 82, and X, Y and Z represent connection points 94 for the horizontal polarization feed line 84.

[0044] Figure 4 shows an embodiment of the invention including a single element for dual linear polarization, which is equally applicable to all types of antennas. Signals arriving from connection point B to connection point V3, connection point A to connection point V1, and connection point H2 to connection point Y experience an additional 180° -degree phase shift either due to an additional length of conductor 96 for a narrowband signal or a phase shifter with a 180° hybrid (not shown) for a wideband signal. That is, if the application is narrowband, an additional length of conductor is used, and if application is wideband, a 180° hybrid is used. In broadband applications, the 180° phase shift can be added by using hybrids, digital phase shifters, and/or analog phase shifters. Azimuth scanning is implemented by applying a θ_2° phase shift 100 in the horizontal polarization feed line 84, and elevation scanning is implemented by applying a θ_1° phase shift 98 in the vertical polarization feed line 82.

[0045] To be able to steer the beam in azimuth (horizontal direction) and elevation (vertical direction), there is a phase difference between horizontal elements for azimuth steering and between vertical elements for elevation steering. Figure 4 shows the feed line length from H2 to Y and H4 to Y is longer than from H1 to X and H3 to X, which adds the phase difference to the signal that steers the beam in azimuth. Similarly, the feed line length from V3 to B and V4 to B is longer than from V1 to A and V2 to A, which adds the phase difference to the signal that steers the beam in elevation. The additional phase may be fixed or variable. In this case, the steering angles are introduced by extra length in the feed line. However, these additional phases can also be added by digital or analog phase shifters or hybrids. These additional phase delays are referred to as θ_1 phase delay 98 for elevation (vertical direction) and θ_2 phase delay 100 for azimuth (horizontal direction).

[0046] In a first example implementation of the embodiment shown in Figure 4, horizontal polarization is received by the vertical polarization feed line 82. Specifically, signal V1 is fed at vertical polarization feed point V1 at an angle of 0° , signal V2 is fed at vertical polarization feed point V2 at an angle of θ_2° , signal V3 is fed at vertical polarization feed point V3 at an angle of 0° , and signal V4 is fed at vertical polarization feed point V4 at an angle of θ_2° . For normalized feed signals, $V1=V2=V3=V4=1$. The signal at connection point A 92 equals $V1$ at $180^\circ+V2$ at θ_2° , the signal at connection point B 92 equals $V3$ at $(180+\theta_1)^\circ+V4$ at $(\theta_1+\theta_2)^\circ$, and the signal at connection point C 92 equals $V1$ at $180^\circ+V2$ at $\theta_2^\circ+V3$ at $(180+\theta_1)^\circ+V4$ at $(\theta_1+\theta_2)^\circ$. The magnitude of the signal in the X direction is equal to $-1+\cos(\theta_2)+\cos(180+\theta_1)+\cos(\theta_1+\theta_2)$, and the magnitude of the signal in the Y direction is equal to $\sin(\theta_2)+\sin(180+\theta_1)+\sin(\theta_1+\theta_2)$. Thus, undesirable signals are

substantially attenuated by at least 6dB. Point C is the output of the vertical polarization feed line 82 while the antenna 80 is receiving. As indicated above, no horizontal polarization signal is received at point C. The isolation is increased up to infinity, which indicates that one element can be used for both polarizations simultaneously without isolation issues.

[0047] For example, if $\theta_1=30$ and $\theta_2=60$, the magnitude of the signal in the X direction is equal to $-1 + \cos(60) + \cos(210) + \cos(90)$, and the magnitude of the signal in the Y direction is equal to $\sin(60) + \sin(210) + \sin(90)$. Thus, the magnitude of the signal in the X direction equals -1.36, and the magnitude of the signal in the Y direction equals 1.36. Therefore, the magnitude of the total signal= 1.92 or 5.6dB. If the embodiment shown in Figure 4 is not used, the magnitude of the unwanted signal at connection point C would equal 4 or 12dB. As a result, the embodiment shown in Figure 4 provides an improvement of $12-5.6=6.4$ dB.

[0048] As another example, if $\theta_1=60$ and $\theta_2=60$, the magnitude of the signal in the X direction equals $-1 + \cos(60) + \cos(240) + \cos(120)$, and the magnitude of the signal in the Y direction equals $\sin(60) + \sin(240) + \sin(120)$. Thus, the magnitude of the signal in the X direction is -1.5, and the magnitude of the signal in the Y direction is 0.86. Therefore, the magnitude of the total signal equals 1.72 or 4.7dB. If the embodiment shown in Figure 4 were not used, the magnitude of the unwanted signal at point C would be 4 or 12dB. Accordingly, in this example, an improvement of $12-4.7=7.3$ dB is achieved.

[0049] In a second example implementation of the embodiment shown in Figure 4, vertical polarization is received by the vertical polarization feed line 82. Specifically, signal V1 is fed at vertical polarization feed point V1 at an angle of 180° , signal V2 is fed at vertical polarization feed point V2 at an angle of 0° , signal V3 is fed at vertical polarization feed point V3 at an angle of 180° , and signal V4 is fed at vertical polarization feed point V4 at an angle of 0° . For normalized feed signals, $V_1=V_2=V_3=V_4=1$. The signal at connection point A equals V1 at $360^\circ+V_2$ at 0° or V1 at $0^\circ+V_2$ at 0° , and the signal at connection point B equals V3 at $(360+\theta_1)^\circ+V_4$ at θ_1° or V3 at $\theta_1^\circ+V_4$ at θ_1° . All four signals add at connection point C to equal V1 at $0^\circ+V_2$ at $0^\circ+V_3$ at $\theta_1^\circ+V_4$ at θ_1° . This result indicates that a vertical polarization signal can be received and transmitted from the vertical polarization feed line 82 without any cancellation or degradation. Point C is the output of the vertical polarization feed line while the antenna is receiving. As indicated above, at point C, the vertical signal is received without any cancelation or attenuation as desired while no horizontal polarization signal is received, which indicates that one element can be used for both polarizations simultaneously without cancellation or attenuation issues.

[0050] In a third example implementation of the embodiment shown in Figure 4, vertical polarization is received by the horizontal polarization feed line 84. Spe-

cifically, signal H1 is fed at horizontal polarization feed point H1 at an angle of 0° , signal H2 is fed at horizontal polarization feed point H2 at an angle of 0° , signal H3 is fed at horizontal polarization feed point H3 at an angle of θ_1° , and signal H4 is fed at horizontal polarization feed point H4 at an angle of θ_1° . For normalized feed signals, $H_1=H_2=H_3=H_4=1$. The signal at connection point X equals H1 at $180^\circ+H_3$ at θ_1° , and the signal at connection point Y equals H3 at $(180+\theta_2)^\circ+H_4$ at $(\theta_1+\theta_2)^\circ$. All four signals add up at connection point Z to equal H1 at $180^\circ+H_2$ at $(180+\theta_2)^\circ+H_3$ at $\theta_1^\circ+H_4$ at $(\theta_1+\theta_2)^\circ$. The magnitude of the signal on the X axis equals $-1 + \cos(180+\theta_2) + \cos(\theta_1) + \cos(\theta_1+\theta_2)$, and the magnitude of the signal on the Y axis equals $\sin(\theta_1) + \sin(180+\theta_2) + \sin(\theta_1+\theta_2)$. This results in an attenuation of at least 6db in the unwanted signal. The point Z is the output of the horizontal feed line while the antenna is receiving. At point Z, only horizontal polarization signal must be received while little or no vertical polarization is received. As indicated above, no vertical signal is received at point Z. The isolation is increased up to infinity. Therefore complete isolation between polarizations is achieved in this configuration, which indicates that one element can be used for both polarizations simultaneously without isolation issues.

[0051] For example, if $\theta_1=60$ and $\theta_2=30$, the magnitude of the signal in the X axes equals $-1 + \cos(60) + \cos(210) + \cos(90)$, and the magnitude of the signal in the Y axes= $\sin(60) + \sin(210) + \sin(90)$. Thus, the magnitude of the signal in the X axes is -1.36, and the magnitude of the signal in the Y axes is 1.36. Therefore, the magnitude of the total signal equals 1.92 or 5.6dB, and the magnitude of the unwanted signal at point C would be equal to 4 or 12dB if this embodiment had not been implemented. Accordingly, in this example, a $12-5.6=6.4$ dB improvement is achieved.

[0052] As another example, if $\theta_1=60$ and $\theta_2=60$, the magnitude of the signal in the X axes= $-1 + \cos(240) + \cos(60) + \cos(120)$, and the magnitude of the signal in the Y axes= $\sin(60) + \sin(240) + \sin(120)$. Thus, the magnitude of the signal in the X axes is -1.5, and the magnitude of the signal in the Y axes is 0.86. Therefore, the magnitude of the total signal is 1.72 or 4.7dB. Since the magnitude of the unwanted signal at point C would equal 4 or 12dB without implementing this embodiment, a $12-4.7$ or 7.3 dB improvement is achieved. To be able to use one element antenna for both polarizations, the isolation between two signals (vertical and horizontal) must be sufficient. In accordance with this embodiment, the isolation is improved by 7.3 dB, which indicates that one element can be used for both polarizations simultaneously.

[0053] In a fourth example implementation of the embodiment shown in Figure 4, horizontal polarization is received by the horizontal polarization feed line 84. Specifically, signal H1 is fed at horizontal polarization feed point H1 at an angle of 180° , signal H2 is fed at horizontal polarization feed point H2 at an angle of 180° , signal H3

is fed at horizontal polarization feed point H3 at an angle of 0° , and signal H4 is fed at horizontal polarization feed point H4 at an angle of 0° . For normalized feed signals, $H1=H2=H3=H4=1$. The signal at connection point X equals $H1$ at $360^\circ+H3$ at 0° or $H1$ at $0^\circ+H3$ at 0° , and the signal at connection point Y equals $H2$ at $(360+02^\circ)+H4$ at 02° or $H2$ at $02^\circ+H4$ at 02° . All four signals add at connection point Z to equal $H1$ at $0^\circ+H2$ at $0^\circ+H3$ at $02^\circ+V4$ at 02° . This result indicates that the horizontal polarization signal can be received and transmitted from the horizontal polarization feed line 84 without any cancellation or degradation. Point Z is the output of the horizontal polarization feed line 84 while the antenna 80 is receiving. Only horizontal polarization signals are received at point Z while little or no vertical polarization signal is received. As shown above, at point Z, a horizontal polarization signal is received without any cancellation or attenuation as desired, which indicates that one element can be used for both polarizations simultaneously without attenuation issues.

[0054] Figure 5 shows an antenna 100 having vertical and horizontal polarization feed lines that provides isolation between polarizations without azimuth or elevation scanning. The antenna 100 transmits and receives in two polarizations, such as two linear polarizations, such as vertical and horizontal polarizations. However, alternative embodiments are equally applicable to any type of polarization, such as circular polarization. Line 102 represents a vertical polarization feed line, line 104 represents a horizontal polarization feed line, and a square represents an antenna element 106. Feed points V1, V2 represent vertical polarization feed points 108, and feed points H1, H2 represent horizontal polarization feed points 110. Feed point D represents feed point 112 for the vertical polarization feed line 102, and feed point W represents feed point 114 for the horizontal polarization feed line 104.

[0055] Figure 5 shows an embodiment including a single element for dual linear polarization, which is equally applicable to all types of antennas. Signals travelling between feed point D and feed point V1 and signals travelling between feed point W and feed point H1 experience an additional 180-degree phase shift 116, 118, respectively, either due to an additional length of conductor 116, 118 for a narrowband signal or a phase shifter with a 180° hybrid (not shown) for a wideband signal. That is, in narrowband applications, such as those with bit rates less than or equal to 1.544 Mbps, the additional length of conductor is used, and for wideband applications, such as those having bit rates of 64 Kbps to 2 Mbps, the 180° hybrid is used. In broadband applications, the 180° phase shift can be implemented by using hybrids, digital phase shifters, and/or analog phase shifters.

[0056] In a first example concerning the embodiment shown in Figure 5, horizontal polarization is received by a vertical feed line 102. Specifically, signal V1 is fed at vertical polarization feed point V1 108 at an angle of 0° , and signal V2 is fed at vertical polarization feed point V2

108 at an angle of 0° . For normalized feed signals, $V1=V2=1$. The signal at feed point D equals $V1$ at $180^\circ+V2$ at 0° . Therefore, the signal at feed point D is equal to $-V1$ at $0^\circ+V2$ at 0° , which equals 0. Since the magnitudes of the signals are equal, the signals cancel each other, which indicates that undesirable horizontal polarization signal magnitudes become zero at feed point D. Feed point D is an output of the vertical polarization feed line while the antenna 100 is receiving. As indicated above, no horizontal polarization signal is received at feed point D. Thus, isolation is increased to infinity, which shows that one element can be used for both polarizations simultaneously without any isolation issues.

[0057] In a second example concerning the embodiment shown in Figure 5, vertical polarization is received by the vertical feed line 102. Specifically, signal V1 is fed at vertical polarization feed point V1 108 at an angle of 180° , and signal V2 is fed at vertical polarization feed point V2 108 at an angle of 0° . For normalized feed signals, $V1=V2=1$. The signal at feed point D equals $V1$ at $360^\circ+V2$ at 0° . Since a 360° degree phase shift is equivalent to a 0° degree phase shift, the signal at feed point D can be rewritten as $V1$ at $0^\circ+V2$ at 0. This result indicates that a vertical polarization signal can be received and transmitted from the vertical feed line 102 without cancellation or degradation. Feed point D is the output of the vertical polarization feed line 102 while the antenna 100 is receiving. As indicated above, at feed point D, the vertical signal is received without cancellation or attenuation as desired while no horizontal polarization signal is received. This shows that one element can be used for both polarizations simultaneously without cancellation or attenuation issues.

[0058] In a third example concerning the embodiment shown in Figure 5, vertical polarization is received by a horizontal feed line 104. Specifically, signal H1 is fed at horizontal polarization feed point H1 110 at an angle of 0° , and signal H2 is fed at horizontal polarization feed point H2 110 at an angle of 0° . For normalized feed signals, $H1=H2=1$. The signal at feed point W equals $H1$ at $180^\circ+H2$ at 0° . Therefore, the signal at connection point Z is equal to $-H1$ at $0^\circ+H2$ at 0° , which equals 0. Since the magnitudes of the signals are equal, the signals cancel each other, which indicates that the magnitude of undesirable vertical polarization signals becomes zero at feed point W, which is the horizontal polarization feed point. Therefore, complete isolation between polarizations is achieved in this configuration. Feed point W is an output of the horizontal polarization feed line 104 while the antenna 100 is receiving. As indicated above, no vertical polarization signal is received at feed point W. The isolation is increased to infinity, which indicates that one element can be used for both polarizations simultaneously without isolation issues.

[0059] In a fourth example concerning the embodiment shown in Figure 5, horizontal polarization is received by the horizontal feed line 104. Specifically, signal H1 is fed at horizontal polarization feed point H1 at an angle of

180°, and signal H2 is fed at horizontal polarization feed point H2 at an angle of 0°. For normalized feed signals, $H1=H2=1$. The signal at feed point W equals H1 at $360^\circ+H2$ at 0°. Since a 360° degree phase shift is equivalent to a 0° degree phase shift, the signal at feed point W can be rewritten as H1 at $0^\circ+H2$ at 0°. This result indicates that a horizontal polarization signal can be received and transmitted from the horizontal feed line without cancellation or degradation. Feed point W is the output of the horizontal polarization feed line 104 while the antenna 100 is receiving. As indicated above, at feed point W, the horizontal signal is received without cancellation or attenuation as desired while no vertical polarization signal is received, which indicates that one element can be used for both polarizations simultaneously without cancellation or attenuation issues.

[0060] Accordingly, embodiments of the invention provide increased isolation between polarizations in an antenna by cancelling one polarization signal while another is being used. Five different feed network embodiments are shown in Figures 1-5. Specifically, Figure 1 shows an embodiment which does not implement scanning, Figure 2 shows an embodiment implementing scanning in elevation, Figure 3 shows an embodiment implementing scanning in azimuth, Figure 4 shows an embodiment implementing scanning in both elevation and azimuth, and Figure 5 shows a single element embodiment that does not implement scanning in either elevation or azimuth. For the embodiments shown in Figures 1-3 and 5, complete isolation is achieved between polarizations, and the embodiment shown in Figure 4 achieves at least a 6db level of isolation.

[0061] Although embodiments of the invention are disclosed with one (1) and four (4) elements, the invention is not limited to four (4) elements, and is equally applicable to configurations including any number of elements, such as but not limited to one (1), two (2), four (4), eight (8), twelve (12), and sixteen (16) elements. Further, any type of element can be used while remaining within the scope of the invention. Embodiments of the invention make it possible to use one element simultaneously for two (2) polarizations. Embodiments of the invention are also applicable to phased arrays.

[0062] Although the specification describes components and functions implemented in the embodiments with reference to particular standards and protocols, the embodiment are not limited to such standards and protocols.

[0063] The illustrations of embodiments described herein are intended to provide a general understanding of the structure of various embodiments, and they are not intended to serve as a complete description of all the elements and features of apparatus and systems that might make use of the structures described herein. Many other embodiments will be apparent to those of skill in the art upon reviewing the above description. Other embodiments are utilized and derived therefrom, such that structural and logical substitutions and changes are

made without departing from the scope of this disclosure. Figures are also merely representational and are not drawn to scale. Certain proportions thereof are exaggerated, while others are decreased. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense.

[0064] Such embodiments of the inventive subject matter are referred to herein, individually and/or collectively, by the term "embodiment" merely for convenience and without intending to voluntarily limit the scope of this application to any single embodiment or inventive concept if more than one is in fact shown. Thus, although specific embodiments have been illustrated and described herein, it should be appreciated that any arrangement calculated to achieve the same purpose are substituted for the specific embodiments shown. This disclosure is intended to cover any and all adaptations or variations of various embodiments. Combinations of the above embodiments, and other embodiments not specifically described herein, will be apparent to those of skill in the art upon reviewing the above description.

[0065] In the foregoing description of the embodiments, various features are grouped together in a single embodiment for the purpose of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting that the claimed embodiments have more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter lies in less than all features of a single embodiment. Thus the following claims are hereby incorporated into the detailed description, with each claim standing on its own as a separate example embodiment.

[0066] The abstract is provided to comply with 37 C.F.R. § 1.72(b), which requires an abstract that will allow the reader to quickly ascertain the nature of the technical disclosure. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. In addition, in the foregoing Detailed Description, it can be seen that various features are grouped together in a single embodiment for the purpose of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed embodiments require more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter lies in less than all features of a single embodiment. Thus the following claims are hereby incorporated into the Detailed Description, with each claim standing on its own as separately claimed subject matter.

[0067] Although specific example embodiments have been described, it will be evident that various modifications and changes are made to these embodiments without departing from the broader scope of the inventive subject matter described herein. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense. The accompanying drawings that form a part hereof, show by way of illustration, and without limitation, specific embodiments in which the

subject matter are practiced. The embodiments illustrated are described in sufficient detail to enable those skilled in the art to practice the teachings herein. Other embodiments are utilized and derived therefrom, such that structural and logical substitutions and changes are made without departing from the scope of this disclosure. This Detailed Description, therefore, is not to be taken in a limiting sense, and the scope of various embodiments is defined only by the appended claims, along with the full range of equivalents to which such claims are entitled.

[0068] Given the teachings of the invention provided herein, one of ordinary skill in the art will be able to contemplate other implementations and applications of the techniques of the invention. Although illustrative embodiments of the invention have been described herein with reference to the accompanying drawings, it is to be understood that the invention is not limited to those precise embodiments, and that various other changes and modifications are made therein by one skilled in the art without departing from the scope of the appended claims.

Claims

1. A multi-polarized phased array antenna, which comprises:

an element, the element being fed with a first polarization signal at a first angle, a second polarization signal at a second angle, the first polarization signal at a third angle, and the second polarization signal at a fourth angle, the first polarization signal comprising a first polarization, the second polarization signal comprising a second polarization, the first polarization being different from the second polarization;

a first feed line operatively coupling the first polarization signal to the element, the first feed line being associated with the first polarization;

a second feed line operatively coupling the second polarization signal to the element, the second feed line being associated with the second polarization;

a first phase shifter operatively coupled in the first feed line; and

a second phase shifter operatively coupled in the second feed line, one of the first polarization signal and the second polarization signal being cancelled at a feed point in at least one of the first feed line and the second feed line by operation of the first phase shifter, second phase shifter, first angle, second angle, third angle, and fourth angle, at least one of the first phase shifter and the second phase shifter comprising at least one of a digital phase shifter and analog phase shifter, the analog phase shifter comprising at least one length of conductor in addition to that required to couple at least one of (1) the first

feed line across the first phase shifter and (2) the second feed line across the second phase shifter using a straight conductor, the at least one length of conductor providing a phase shift, the first phase shifter providing a first 180° phase shift between the first and third angles, the second phase shifter providing a second 180° phase shift between the second and fourth angles.

2. The multi-polarized phased array antenna, as defined by Claim 1, wherein the first feed line is bent in only right angles.

3. The multi-polarized phased array antenna, as defined by Claim 1, wherein the second feed line is bent in only right angles.

4. The multi-polarized phased array antenna, as defined by Claim 1, wherein the element comprises a patch antenna.

5. The multi-polarized phased array antenna, as defined by Claim 1, wherein the first feed line at least one of transmits and receives at least one of a vertically polarized signal, horizontally polarized signal, right-hand clockwise circularly polarized signal, and left-hand counterclockwise circularly polarized signal.

6. The multi-polarized phased array antenna, as defined by Claim 1, wherein the second feed line at least one of transmits and receives at least one of a vertically polarized signal, horizontally polarized signal, right-hand clockwise circularly polarized signal, and left-hand counterclockwise circularly polarized signal.

7. The multi-polarized phased array antenna, as defined by Claim 1, wherein the first feed line is a horizontally polarized feed line, the second feed line being a vertically polarized feed line.

8. A method of increasing isolation between polarizations in a multi-polarized phased array antenna, the method comprising:

coupling an element operatively to a first polarization signal using a first feed line, the element being fed with the first polarization signal at a first angle, a second polarization signal at a second angle, the first polarization signal at a third angle, and the second polarization signal at a fourth angle, the first polarization signal comprising a first polarization, the second polarization signal comprising a second polarization, the first polarization being different from the second polarization;

coupling the element operatively to the second polarization signal using a second feed line, the first feed line being associated with the first polarization, the second feed line being associated with the second polarization ; 5
 coupling a first phase shifter operatively in the first feed line; and
 coupling a second phase shifter operatively in the second feed line, at least one of the first phase shifter and the second phase shifter comprising at least one of a digital phase shifter and an analog phase shifter, the analog phase shifter comprising at least one length of conductor in addition to that required to couple at least one of (1) the first feed line across the first phase shifter using a straight conductor 1 and (2) the second feed line across the second phase shifter using a straight conductor, the at least one length of conductor providing a phase shift, the first phase shifter providing a first 180° phase shift between (1) the first and third angles, the second phase shifter providing a second 180° phase shift between the second and fourth angles. 10
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9. The method, as defined by Claim 8, wherein the first feed line is bent in only right angles. 25
10. The method, as defined by Claim 8, wherein the second feed line is bent in only right angles. 30
11. The method, as defined by Claim 8, further comprising configuring the first feed line to at least one of transmit and receive at least one of a vertically polarized signal, horizontally polarized signal, right-hand clockwise circularly polarized signal, and left-hand counterclockwise circularly polarized signal. 35
12. The method, as defined by Claim 8, further comprising configuring the second feed line to at least one of transmit and receive at least one of a vertically polarized signal, horizontally polarized signal, right-hand clockwise circularly polarized signal, and left-hand counterclockwise circularly polarized signal. 40
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13. The method, as defined by Claim 8, further comprising:
 configuring the first feed line to be a horizontally polarized feed line; 50
 and
 configuring the second feed line to be a vertically polarized feed line. 55

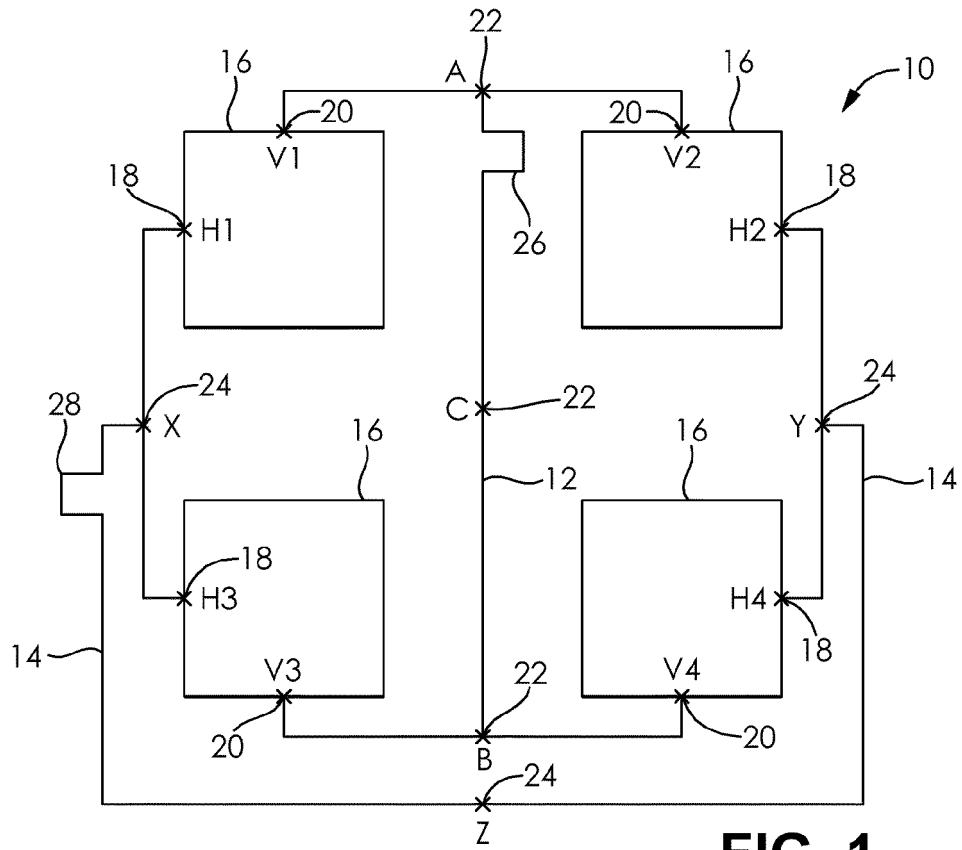


FIG. 1

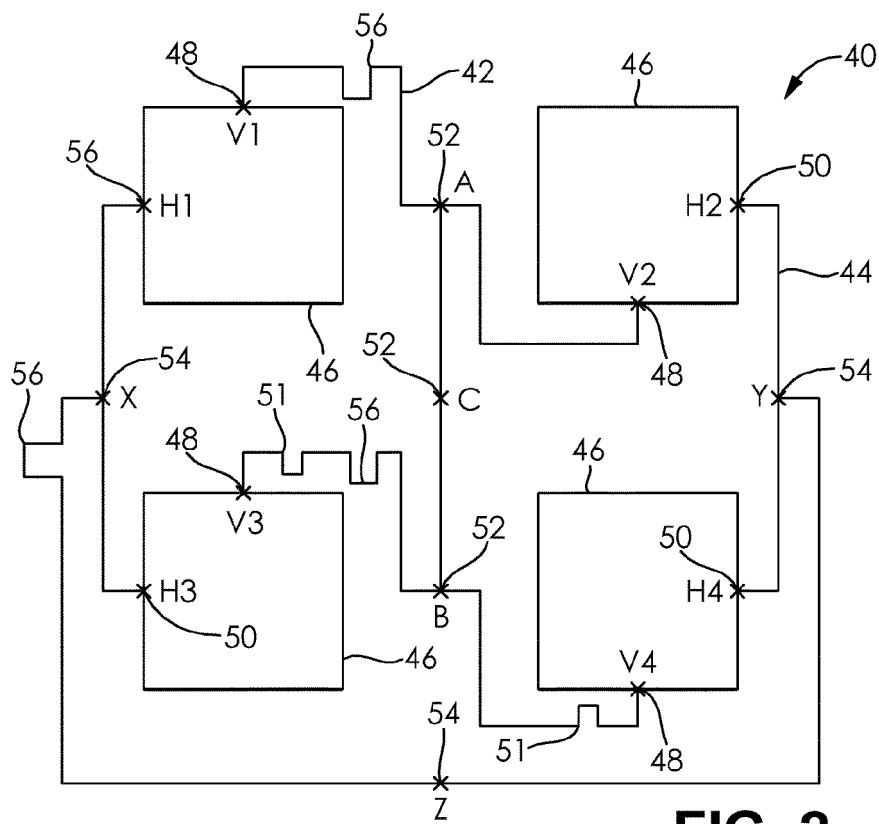


FIG. 2

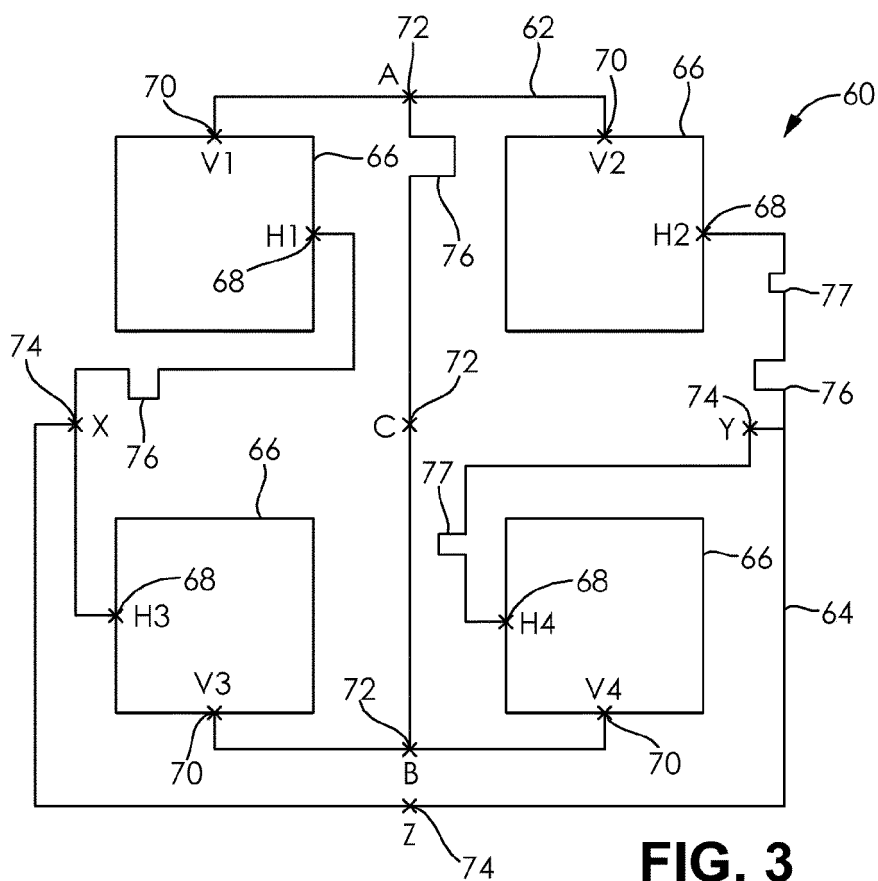


FIG. 3

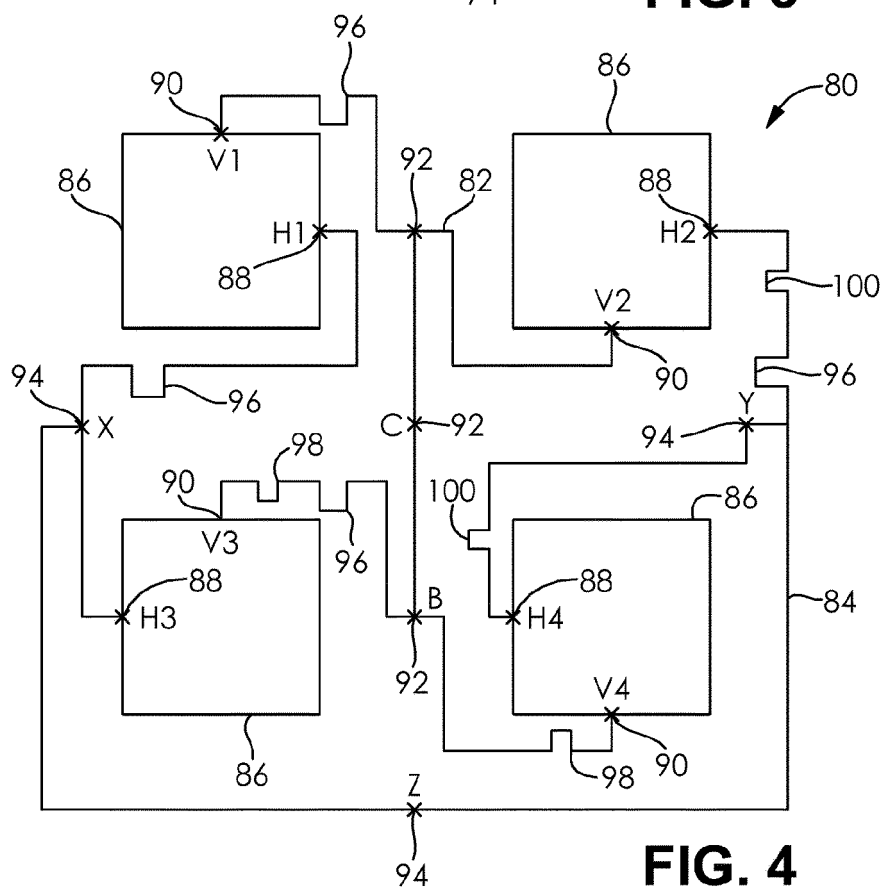


FIG. 4

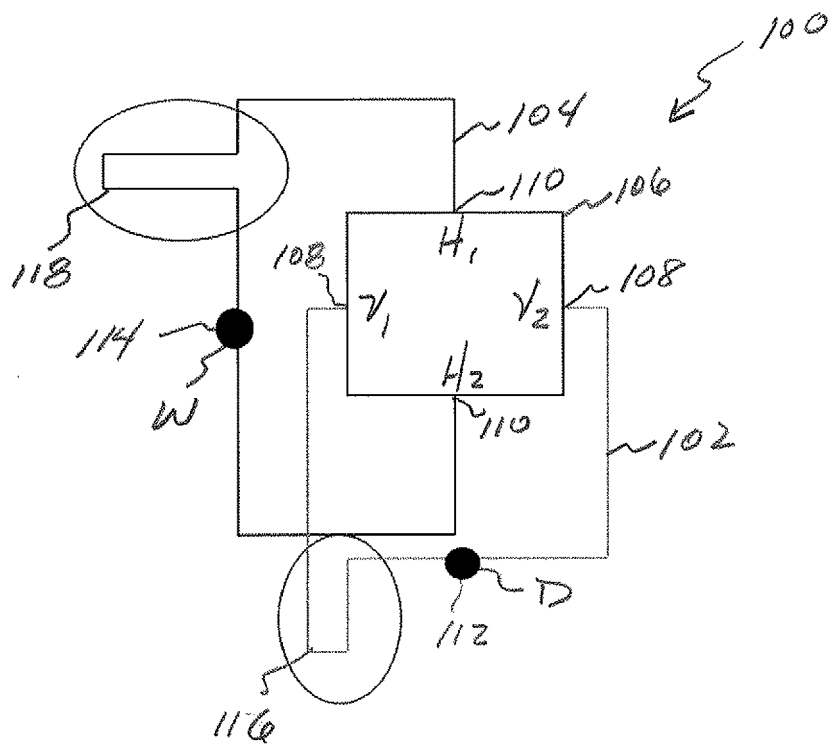


FIGURE 5



EUROPEAN SEARCH REPORT

Application Number
EP 17 17 6162

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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	US 2002/014995 A1 (ROBERTS ARTHUR GEORGE [NZ]) 7 February 2002 (2002-02-07) * figure 1 * * paragraph [0002] - paragraph [0003] * * abstract *	1-13	INV. H01Q9/04 H01Q21/06
X	US 2013/201065 A1 (PARSCHE FRANCIS EUGENE [US]) 8 August 2013 (2013-08-08) * figure 2 * * figure 4 * * paragraph [0029] * * paragraph [0046] - paragraph [0049] * * paragraph [0053] - paragraph [0054] *	1-3,5-13	
A,D	US 2013/234908 A1 (HOWARD JOHN [US] ET AL) 12 September 2013 (2013-09-12) * the whole document *	1-13	
			TECHNICAL FIELDS SEARCHED (IPC)
			H01Q
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 8 November 2017	Examiner Mitchell-Thomas, R
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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ON EUROPEAN PATENT APPLICATION NO.**

EP 17 17 6162

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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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08-11-2017

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2002014995 A1	07-02-2002	NZ 506062 A	20-12-2002
		US 2002014995 A1	07-02-2002
-----	-----	-----	-----
US 2013201065 A1	08-08-2013	US 2013201065 A1	08-08-2013
		WO 2013116170 A1	08-08-2013
-----	-----	-----	-----
US 2013234908 A1	12-09-2013	NONE	
-----	-----	-----	-----

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Patent documents cited in the description

- US 13479928 B [0001]
- US 61609619 B [0001]