

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
8 January 2009 (08.01.2009)

PCT

(10) International Publication Number  
WO 2009/005654 A1

- (51) **International Patent Classification:**  
H04B 7/185 (2006.01) H04B 7/08 (2006.01)
- (21) **International Application Number:**  
PCT/US2008/007885
- (22) **International Filing Date:** 25 June 2008 (25.06.2008)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:**  
60/947,778 3 July 2007 (03.07.2007) US  
12/145,118 24 June 2008 (24.06.2008) US
- (71) **Applicant (for all designated States except US):** ATC TECHNOLOGIES, LLC [US/US]; 10802 Parkbridge Boulevard, Reston, VA 20191-5416 (US).
- (72) **Inventor; and**
- (75) **Inventor/Applicant (for US only):** KARABINIS, Peter, D. [US/US]; 1705 Lake Shore Crest Drive, Apt #22, Reston, VA 20190 (US).

- (74) **Agent:** MYERS BIGEL SIBLEY & SAJOVEC, P.A.; P.O. Box 37428, Raleigh, NC 27627 (US).
- (81) **Designated States (unless otherwise indicated, for every kind of national protection available):** AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.
- (84) **Designated States (unless otherwise indicated, for every kind of regional protection available):** ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) **Title:** SYSTEMS AND METHODS FOR REDUCING POWER ROBBING IMPACT OF INTERFERENCE TO A SATELLITE

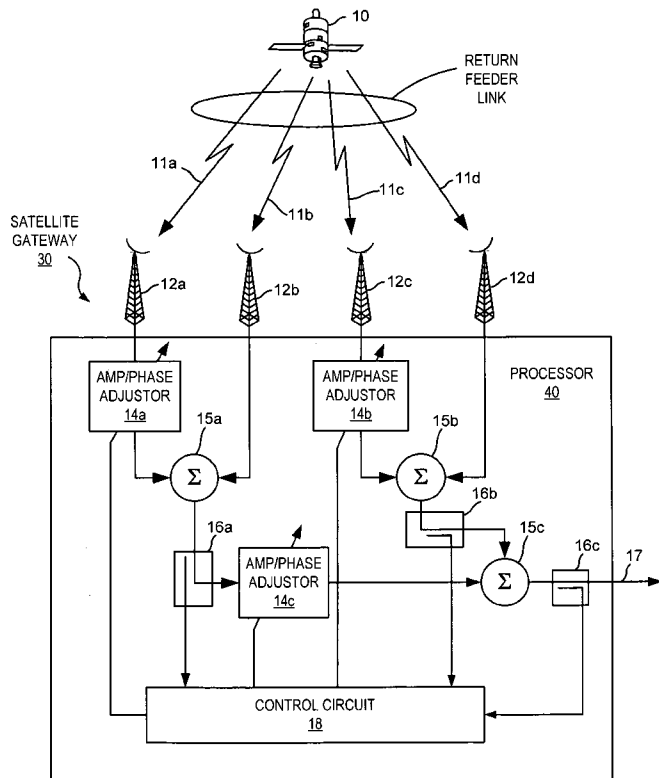


FIGURE 1

(57) **Abstract:** Processing return feeder link signals at a satellite gateway including a first and second receive antennas includes receiving first and second return feeder link signals at the first and second receive antennas, respectively, modulating a phase of the first return feeder link signal to form an adjusted first feeder link signal, combining the adjusted first feeder link signal with the second return feeder link signal to form a combined feeder link signal, detecting periodic amplitude variation in the combined feeder link signal, and shifting a phase of the first return feeder link signal to reduce periodic amplitude variation in the combined feeder link signal.

WO 2009/005654 A1



**Published:**

- *with international search report*
- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

## SYSTEMS AND METHODS FOR REDUCING POWER ROBBING IMPACT OF INTERFERENCE TO A SATELLITE

### CROSS REFERENCE TO RELATED APPLICATION

[0001] The present application claims the benefit of and priority to U.S. Provisional Patent Application No. 60/947,778, filed July 3, 2007, entitled "Systems And Methods For Reducing Power Robbing Impact Of Interference To A Satellite," the disclosure of which is hereby incorporated herein by reference in its entirety.

### FIELD OF THE INVENTION

[0002] This invention relates to wireless communications systems, methods and components thereof and more particularly to satellite wireless communications systems, methods and components thereof.

### BACKGROUND

[0003] Satellite radioterminal communications systems and methods are widely used for radioterminal communications. Satellite radioterminal communications systems and methods generally employ at least one space-based component, such as one or more satellites, that is/are configured to wirelessly communicate with a plurality of satellite radioterminals.

[0004] A satellite radioterminal communications system or method may utilize a single satellite antenna pattern (beam or cell) covering an entire service region served by the system. Alternatively or in combination with the above, in cellular satellite radioterminal communications systems and methods, multiple satellite antenna patterns (beams or cells) are provided, each of which can serve a substantially distinct service region in an overall service region, to collectively provide service to the overall service region. Thus, a cellular architecture that is similar to that used in conventional terrestrial cellular radioterminal systems and methods can be implemented in cellular satellite-based systems and methods. The satellite typically communicates with radioterminals over a bidirectional communications pathway, with radioterminal communications signals being communicated from the satellite to the radioterminal over a downlink or forward link (also referred to as forward service link), and from the radioterminal to the satellite over an uplink or return link

(also referred to as return service link). In some cases, such as, for example, in broadcasting, the satellite may communicate information to one or more radioterminals unidirectionally.

**[0005]** The overall design and operation of cellular satellite radioterminal systems and methods are well known to those having skill in the art, and need not be described further herein. Moreover, as used herein, the term "radioterminal" includes cellular and/or satellite radiotelephones with or without a multi-line display; Personal Communications System (PCS) terminals that may combine a radioterminal with data processing, facsimile and/or data communications capabilities; Personal Digital Assistants (PDA) that can include a radio frequency transceiver and/or a pager, Internet/Intranet access, Web browser, organizer, calendar and/or a global positioning system (GPS) receiver; and/or conventional laptop and/or palmtop computers or other appliances, which include a radio frequency transceiver. A radioterminal also may be referred to herein as a "radiotelephone," a "mobile terminal," a "user device," a "wireless transmitter," a "wireless receiver," a "transceiver" or simply as a "terminal". As used herein, the term(s) "radioterminal," "radiotelephone," "mobile terminal," "user device," "wireless transmitter," "wireless receiver," "transceiver" and/or "terminal" also include(s) any other radiating user device, equipment and/or source that may have time-varying or fixed geographic coordinates and/or may be portable, transportable, installed in a vehicle (aeronautical, maritime, or land-based) and/or situated and/or configured to operate locally and/or in a distributed fashion over one or more terrestrial and/or extra-terrestrial location(s). Furthermore, as used herein, the term "space-based component" or "space-based system" includes one or more satellites at any orbit (geostationary, substantially geostationary, medium earth orbit, low earth orbit, etc.) and/or one or more other objects and/or platforms (e. g., airplanes, balloons, unmanned vehicles, space crafts, missiles, etc.) that has/have a trajectory above the earth at any altitude.

**[0006]** The above description has focused on communications between the satellite and the radioterminals. However, cellular satellite communications systems and methods also generally employ a bidirectional feeder link for communications between one or more satellite gateway(s) and the satellite(s). The bidirectional feeder link includes a forward feeder link from the gateway(s) to the satellite(s) and a return feeder link from the satellite(s) to the gateway(s). The forward feeder link and the return feeder link each uses one or more carriers.

**[0007]** A satellite generally includes at least one feeder link amplifier that is used to amplify a return feeder link signal prior to transmitting the return feeder link signal from the satellite to the satellite gateway(s). The satellite may also inadvertently receive a level of

interference, over its return service links, from emissions of one or more terrestrial networks and/or satellite terminals of other operators (e.g., Inmarsat), and the satellite may not be configured to separate and/or discard the level of interference. Thus, the satellite may inadvertently form a return feeder link signal that includes at least some of the level of interference as well as one or more desired signals.

[0008] The feeder link amplifier may be operatively configured to not exceed a maximum level of output power in order to, for example, maintain a desired level of linearity. As such, as the level of interference increases, an amount of amplification applied to a desired signal may be reduced. This reduction is referred to as "power robbing."

[0009] Power robbing may be reduced by increasing a capability (e.g., size) of the feeder link amplifier to accommodate a desired level of amplification of one or more desired signals along with the level of interference while maintaining a desired level of linearity. Unfortunately, an increased capability amplifier (e.g., a larger amplifier) may undesirably increase cost, power consumption and/or weight of a satellite. Power robbing also may be decreased by increasing an aperture of the satellite's feeder link antenna(s). However, increasing the aperture of the satellite's feeder link antenna(s) may also undesirably increase the size, cost and/or weight of the satellite.

## SUMMARY

[0010] Some embodiments provide methods of processing return feeder link signals at a satellite gateway including a plurality of spatially diverse receive antennas. The methods include receiving respective return feeder link signals at each of the plurality of receive antennas, and selectively adjusting amplitudes and/or phases of a plurality of the return feeder link signals received at the plurality of receive antennas in response to amplitude/phase adjustment settings to provide a plurality of adjusted return feeder link signals. The plurality of adjusted feeder link signals are combined to generate a combined return feeder link signal, and periodic amplitude variation in the combined return feeder link signal is detected. The amplitude/phase adjustment settings are configured in response to the combined return feeder link signal to reduce periodic amplitude variation in the combined return feeder link signal.

[0011] Configuring the amplitude/phase adjustment settings may include providing non-periodic phase adjustment signals to a plurality of amplitude/phase adjustors that process the plurality of return feeder link signals.

[0012] Selectively adjusting amplitudes and/or phases of the return feeder link signals may include adjusting the amplitude/phase of a first one of the return feeder link signals at a

first adjustment frequency and adjusting the amplitude/phase of a second one of the return feeder link signals at a second adjustment frequency that is different from the first adjustment frequency. The first adjustment frequency may be 10 Hz and the second adjustment frequency may be 50 Hz.

[0013] The methods may further include adjusting amplitudes/phases of the first and second return feeder link signals using respective first and second periodic functions that are in phase quadrature therebetween. The first and second periodic functions may include sinusoidal functions.

[0014] The plurality of receive antennas may include four antennas, and the methods may further include receiving first, second, third and fourth return feeder link signals at respective ones of the plurality of receive antennas, selectively adjusting amplitudes and/or phases of the first and second return feeder link signals received at the first and second receive antennas to generate respective first and second adjusted feeder link signals, combining the first adjusted feeder link signal and the third return feeder link signal to generate a first intermediate combined signal, combining the second adjusted feeder link signal and the fourth return feeder link signal to generate a second intermediate combined signal, and combining the first intermediate combined signal and the second intermediate combined signal to generate the combined return feeder link signal.

[0015] The methods may further include adjusting an amplitude and/or phase of the first intermediate combined signal to generate an adjusted intermediate combined signal, and combining the first intermediate combined signal and the second intermediate combined signal may include combining the adjusted intermediate combined signal and the second intermediate combined signal.

[0016] The plurality of receive antennas may include four antennas, and the methods may further include receiving first, second, third and fourth return feeder link signals at respective ones of the plurality of receive antennas, selectively adjusting amplitudes and/or phases of the first, second and third return feeder link signals received at the first, second and third receive antennas to generate respective first, second and third adjusted feeder link signals, and combining the first, second and third adjusted feeder link signals and the fourth return feeder link signal to generate the combined return feeder link signal.

[0017] Combining the plurality of adjusted feeder link signals to generate a combined return feeder link signal may include RF combining the signals. In some embodiments, the methods may further include converting the feeder link signals to an intermediate frequency, and combining the plurality of adjusted feeder link signals to generate a combined return

feeder link signal may include combining intermediate frequency signals. In some embodiments, the methods may further include converting the combined return feeder link signal to baseband, and combining the baseband combined return feeder link signal with another baseband signal.

**[0018]** A satellite gateway according to some embodiments includes a plurality of receive antennas, and a processor coupled to the plurality of receive antennas and configured to receive respective return feeder link signals from each of the plurality of receive antennas. The processor is further configured to selectively adjust amplitudes and/or phases of a plurality of the return feeder link signals received at the plurality of receive antennas in response to amplitude/phase adjustment settings to provide a plurality of adjusted return feeder link signals, and to combine the plurality of adjusted feeder link signals to generate a combined return feeder link signal.

**[0019]** The processor may include a control circuit configured to detect periodic amplitude variation in the combined return feeder link signal, and to configure the amplitude/phase adjustment settings in response to periodic amplitude variation in the combined return feeder link signal to reduce periodic amplitude variation in the combined return feeder link signal.

**[0020]** The control circuit may be configured to provide non-periodic phase adjustment signals to a plurality of amplitude/phase adjustors that process the plurality of return feeder link signals.

**[0021]** The processor may include a first amplitude/phase adjustor that is configured to selectively adjust the amplitude/phase of a first one of the return feeder link signals at a first adjustment frequency and a second amplitude/phase adjustor that is configured to selectively adjust the amplitude/phase of a second one of the return feeder link signals at a second adjustment frequency that is different from the first adjustment frequency.

**[0022]** The first amplitude/phase adjustor and the second amplitude/phase adjustor may adjust amplitudes/phases of the first and second return feeder link signals using respective first and second periodic functions that are in phase quadrature therebetween. The first and second periodic functions include sinusoidal functions.

**[0023]** The plurality of receive antennas may include four antennas, and the processor may further include a first amplitude/phase adjustor configured to selectively adjust amplitude/phase of a first return feeder link signal, a second amplitude/phase adjustor configured to selectively adjust amplitude/phase of a second return feeder link signal, a first combiner configured to combine the first return feeder link signal and a third return feeder

link signal to form a first intermediate combined signal, a second combiner configured to combine the second return feeder link signal and a fourth return feeder link signal to form a second intermediate combined signal, and a third combiner configured to combine the first intermediate combined signal and the second intermediate combined signal to generate a combined return feeder link signal.

[0024] The processor may further include a third amplitude/phase adjustor configured to selectively adjust amplitude/phase of the first intermediate combined signal to generate an adjusted intermediate combined signal. The third combiner may be configured to combine the adjusted intermediate combined signal and the second intermediate combined signal.

[0025] The plurality of receive antennas may include four antennas, and the processor may further include a first amplitude/phase adjustor configured to selectively adjust amplitude/phase of a first return feeder link signal, a second amplitude/phase adjustor configured to selectively adjust amplitude/phase of a second return feeder link signal, a third amplitude/phase adjustor configured to selectively adjust amplitude/phase of a third return feeder link signal, and a combiner configured to combine the first return feeder link signal, the second return feeder link signal, the third return feeder link signal and a fourth return feeder link signal to form the combined return feeder link signal.

[0026] Methods of processing return feeder link signals at a satellite gateway including a first and second receive antennas according to further embodiments include receiving first and second return feeder link signals at the first and second receive antennas, respectively, modulating a phase of the first return feeder link signal to form an adjusted first feeder link signal, combining the adjusted first feeder link signal with the second return feeder link signal to form a combined feeder link signal, detecting periodic amplitude variation in the combined feeder link signal, and shifting a phase of the first return feeder link signal to reduce periodic amplitude variation in the combined feeder link signal.

[0027] The methods may further include receiving third and fourth return feeder link signals at respective third and fourth receive antennas, modulating a phase of the third return feeder link signal to form an adjusted third feeder link signal, combining the adjusted third feeder link signal with the fourth return feeder link signal to form a second combined feeder link signal, detecting periodic amplitude variation in the second combined feeder link signal, and shifting a phase of the third return feeder link signal to reduce periodic amplitude variation in the second combined feeder link signal.

[0028] The methods may further include modulating a phase of the combined feeder link signal to form an adjusted combined feeder link signal, combining the adjusted combined



feeder link signal with the second combined feeder link signal to form a third combined feeder link signal, detecting periodic amplitude variation in the third combined feeder link signal, and shifting a phase of the combined feeder link signal to reduce periodic amplitude variation in the third combined feeder link signal.

[0029] In some embodiments, the methods may further include receiving third and fourth return feeder link signals at respective third and fourth receive antennas, and modulating phases of the third and fourth return feeder link signals to form an adjusted third feeder link signal and an adjusted fourth feeder link signal. Combining the adjusted first feeder link signal with the second return feeder link signal to form the combined feeder link signal may include combining the adjusted first feeder link signal, the second return feeder link signal, the adjusted third feeder link signal and the adjusted fourth feeder link signal to form the combined feeder link signal.

[0030] A satellite gateway according to further embodiments includes a processor configured to receive first and second return feeder link signals from first and second receive antennas, respectively, a phase modulator configured to modulate a phase of the first return feeder link signal, a phase shifter configured to shift a phase of the first return feeder link signal by a phase delay, a combiner configured to combine the first return feeder link signal with the second return feeder link signal to form a combined feeder link signal, a power detector configured to detect periodic amplitude variation in the combined feeder link signal, and a feedback loop from the power detector to the phase shifter configured to adjust the phase delay to reduce periodic amplitude variation in the combined feeder link signal.

[0031] The processor may be further configured to receive third and fourth return feeder link signals from respective third and fourth receive antennas, and the processor may further include a second phase modulator configured to modulate a phase of the third return feeder link signal, a second phase shifter configured to shift a phase of the third return feeder link signal by a second phase delay, a second combiner configured to combine the third return feeder link signal with the fourth return feeder link signal to form a second combined feeder link signal, a second power detector configured to detect periodic amplitude variation in the second combined feeder link signal, and a second feedback loop from the second power detector to the second phase shifter configured to adjust the second phase delay to reduce periodic amplitude variation in the second combined feeder link signal.

[0032] The satellite gateway may further include a third phase modulator configured to modulate a phase of the combined feeder link signal, a third phase shifter configured to shift a phase of the combined feeder link signal by a third phase delay, a third combiner

configured to combine the combined feeder link signal with the second combined feeder link signal to form a third combined feeder link signal, a third power detector configured to detect periodic amplitude variation in the third combined feeder link signal, and a third feedback loop from the third power detector to the third phase shifter configured to adjust the third phase delay to reduce periodic amplitude variation in the third combined feeder link signal.

[0033] The processor may be further configured to receive third and fourth return feeder link signals from respective third and fourth receive antennas, and the processor may further include a second phase modulator configured to modulate a phase of the third return feeder link signal, a second phase shifter configured to shift a phase of the third return feeder link signal by a second phase delay, a third phase modulator configured to modulate a phase of the fourth return feeder link signal, and a third phase shifter configured to shift a phase of the fourth return feeder link signal by a third phase delay. The combiner may be configured to combine the first, second, third and fourth return feeder link signals to form the combined feeder link signal.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0034] The accompanying drawings, which are included to provide a further understanding of the invention and are incorporated in and constitute a part of this application, illustrate certain embodiment(s) of the invention. In the drawings:

[0035] Figures 1, 2, 3, 4, 5A and 5B are block diagrams illustrating systems/methods according to some embodiments.

[0036] Figures 6A, 6B and 6C are graphs illustrating phase modulation according to some embodiments.

[0037] Figures 7 and 8 are flowcharts illustrating systems/methods according to some embodiments.

#### DETAILED DESCRIPTION

[0038] Specific embodiments of the invention now will be described with reference to the accompanying drawings. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. It will be understood that when an element is referred to as being "connected", "coupled" or "responsive" to another element, it can be directly connected, coupled or responsive to the other element or

intervening elements may be present. Furthermore, "connected", "coupled" or "responsive" as used herein may include wirelessly connected, coupled or responsive.

**[0039]** The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless expressly stated otherwise. It will be further understood that the terms "includes," "comprises," "including" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

**[0040]** Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and the present disclosure, and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

**[0041]** It will be understood that although the terms first and second are used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another element. Thus, a first element below could be termed a second element, and similarly, a second element may be termed a first element without departing from the teachings of the present invention. As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items. The symbol "/" is also used as a shorthand notation for "and/or".

**[0042]** Embodiments of the present invention will be described herein in connection with potential interference that may be caused by components of a first wireless communications system (e.g., a first satellite radioterminal communications system and/or a first terrestrial wireless communications system) to components of the first and/or a second wireless communications system (e.g., the first and/or a second satellite radioterminal communications system), and solutions to reduce or eliminate this potential interference. In some embodiments, the first satellite radioterminal communications system may be a satellite radioterminal communications system that is operated by Mobile Satellite Ventures, LP ("MSV") and the second satellite radioterminal communications system may be an Inmarsat system. However, other first and second radioterminal communications systems may be

provided according to other embodiments of the present invention. It will be understood that two or more embodiments of the present invention as presented herein may be combined in whole or in part to form one or more additional embodiments.

**[0043]** Figure 1 illustrates systems and/or methods for reducing a power robbing effect of interference that may be experienced on a return feeder link by a satellite system including one or more satellites 10. As shown in Figure 1, a satellite gateway 30 is configured with a plurality of feeder link antennas 12a-12d. Each one of the feeder link antennas 12a-12d of the satellite gateway 30 is configured to receive a respective return feeder link signal 11a-11d and to provide the respective return feeder link signal 11a-11d to a processor 40. The processor 40 may include general purpose and/or special purpose hardware and/or software and may be centralized or distributed. Furthermore, the antennas 12a-12d may be located near or remote from the processing hardware of the satellite gateway 30.

**[0044]** The processor 40 is configured to selectively adjust, in amplitude and/or phase, one or more of the return feeder link signals that are provided to the processor 40 by the respective feeder link antennas 12a-12d and, following the selective adjustment(s), to combine the feeder link signals, using one or more summing nodes 15a-c, to form a combined feeder link signal 17. The selective adjustment(s) in amplitude and/or phase provided by processor 40 using amplitude/phase adjustors 14a, 14b and 14c may, according to some embodiments, be phase adjustments wherein a phase adjustment may include a periodic phase adjustment and a non-periodic phase adjustment, as described in Karabinis "*Maximum-Power and Amplitude-Equalizing Algorithms for Phase Control in Space Diversity Combining*," The Bell System Technical Journal, January 1983, Vol. 62, No. 1, Part 1 (pages 63-89), referred to as the "BSTJ Article," which is incorporated herein by reference.

**[0045]** The techniques described in the BSTJ Article were developed, and have been used, to combat multipath fading in wireless communications systems. Multipath fading occurs most often in non-line of sight communications systems, and arises from the fact that a transmitted signal can follow more than one path to the receiver, due to reflections from man-made features, such as buildings, bridges, etc., and/or natural environmental features, such as hills, mountains, trees, etc. Multipath fading is sometimes referred to as Rayleigh fading. Rayleigh fading with a strong line of sight component is said to be Rician fading.

**[0046]** Each path from the transmitter to the receiver can have a different path length, resulting in different propagation delays/phase shifts for signals propagated over different paths. Signals received over various paths can therefore combine destructively at the

receiver, potentially resulting in a severe loss of signal strength at the receiver. Multipath fading can be a particular problem when the receiver is mobile, as the various propagation paths can change dynamically.

[0047] However, multipath fading is not typically a concern for satellite feeder link signals, because the satellite feeder link signal is transmitted over a relatively narrow line of sight beam in which both the satellite and the gateway (or ground station) employ highly directional antennas. That is, satellite feeder link signals are generally characterized by having a single main path directly between the satellite and the gateway. Ancillary paths are generally either nonexistent or not significant. Accordingly, techniques such as those described in the BSTJ Article that are designed to address multipath fading have not been used to process return feeder link signals in satellite gateways.

[0048] The feeder link signal is subject to rain fading, however. Rain fading occurs when there is heavy rainfall over the gateway, which attenuates the feeder link signal and makes demodulation of the signal difficult or impossible. System operators have attempted to address rain fading by using feeder link space diversity switching. In feeder link space diversity switching, at least first and second spatially distant feeder link antennas are used to provide respective first and second feeder link signals to a satellite gateway. However, the first and second feeder link signals are generally not combined. Instead, either the first or the second signal is chosen for demodulation, depending on a signal strength threshold/criterion, and the selected signal is provided to the satellite gateway for further processing and demodulation. In feeder link diversity switching, the first and second feeder link antennas are typically spaced far enough apart that it is statistically unlikely that a significant rain event will occur at the same time in both places. This typically leads to the antennas being placed hundreds of miles apart.

[0049] In contrast, some embodiments provide a satellite feeder link receiver that employs antennas that can be located relatively close together (i.e., much closer together than is required for space diversity switching) and combines the signals received at the antennas to combat not multipath fading, but the effects of power robbing at the satellite.

[0050] Continuing the discussion of Figure 1, three amplitude/phase adjustors 14a-14c are shown, compared to the single amplitude/phase adjustor shown in the BSTJ Article, wherein only two antennas are used. Each one of the amplitude/phase adjustors 14a-14c may be configured to adjust using a different adjustment frequency. A frequency associated with an adjustment performed by amplitude/phase adjustor 14a may, for example, be at a rate of 10 Hz, whereas frequencies associated with adjustments performed by amplitude/phase

adjustors 14b and 14c may, for example, be at rates 50 Hz and 30 Hz, respectively. In some embodiments, first and second amplitude/phase adjustors such as, for example, amplitude/phase adjustors 14a and 14b respectively, may be configured to provide respective first and second periodic phase adjustments, at respective first and second frequencies, using respective first and second periodic functions that are in phase quadrature therebetween. In some embodiments, the first and second periodic functions may be sinusoidal functions or approximately sinusoidal functions. In some embodiments, the first frequency may be equal or approximately equal to the second frequency.

[0051] The control circuit 18 is configured to detect, via signal couplers 16a, 16b and 16c, periodic amplitude variations corresponding to respective periodic phase variations that are imposed on respective combined signals by respective amplitude/phase adjustors 14a, 14b and 14c. The control circuit 18 is also configured to reduce, and in some embodiments, minimize, the detected periodic amplitude variations by providing respective non-periodic phase adjustment signals to the respective amplitude/phase adjustors 14a, 14b and 14c. As is shown in the BSTJ Article, when two signals are combined in substantial phase alignment to form a combined signal, thus maximizing received signal power, an amplitude variation in the combined signal due to a phase variation in one of the two signals is reduced and/or minimized.

[0052] In the architecture of Figure 1, the frequency of the periodic phase adjustment at the amplitude/phase adjustor 14a may be the same or different to that of the amplitude/phase adjustor 14b. However, the frequency of the periodic phase adjustment at the amplitude/phase adjustor 14c may differ from that of both the amplitude/phase adjustor 14a and the amplitude/phase adjustor 14b so that the control circuit 18 can un-ambiguously detect the amplitude variation resulting from the phase variation imposed at the amplitude/phase adjustor 14c, and can disregard any residual amplitude variation due to phase variations at the amplitude/phase adjustor 14a and/or the amplitude/phase adjustor 14b when doing so.

[0053] First and second return feeder link signals are received by the antennas 12a and 12b, respectively. The first return feeder link signal received by the antenna 12a is adjusted by the amplitude/phase adjustor 14a using periodic and non-periodic phase adjustment signals based on settings provided by the control circuit 18. The adjusted first return feeder link signal is then combined at a first summing node 15a with the second return feeder link signal to form a first intermediate combined signal. The amplitude/phase adjustor 14a adjusts a phase of the first return feeder link signal in response to a detected amplitude

variation in the first intermediate combined signal in an attempt to increase or maximize the received signal power of the first intermediate combined signal.

[0054] Third and fourth return feeder link signals are received by the antennas 12c and 12d, respectively. The third return feeder link signal received by the antenna 12c is adjusted by the amplitude/phase adjustor 14b using periodic and non-periodic phase adjustment signals based on settings provided by the control circuit 18. The adjusted third return feeder link signal is then combined at a second summing node 15b with the fourth return feeder link signal to form a second intermediate combined signal. The amplitude/phase adjustor 14b adjusts a phase of the third return feeder link signal in response to a detected amplitude variation in the second intermediate combined signal in an attempt to increase or maximize the received signal power of the second intermediate combined signal.

[0055] The phase of the first intermediate combined signal is adjusted by a third amplitude/phase adjustor 14c, and the phase-adjusted first intermediate combined signal is combined at a third summing node 15c with the second intermediate combined signal to form a combined output signal 17. The amplitude/phase adjustor 14c adjusts a phase of the first intermediate combined signal in response to a detected amplitude variation in the combined output signal in an attempt to increase or maximize the received signal power of the combined output signal. The combined output signal can then be further processed by the processor 40. For example, the combined output signal can be demodulated and the information therein can be detected.

[0056] It will be understood that at least some of the feeder link antennas 12a-12d illustrated in Figure 1 may be co-located, substantially co-located or spaced apart therebetween. The feeder link antennas 12a-12d can be located much closer together than antennas used for space diversity switching. For example, the feeder link antennas 12a-12d can be less than 1 km apart, and in some embodiments less than 100 m apart.

[0057] It will also be understood that the systems/methods illustrated in Figure 1 are not limited to four antennas but fewer or more than four antennas may be used and that the antennas used may be identical, substantially identical or different therebetween. Using four identical or substantially identical antennas 12a-12d (each including identical or substantially identical front-end circuitry) can yield a 6 dB (or approximately a 6 dB) increase in signal-to-noise ratio at output signal 17 compared to signal 17 having been derived from a system using only one antenna (e.g., only antenna 12a). Accordingly, the power robbing effect of interference may be reduced by 6 dB (or approximately by 6 dB).

**[0058]** Figure 2 illustrates an alternate configuration of systems/methods for reducing or eliminating the power robbing effect of interference. The principles remain as described above relative to Figure 1. However, the amplitude/phase adjustors 14a-14c are arranged differently and only a single summing node 15 and a single signal coupler 16 need be used. In particular, three of the four received signals are adjusted by the amplitude/phase adjustors 14a-14c based on respective amplitude/phase adjustment settings in response to detected periodic amplitude variation in the combined signal output by the summing node 15. The amplitudes/phases of the three received signals are adjusted to increase the signal power of the combined signal output by the summing node 15. Many other variations will be apparent to those having skill in the art.

**[0059]** In the architecture of Figure 2, given that a detection of amplitude variation occurs at a common point in the control circuit 18 in response to a signal received from the signal coupler 16, phase variations of different frequencies may be imposed at the amplitude/phase adjustors 14a, 14b and 14c in order to enable the signal coupler 16 and the control circuit 18 to un-ambiguously detect the respective amplitude variations and to adjust each one individually by imposing appropriate (non-periodic) phase adjustments at the amplitude/phase adjustors 14a, 14b and 14c.

**[0060]** Figure 3 illustrates a combiner configured to perform periodic phase adjustment and non-periodic phase adjustment of a diversity signal received using two antennas. As shown therein, a continuous combiner 100 (analogous to the processor 40 of the embodiments of Figures 1 and 2) receives input signals from a main antenna 102 and a diversity antenna 104. The signal received over the diversity antenna 104 is subjected to a fixed delay 106 that equalizes the electrical path length leading to the inputs of the combiner 100.

**[0061]** The signal received via the main antenna 102 is fed into a summing node 114 and is added to an adjusted version of the signal received over the diversity antenna 104 to produce a combined output signal 124. In particular, the signal received over the diversity antenna 104 is adjusted by an amplitude/phase adjustor 115 including at least a phase modulator 108 and a phase shifter 110. The phase modulator 108 provides the periodic phase adjustment described above, while the phase shifter 110 provides the non-periodic phase adjustment discussed above. In the frequency domain, the phase modulator multiplies the received diversity signal by a term having a sinusoidal phase, e.g.,  $e^{j\alpha\sin\omega t}$ , while the phase shifter multiplies the received signal by a term having a fixed phase delay, e.g.,  $e^{j\theta}$ .



[0062] A low frequency oscillator 112 provides a low-frequency sinusoidal signal at a frequency  $\omega_m$  that is used by the phase modulator 108 to modulate the phase of the diversity signal. A power detector 118 receives the output signal via a signal coupler 116, and responsively outputs a power detection signal. It will be appreciated that in a communication signal, power is related to the amplitude of the signal. Thus, the power detection signal provides a measure of the amplitude of the combined signal. The power detection signal is passed through a high pass filter (such as a capacitor) 119 and is mixed with the low-frequency sinusoid output by the low-frequency oscillator 112, and the result is filtered with a loop filter 122. The loop filter 122 can include a low-pass filter, an integrator and an amplifier. The output of the loop filter 122 controls the phase shifter 110 to vary the non-periodic phase adjustment by the phase shifter 110 until periodic amplitude variation in the combined signal in response to the periodic phase adjustment is minimized or otherwise reduced to a desired level.

[0063] In some embodiments, the phase of the received diversity signal is dynamically adjusted so as to always maintain a desired relationship with respect to the main antenna signal phase at the summing node 114. For the purpose of generating a phase-control signal, the phase of the diversity antenna signal is perturbed sinusoidally, resulting in a periodic modulation of the power of the combined signal 124. The fundamental component of the combined signal power modulation is detected by the power detector 118 and used in a feedback arrangement to control the phase delay  $\theta$  of the phase shifter 110. Depending on the phase control algorithm used, the phase correction can be chosen to attempt to maximize the average combined signal power or to minimize the dispersion of the combined signal.

[0064] Figure 4 illustrates a combiner 100A configured to perform periodic phase adjustment and non-periodic phase adjustment of a diversity signal received using four antennas, as illustrated in Figure 1. Referring to Figure 4, a continuous combiner 100A (analogous to the processor 40 of the embodiments of Figure 1) receives input signals from four antennas 102A to 102D. Although not illustrated in Figure 4, the signals received over one or more of the antennas 102A to 102D can be subjected to a fixed delay that equalizes the electrical path length leading to the inputs of the combiner 100A.

[0065] The first input signal received over the first antenna 102A is adjusted by a first amplitude/phase adjustor 115A including at least a first phase modulator 108A and a first phase shifter 110A. The first amplitude/phase adjustor 115A adjusts the first input signal and outputs an adjusted signal.

[0066] A first low frequency oscillator 112A provides a low-frequency sinusoidal signal at a first adjustment frequency  $\omega_{m1}$  that is used by the first phase modulator 108A to modulate the phase of the input signal. The first adjustment frequency  $\omega_{m1}$  may be, for example, 10 Hz.

[0067] The second input signal received via the second antenna 102B is fed into a first summing node 114A, where it is added to the adjusted signal output by the first amplitude/phase adjustor 115A to generate a first intermediate output signal.

[0068] A first power detector 118A receives the first intermediate output signal via a first signal coupler 116A, and responsively outputs a power detection signal. The power detection signal is passed through a first high pass filter (such as a capacitor) 119A and is mixed with the low-frequency sinusoid output by the first low-frequency oscillator 112A, and the result is filtered with a first loop filter 122A, the output of which controls the first phase shifter 110A to vary the non-periodic phase adjustment by the first phase shifter 110A until periodic amplitude variation in the first intermediate output signal in response to the periodic phase adjustment is minimized or otherwise reduced to a desired level.

[0069] The third input signal received over the third antenna 102C is adjusted by a second amplitude/phase adjustor 115B including at least a second phase modulator 108B and a second phase shifter 110B. The second amplitude/phase adjustor 115B adjusts the third input signal and outputs an adjusted signal.

[0070] A second low frequency oscillator 112B provides a low-frequency sinusoidal signal at a frequency  $\omega_{m2}$  that is used by the second phase modulator 108A to modulate the phase of the input signal. The second adjustment frequency  $\omega_{m2}$  may be the same frequency as the first adjustment frequency  $\omega_{m1}$ , for example, 10 Hz. In some embodiments, the second adjustment frequency  $\omega_{m2}$  may be different from the first adjustment frequency  $\omega_{m1}$ .

[0071] The fourth input signal received via the fourth antenna 102D is fed into a second summing node 114B, where it is added to the adjusted signal output by the second amplitude/phase adjustor 115B to generate a second intermediate output signal.

[0072] A second power detector 118B receives the second intermediate output signal via a second signal coupler 116B, and responsively outputs a power detection signal. The power detection signal is passed through a second high pass filter (such as a capacitor) 119B and is mixed with the low-frequency sinusoid output by the second low-frequency oscillator 112B, and the result is filtered with a second loop filter 122B, the output of which controls the second phase shifter 110B to vary the non-periodic phase adjustment by the phase shifter

110B until periodic amplitude variation in the second intermediate output signal in response to the periodic phase adjustment is minimized or otherwise reduced to a desired level.

[0073] The first intermediate output signal output by the first summing node 114A is adjusted by a third amplitude/phase adjustor 115C including at least a third phase modulator 108C and a third phase shifter 110C.

[0074] A third low frequency oscillator 112C provides a low-frequency sinusoidal signal at a third adjustment frequency  $\omega_{m3}$  that is used by the third phase modulator 108C to modulate the phase of the signal. The third adjustment frequency  $\omega_{m3}$  may be a different frequency from the first and second adjustment frequencies  $\omega_{m1}$  and  $\omega_{m1}$ , and may be, for example, 100 Hz.

[0075] The second intermediate output signal output by the second summing node 114B is fed into a third summing node 114C, where it is added to the signal output by the third amplitude/phase adjustor 115C to generate a combined output signal 124.

[0076] A third power detector 118C receives the combined output signal 124 via a third signal coupler 116C, and responsively outputs a power detection signal. The power detection signal is passed through a third high pass filter (such as a capacitor) 119C and is mixed with the low-frequency sinusoid output by the third low-frequency oscillator 112C, and the result is filtered with a third loop filter 122C, the output of which controls the third phase shifter 110C to vary the non-periodic phase adjustment by the third phase shifter 110C until periodic amplitude variation in the combined output signal 124 in response to the periodic phase adjustment is minimized or otherwise reduced to a desired level.

[0077] Figure 5A illustrates a combiner 100B according to some embodiments configured to perform periodic phase adjustment and non-periodic phase adjustment of a diversity signal received using four antennas, as illustrated in Figure 2. Referring to Figure 5A, a continuous combiner 100B (analogous to the processor 40 of the embodiments of Figure 2) receives input signals from four antennas 102A to 102D. Although not illustrated in Figure 4, the signals received over one or more of the antennas 102A to 102D can be subjected to a fixed delay that equalizes the electrical path length leading to the inputs of the combiner 100A.

[0078] The first input signal received over the first antenna 102A is adjusted by a first amplitude/phase adjustor 115A including at least a first phase modulator 108A and a first phase shifter 110A. The first amplitude/phase adjustor 115A adjusts the first input signal and outputs an adjusted signal.

[0079] A first low frequency oscillator 112A provides a low-frequency sinusoidal signal at a first adjustment frequency  $\omega_{m1}$  that is used by the first phase modulator 108A to modulate the phase of the signal. The first adjustment frequency  $\omega_{m1}$  may be, for example, 10 Hz.

[0080] The second input signal received via the second antenna 102B is fed into a first summing node 114A, where it is added to the adjusted signal output by the first amplitude/phase adjustor 115A to generate a first intermediate output signal.

[0081] A first power detector 118A receives the first intermediate output signal via a first signal coupler 116A, and responsively outputs a power detection signal. The power detection signal is passed through a first high pass filter (such as a capacitor) 119A and is mixed with the low-frequency sinusoid output by the first low-frequency oscillator 112A, and the result is filtered with a first loop filter 122A, the output of which controls the first phase shifter 110A to vary the non-periodic phase adjustment by the first phase shifter 110A until periodic amplitude variation in the first intermediate output signal in response to the periodic phase adjustment is minimized or otherwise reduced to a desired level.

[0082] The third input signal received over the third antenna 102C is adjusted by a second amplitude/phase adjustor 115B including at least a second phase modulator 108B and a second phase shifter 110B. The second amplitude/phase adjustor 115B adjusts the third input signal and outputs an adjusted signal.

[0083] A second low frequency oscillator 112B provides a low-frequency sinusoidal signal at a frequency  $\omega_{m2}$  that is used by the second phase modulator 108A to modulate the phase of the input signal. The second adjustment frequency  $\omega_{m2}$  may be different from the first adjustment frequency  $\omega_{m1}$ , and may be, for example, 30 Hz.

[0084] The adjusted signal output by the second amplitude/phase adjustor 115B is added to the first intermediate output signal at a second summing node 114B to generate a second intermediate output signal.

[0085] A second power detector 118B receives the second intermediate output signal via a second signal coupler 116B, and responsively outputs a power detection signal. The power detection signal is passed through a second high pass filter (such as a capacitor) 119B and is mixed with the low-frequency sinusoid output by the second low-frequency oscillator 112B, and the result is filtered with a second loop filter 122B, the output of which controls the second phase shifter 110B to vary the non-periodic phase adjustment by the phase shifter

110B until periodic amplitude variation in the second intermediate output signal in response to the periodic phase adjustment is minimized or otherwise reduced to a desired level.

[0086] The fourth input signal received via the fourth antenna 102D is adjusted by a third amplitude/phase adjustor 115C including at least a third phase modulator 108C and a third phase shifter 110C. The third amplitude/phase adjustor 115C adjusts the fourth input signal and outputs an adjusted signal.

[0087] A third low frequency oscillator 112C provides a low-frequency sinusoidal signal at a third adjustment frequency  $\omega_{m3}$  that is used by the third phase modulator 108C to modulate the phase of the signal. The third adjustment frequency  $\omega_{m3}$  may be a different frequency from the first and second adjustment frequencies  $\omega_{m1}$  and  $\omega_{m1}$ , and may be, for example, 50 Hz.

[0088] The second intermediate output signal output by the second summing node 114B is fed into a third summing node 114C, where it is added to the adjusted signal output by the third amplitude/phase adjustor 115C to generate a combined output signal 124.

[0089] A third power detector 118C receives the combined output signal 124 via a third signal coupler 116C, and responsively outputs a power detection signal. The power detection signal is passed through a third high pass filter (such as a capacitor) 119C and is mixed with the low-frequency sinusoid output by the third low-frequency oscillator 112C, and the result is filtered with a third loop filter 122C, the output of which controls the third phase shifter 110C to vary the non-periodic phase adjustment by the third phase shifter 110C until periodic amplitude variation in the combined output signal 124 in response to the periodic phase adjustment is minimized or otherwise reduced to a desired level.

[0090] Figure 5B illustrates a combiner 100C according to some embodiments configured to perform periodic phase adjustment and non-periodic phase adjustment of a diversity signal received using four antennas, as illustrated in Figure 2. Referring to Figure 5B, a continuous combiner 100C (analogous to the processor 40 of the embodiments of Figure 2) receives input signals from four antennas 102A to 102D. Although not illustrated in Figure 4, the signals received over one or more of the antennas 102A to 102D can be subjected to a fixed delay that equalizes the electrical path length leading to the inputs of the combiner 100A.

[0091] In the embodiments of Figure 5B, three of the four antenna signals are adjusted as described above, and all four signals (including the three adjusted signals) are added together at a common summing node 114 to generate a combined output signal 124.

[0092] In particular, the first input signal received over the first antenna 102A is adjusted by a first amplitude/phase adjustor 115A including at least a first phase modulator 108A and a first phase shifter 110A.

[0093] A first low frequency oscillator 112A provides a low-frequency sinusoidal signal at a first adjustment frequency  $\omega_{m1}$  that is used by the first phase modulator 108A to modulate the phase of the input signal. The first adjustment frequency  $\omega_{m1}$  may be, for example, 10 Hz.

[0094] A first power detector 118A receives the combined output signal via a first signal coupler 116A, and responsively outputs a power detection signal. The power detection signal is passed through a first high pass filter (such as a capacitor) 119A and is mixed with the low-frequency sinusoid output by the first low-frequency oscillator 112A, and the result is filtered with a first loop filter 122A, the output of which controls the first phase shifter 110A to vary the non-periodic phase adjustment by the first phase shifter 110A.

[0095] The second input signal received via the second antenna 102B is fed into the common summing node 114.

[0096] The third input signal received over the third antenna 102C is adjusted by a second amplitude/phase adjustor 115B including at least a second phase modulator 108B and a second phase shifter 110B. The second amplitude/phase adjustor 115B adjusts the third input signal and outputs an adjusted signal.

[0097] A second low frequency oscillator 112B provides a low-frequency sinusoidal signal at a frequency  $\omega_{m2}$  that is used by the second phase modulator 108A to modulate the phase of the input signal. The second adjustment frequency  $\omega_{m2}$  may be different from the first adjustment frequency  $\omega_{m1}$ , and may be, for example, 1 Hz.

[0098] The adjusted signal output by the second amplitude/phase adjustor 115B is fed into the common summing node 114.

[0099] A second power detector 118B receives the combined output signal via the first signal coupler 116A, and responsively outputs a power detection signal. The power detection signal is passed through a second high pass filter (such as a capacitor) 119B and is mixed with the low-frequency sinusoid output by the second low-frequency oscillator 112B, and the result is filtered with a second loop filter 122B, the output of which controls the second phase shifter 110B to vary the non-periodic phase adjustment by the phase shifter 110B.

[00100] The fourth input signal received via the fourth antenna 102D is adjusted by a third amplitude/phase adjustor 115C including at least a third phase modulator 108C and a third phase shifter 110C. The third amplitude/phase adjustor 115C adjusts the fourth input signal and outputs an adjusted signal.

[00101] A third low frequency oscillator 112C provides a low-frequency sinusoidal signal at a third adjustment frequency  $\omega_{m3}$  that is used by the third phase modulator 108C to modulate the phase of the input signal. The third adjustment frequency  $\omega_{m3}$  may be a different frequency from the first and second adjustment frequencies  $\omega_{m1}$  and  $\omega_{m2}$ , and may be, for example, 100 Hz.

[00102] The adjusted signal output by the third phase shifter 110C is fed into the common summing node 114.

[00103] A third power detector 118C receives the combined output signal 124 via a second signal coupler 116B, and responsively outputs a power detection signal. The power detection signal is passed through a third high pass filter (such as a capacitor) 119C and is mixed with the low-frequency sinusoid output by the third low-frequency oscillator 112C, and the result is filtered with a third loop filter 122C, the output of which controls the third phase shifter 110C to vary the non-periodic phase adjustment by the third phase shifter 110C.

[00104] The non-periodic phase adjustments by the first, second and third phase shifters 110A, 110B and 110C are adjusted until periodic amplitude variation in the combined output signal 124 in response to the periodic phase adjustment is minimized or otherwise reduced to a desired level.

[00105] Figures 6A-6C provide a graphical illustration of some operations of the combiner 100. In particular, Figures 6A-6C are phasor diagrams showing the effects in vector space of periodic and non-periodic phase adjustment of a diversity signal that is combined with a primary signal.

[00106] Figure 6A illustrates a primary signal 202, a diversity signal 204 and a combined signal 206 that is represented as a vector sum of the primary signal 202 and the diversity signal 204. In the example illustrated in Figures 6A-6C, the diversity signal 204 is rotated from the primary signal 202 by a phase of  $90^\circ$  before phase adjustment. As the phase of the diversity signal 204 is modulated (i.e., periodically adjusted), the vector representing the diversity signal 204 oscillates between a first position 204' and a second position 204". Consequently, the vector representing the combined signal 206 oscillates between a first

position 206' and a second position 206". As is apparent from Figure 6A, the combined signal at the first position 206' has a smaller amplitude than the combined signal at the second position 206". Thus, the combined signal 206 exhibits a relatively large periodic amplitude variation.

[00107] Figure 6B illustrates a primary signal 202, a diversity signal 204A and a combined signal 206A, where the diversity signal 204A has been phase shifted by a non-periodic phase adjustment  $\theta_1$ . As the phase of the diversity signal 204A is periodically adjusted, the vector representing the diversity signal 204A oscillates between a first position 204A' and a second position 204A". Consequently, the vector representing the combined signal 206A oscillates between a first position 206A' and a second position 206A". Comparing Figure 6A and Figure 6B, periodic amplitude variation of the combined signal 206A of Figure 6B is smaller than that of the combined signal 206 of Figure 6A.

[00108] Referring to Figure 6C, the adjusted diversity signal 204B has been phase shifted by a non-periodic phase adjustment  $\theta_2$ , where  $\theta_2$  is about equal to  $90^\circ$  (i.e., the amount the phase of the diversity signal 204 was originally rotated from the phase of the main signal 202). In this case, the periodic amplitude variation of the combined signal 206B is reduced to a minimum. Consequently, the received signal power of the combined signal 206B is at a maximum.

[00109] Systems/methods according to some embodiments are illustrated in Figures 7 and 8. Referring to Figures 1 and 7, a plurality of return feeder link signals 11a-11d are received at a satellite gateway 30 (Block 302). Amplitudes/phases of at least some of the return feeder link signals are adjusted using a periodic phase adjustment and a non-periodic phase adjustment (Block 304). For example, phases of at least some of the return feeder link signals can be modulated using one or more periodic functions, and/or can be shifted by one or more phase delays. The feeder link signals are combined (Block 306), and periodic amplitude variation in the combined signal is detected, for example, using a power detector (Block 308). The non-periodic phase adjustment is then configured to reduce and/or minimize the periodic amplitude variation in the combined signal (Block 310). Accordingly, signal power of the combined signal can be increased, thereby offsetting some of the effects of power robbing in a satellite return feeder link.

[00110] Referring to Figure 8, a plurality of return feeder link signals are received at a satellite gateway 30 (Block 402). The phase of a first return feeder link signal is modulated using a periodic function, such as a sine function (Block 404). The feeder link



signals are combined (Block 406), and periodic amplitude variation in the combined signal is detected, for example, using a power detector (Block 408). The phase of the first return feeder link signal is then shifted by a phase delay to reduce and/or minimize the periodic amplitude variation in the combined signal (Block 410). Accordingly, signal power of the combined signal can be increased, thereby offsetting some of the effects of power robbing in a satellite return feeder link.

**[00111]** Embodiments of the present invention may be sharply contrasted with feeder link space diversity switching that may be conventionally used to reduce the effects of rain fading and/or other local disturbances on a feeder link. In accordance with feeder link space diversity switching, at least first and second spatially distant feeder link antennas are used to provide respective first and second feeder link signals to a satellite gateway. However, the first and second feeder link signals are generally not combined. Instead, either the first or the second signal is chosen, depending on a signal strength threshold/criterion, and is provided to the satellite gateway for further processing and demodulation. In sharp contrast, in some embodiments the various return feeder link signals 11a-11d are combined by processor 40 at a radio frequency (RF) of the return feeder link and/or at an intermediate frequency (IF) associated with the return feeder link (not shown). Combination at base band is not performed in these embodiments, obviating a need for a plurality of gateway signal paths and associated equipment thereof. Instead, combination at RF and/or IF is performed, as described above, and a single (combined) signal, signal 17, is used via one gateway down conversion signal path to generate one or more signals at base band for information recovery. In other embodiments, diversity combining of base band signals may also be performed in addition to combining at RF and/or IF as shown in Figures 1-5B. This may be performed, for example, in a system using a Code Division Multiple Access (CDMA) air interface. By adjusting the phase of the feeder link signals and combining the signals at RF/IF, as described herein, some embodiments of the present invention can provide operations that can have an effect of increasing a feeder link aperture of the satellite antenna and/or a capability (e.g., size) of a feeder link power amplifier of the satellite without a need to increase a size, weight, and/or cost thereof. In fact, by reducing the effect of interference, a lower power amplifier and/or a smaller antenna may be used at the satellite thereby allowing reduction of the cost, weight and/or complexity of the satellite.

**[00112]** In the drawings and specification, there have been disclosed typical embodiments of the invention and, although specific terms are employed, they are used in a

generic and descriptive sense only and not for purposes of limitation, the scope of the invention being set forth in the following claims.

**What is Claimed is:**

1. A method of processing return feeder link signals at a satellite gateway including a plurality of spatially diverse receive antennas, the method comprising:
  - receiving respective return feeder link signals at each of the plurality of receive antennas;
  - selectively adjusting amplitudes and/or phases of a plurality of the return feeder link signals received at the plurality of receive antennas in response to amplitude/phase adjustment settings to provide a plurality of adjusted return feeder link signals;
  - combining the plurality of adjusted feeder link signals to generate a combined return feeder link signal;
  - detecting periodic amplitude variation in the combined return feeder link signal; and
  - configuring the amplitude/phase adjustment settings in response to the combined return feeder link signal to reduce the periodic amplitude variation in the combined return feeder link signal.
2. The method of Claim 1, wherein configuring the amplitude/phase adjustment settings comprises providing non-periodic phase adjustment signals to a plurality of amplitude/phase adjustors that process the plurality of return feeder link signals.
3. The method of Claim 1, wherein selectively adjusting amplitudes and/or phases of the return feeder link signals comprises adjusting the amplitude/phase of a first one of the return feeder link signals at a first adjustment frequency and adjusting the amplitude/phase of a second one of the return feeder link signals at a second adjustment frequency that is different from the first adjustment frequency.
4. The method of Claim 3, wherein the first adjustment frequency is 10 Hz and the second adjustment frequency is 50 Hz.
5. The method of Claim 3, further comprising adjusting amplitudes/phases of the first and second return feeder link signals using respective first and second periodic functions that are in phase quadrature therebetween.

6. The method of Claim 5, wherein the first and second periodic functions comprise sinusoidal functions.

7. The method of Claim 1, wherein the plurality of receive antennas comprises four antennas, the method further comprising:

receiving first, second, third and fourth return feeder link signal at respective ones of the plurality of receive antennas;

selectively adjusting amplitudes and/or phases of the first and second return feeder link signals received at the first and second receive antennas to generate respective first and second adjusted feeder link signals;

combining the first adjusted feeder link signal and the third return feeder link signal to generate a first intermediate combined signal;

combining the second adjusted feeder link signal and the fourth return feeder link signal to generate a second intermediate combined signal; and

combining the first intermediate combined signal and the second intermediate combined signal to generate the combined return feeder link signal.

8. The method of Claim 7, further comprising:

adjusting an amplitude and/or phase of the first intermediate combined signal to generate an adjusted intermediate combined signal;

wherein combining the first intermediate combined signal and the second intermediate combined signal comprises combining the adjusted intermediate combined signal and the second intermediate combined signal.

9. The method of Claim 1, wherein the plurality of receive antennas comprises four antennas, the method further comprising:

receiving first, second, third and fourth return feeder link signal at respective ones of the plurality of receive antennas;

selectively adjusting amplitudes and/or phases of the first, second and third return feeder link signals received at the first, second and third receive antennas to generate respective first, second and third adjusted feeder link signals; and

combining the first, second and third adjusted feeder link signals and the fourth return feeder link signal to generate the combined return feeder link signal.

10. The method of Claim 1, wherein combining the plurality of adjusted feeder link signals to generate a combined return feeder link signal comprises RF combining the signals.

11. The method of Claim 1, further comprising converting the feeder link signals to an intermediate frequency, wherein combining the plurality of adjusted feeder link signals to generate a combined return feeder link signal comprises combining intermediate frequency signals.

12. The method of Claim 1, further comprising:  
converting the combined return feeder link signal to baseband; and  
combining the baseband combined return feeder link signal with another baseband signal.

13. A satellite gateway comprising:  
a plurality of receive antennas; and  
a processor coupled to the plurality of receive antennas and configured to receive respective return feeder link signals from each of the plurality of receive antennas, configured to selectively adjust amplitudes and/or phases of a plurality of the return feeder link signals received at the plurality of receive antennas in response to amplitude/phase adjustment settings to provide a plurality of adjusted return feeder link signals, and configured to combine the plurality of adjusted feeder link signals to generate a combined return feeder link signal;

wherein the processor comprises a control circuit configured to detect periodic amplitude variation in the combined return feeder link signal, and to configure the amplitude/phase adjustment settings in response to periodic amplitude variation in the combined return feeder link signal to reduce periodic amplitude variation in the combined return feeder link signal.

14. The satellite gateway of Claim 13, wherein the control circuit is configured to provide non-periodic phase adjustment signals to a plurality of amplitude/phase adjusters that process the plurality of return feeder link signals.

15. The satellite gateway of Claim 13, wherein the processor comprises a first amplitude/phase adjustor that is configured to selectively adjust the amplitude/phase of a first one of the return feeder link signals at a first adjustment frequency and a second amplitude/phase adjustor that is configured to selectively adjust the amplitude/phase of a second one of the return feeder link signals at a second adjustment frequency that is different from the first adjustment frequency.

16. The satellite gateway of Claim 15, wherein the first adjustment frequency is 10 Hz and the second adjustment frequency is 50 Hz.

17. The satellite gateway of Claim 15, wherein the first amplitude/phase adjustor and the second amplitude/phase adjustor adjust amplitudes/phases of the first and second return feeder link signals using respective first and second periodic functions that are in phase quadrature therebetween.

18. The satellite gateway of Claim 17, wherein the first and second periodic functions comprise sinusoidal functions.

19. The satellite gateway of Claim 13, wherein the plurality of receive antennas comprises four antennas, and wherein the processor further comprises:

a first amplitude/phase adjustor configured to selectively adjust amplitude/phase of a first return feeder link signal;

a second amplitude/phase adjustor configured to selectively adjust amplitude/phase of a second return feeder link signal;

a first combiner configured to combine the first return feeder link signal and a third return feeder link signal to form a first intermediate combined signal;

a second combiner configured to combine the second return feeder link signal and a fourth return feeder link signal to form a second intermediate combined signal; and

a third combiner configured to combine the first intermediate combined signal and the second intermediate combined signal to generate a combined return feeder link signal.

20. The satellite gateway of Claim 19, wherein the processor further comprises:

a third amplitude/phase adjustor configured to selectively adjust amplitude/phase of the first intermediate combined signal to generate an adjusted intermediate combined signal;

wherein the third combiner is configured to combine the adjusted intermediate combined signal and the second intermediate combined signal.

21. The satellite gateway of Claim 13, wherein the plurality of receive antennas comprises four antennas, and wherein the processor further comprises:

a first amplitude/phase adjustor configured to selectively adjust amplitude/phase of a first return feeder link signal;

a second amplitude/phase adjustor configured to selectively adjust amplitude/phase of a second return feeder link signal;

a third amplitude/phase adjustor configured to selectively adjust amplitude/phase of a third return feeder link signal; and

a combiner configured to combine the first return feeder link signal, the second return feeder link signal, the third return feeder link signal and a fourth return feeder link signal to form the combined return feeder link signal.

22. A method of processing return feeder link signals at a satellite gateway including a first and second receive antennas, the method comprising:

receiving first and second return feeder link signals at the first and second receive antennas, respectively;

modulating a phase of the first return feeder link signal to form an adjusted first feeder link signal;

combining the adjusted first feeder link signal with the second return feeder link signal to form a combined feeder link signal;

detecting periodic amplitude variation in the combined feeder link signal; and

shifting a phase of the first return feeder link signal to reduce the periodic amplitude variation in the combined feeder link signal.

23. The method of Claim 22, further comprising:

receiving third and fourth return feeder link signals at respective third and fourth receive antennas;

modulating a phase of the third return feeder link signal to form an adjusted third feeder link signal;

combining the adjusted third feeder link signal with the fourth return feeder link signal to form a second combined feeder link signal;

detecting periodic amplitude variation in the second combined feeder link signal; and shifting a phase of the third return feeder link signal to reduce periodic amplitude variation in the second combined feeder link signal.

24. The method of Claim 23, further comprising:  
modulating a phase of the combined feeder link signal to form an adjusted combined feeder link signal;  
combining the adjusted combined feeder link signal with the second combined feeder link signal to form a third combined feeder link signal;  
detecting periodic amplitude variation in the third combined feeder link signal; and shifting a phase of the combined feeder link signal to reduce periodic amplitude variation in the third combined feeder link signal.

25. The method of Claim 22, further comprising:  
receiving third and fourth return feeder link signals at respective third and fourth receive antennas; and  
modulating phases of the third and fourth return feeder link signals to form an adjusted third feeder link signal and an adjusted fourth feeder link signal;  
wherein combining the adjusted first feeder link signal with the second return feeder link signal to form the combined feeder link signal comprises combining the adjusted first feeder link signal, the second return feeder link signal, the adjusted third feeder link signal and the adjusted fourth feeder link signal to form the combined feeder link signal.

26. A satellite gateway, comprising:  
a processor configured to receive first and second return feeder link signals from first and second receive antennas, respectively;  
a phase modulator configured to modulate a phase of the first return feeder link signal;  
a phase shifter configured to shift a phase of the first return feeder link signal by a phase delay;  
a combiner configured to combine the first return feeder link signal with the second return feeder link signal to form a combined feeder link signal;  
a power detector configured to detect periodic amplitude variation in the combined feeder link signal; and



a feedback loop from the power detector to the phase shifter configured to adjust the phase delay to reduce periodic amplitude variation in the combined feeder link signal.

27. The satellite gateway of Claim 26, wherein the processor is further configured to receive third and fourth return feeder link signals from respective third and fourth receive antennas, and wherein the processor further comprises:

a second phase modulator configured to modulate a phase of the third return feeder link signal;

a second phase shifter configured to shift a phase of the third return feeder link signal by a second phase delay;

a second combiner configured to combine the third return feeder link signal with the fourth return feeder link signal to form a second combined feeder link signal;

a second power detector configured to detect periodic amplitude variation in the second combined feeder link signal; and

a second feedback loop from the second power detector to the second phase shifter configured to adjust the second phase delay to reduce periodic amplitude variation in the second combined feeder link signal.

28. The satellite gateway of Claim 27, further comprising:

a third phase modulator configured to modulate a phase of the combined feeder link signal;

a third phase shifter configured to shift a phase of the third combined feeder link signal by a third phase delay;

a third combiner configured to combine the combined feeder link signal with the second combined feeder link signal to form a third combined feeder link signal;

a third power detector configured to detect periodic amplitude variation in the third combined feeder link signal; and

a third feedback loop from the third power detector to the third phase shifter configured to adjust the third phase delay to reduce periodic amplitude variation in the third combined feeder link signal.

29. The satellite gateway of Claim 26, wherein the processor is further configured to receive third and fourth return feeder link signals from respective third and fourth receive antennas, and wherein the processor further comprises:

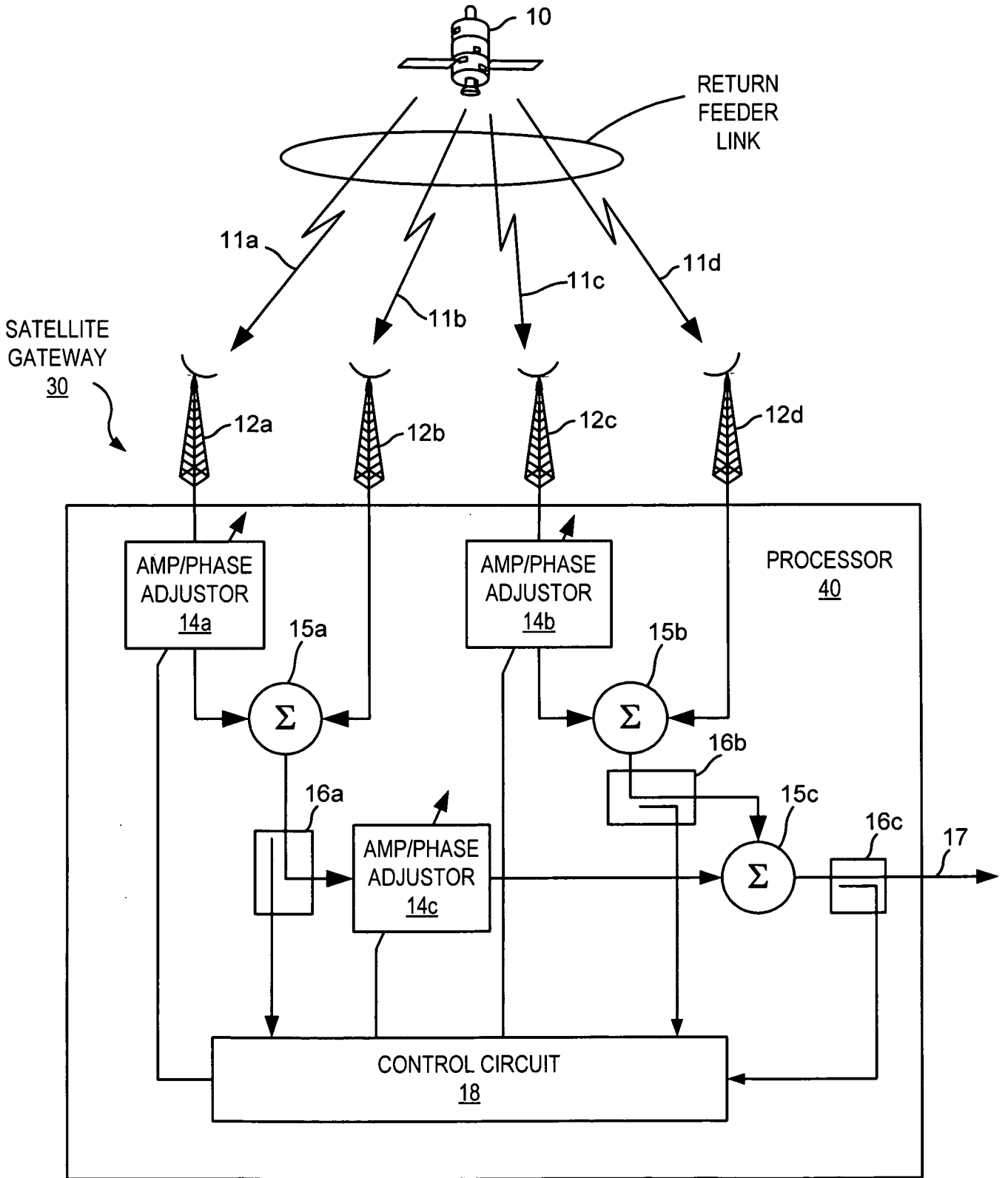
a second phase modulator configured to modulate a phase of the third return feeder link signal;

a second phase shifter configured to shift a phase of the third return feeder link signal by a second phase delay;

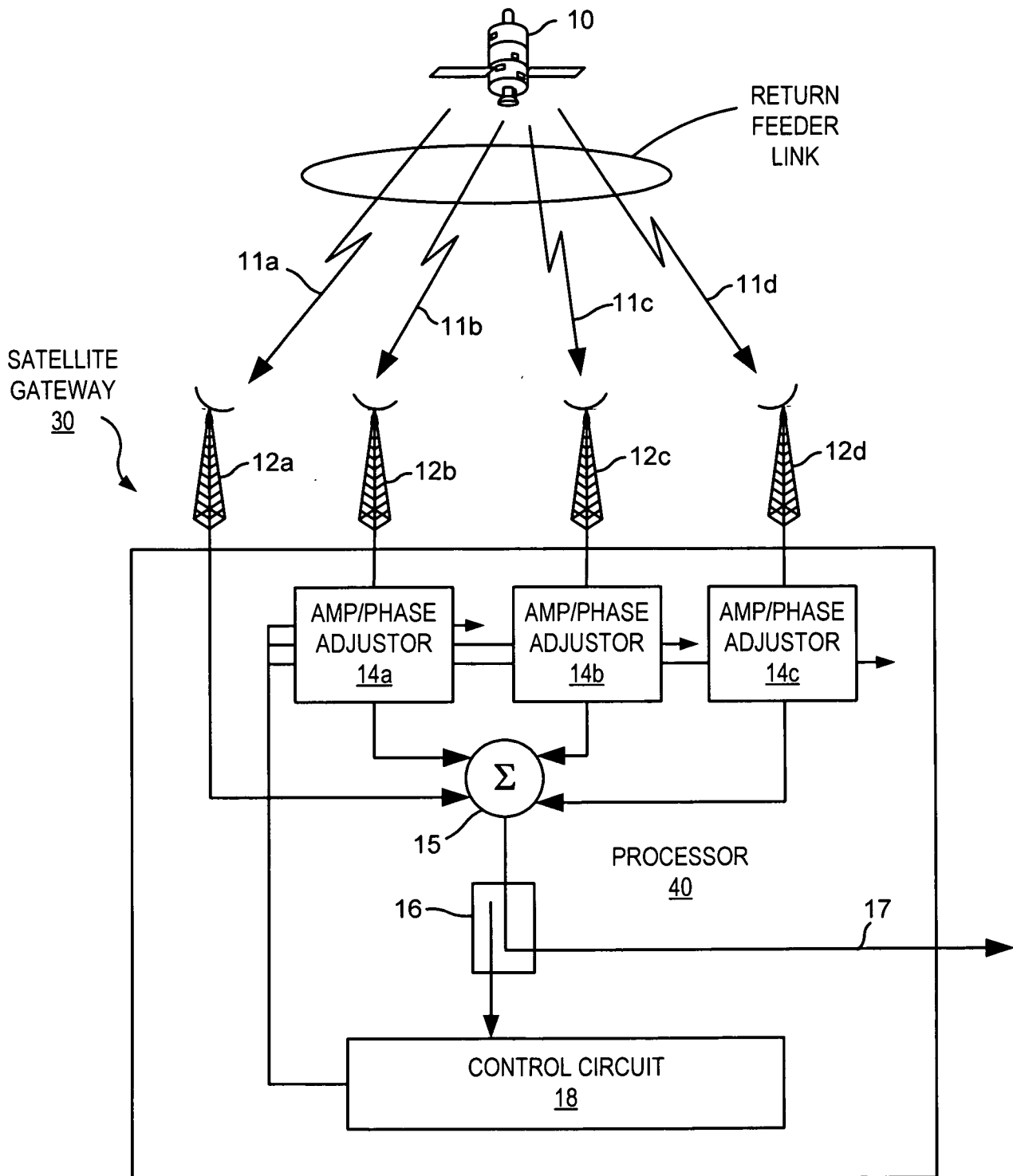
a third phase modulator configured to modulate a phase of the fourth return feeder link signal; and

a third phase shifter configured to shift a phase of the fourth return feeder link signal by a third phase delay;

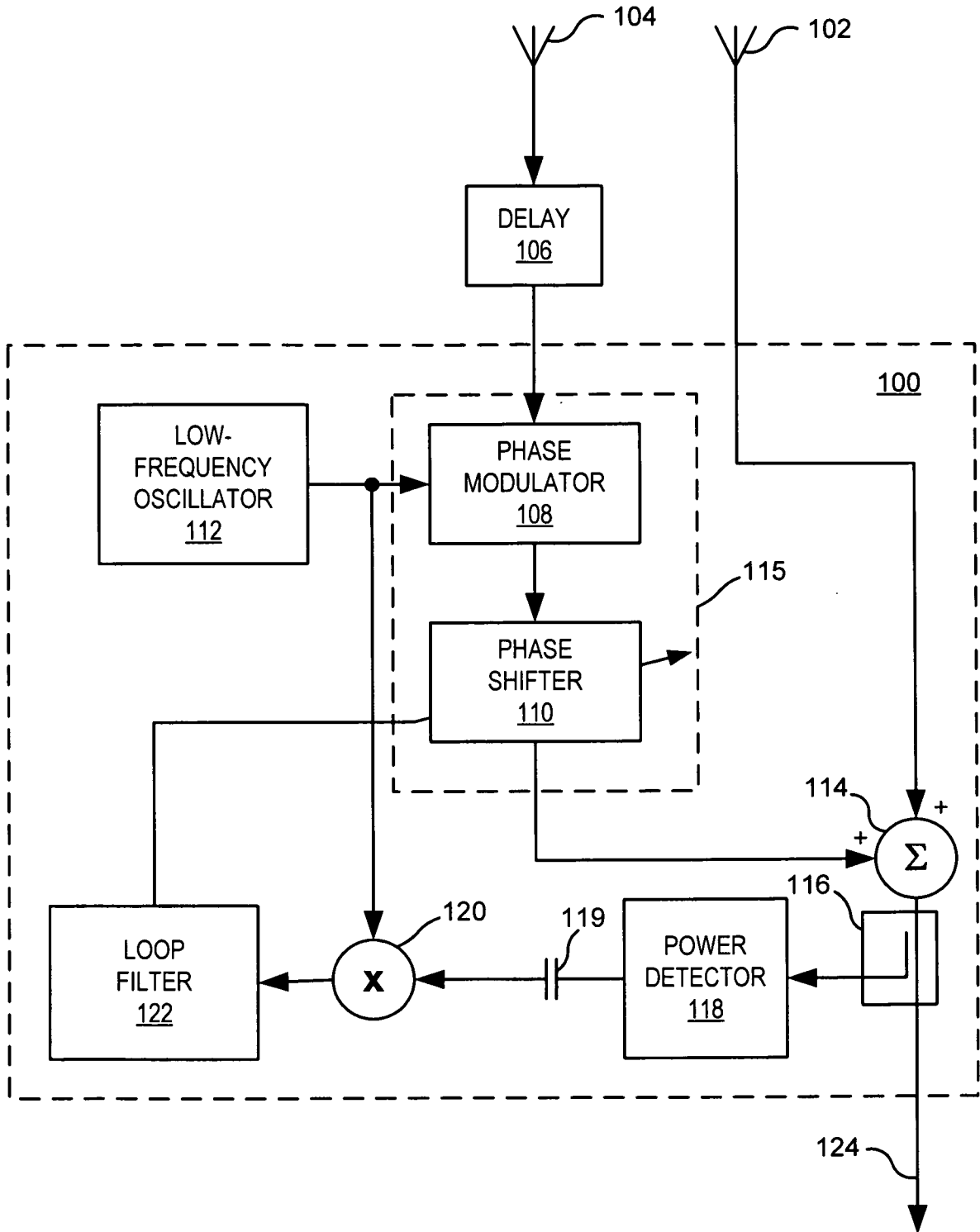
wherein the combiner is configured to combine the first, second, third and fourth return feeder link signals to form the combined feeder link signal.



**FIGURE 1**



**FIGURE 2**



**FIGURE 3**

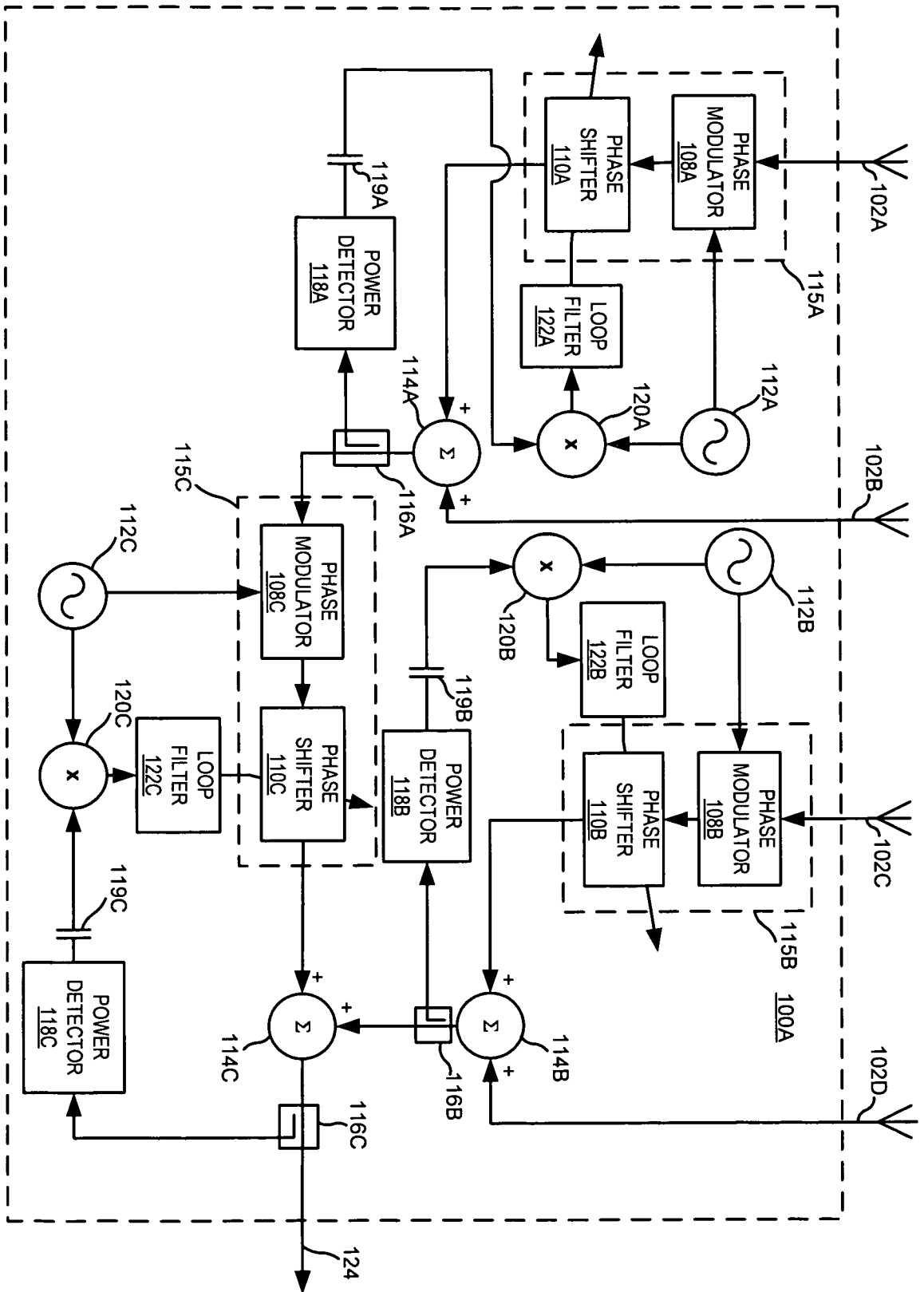


FIGURE 4

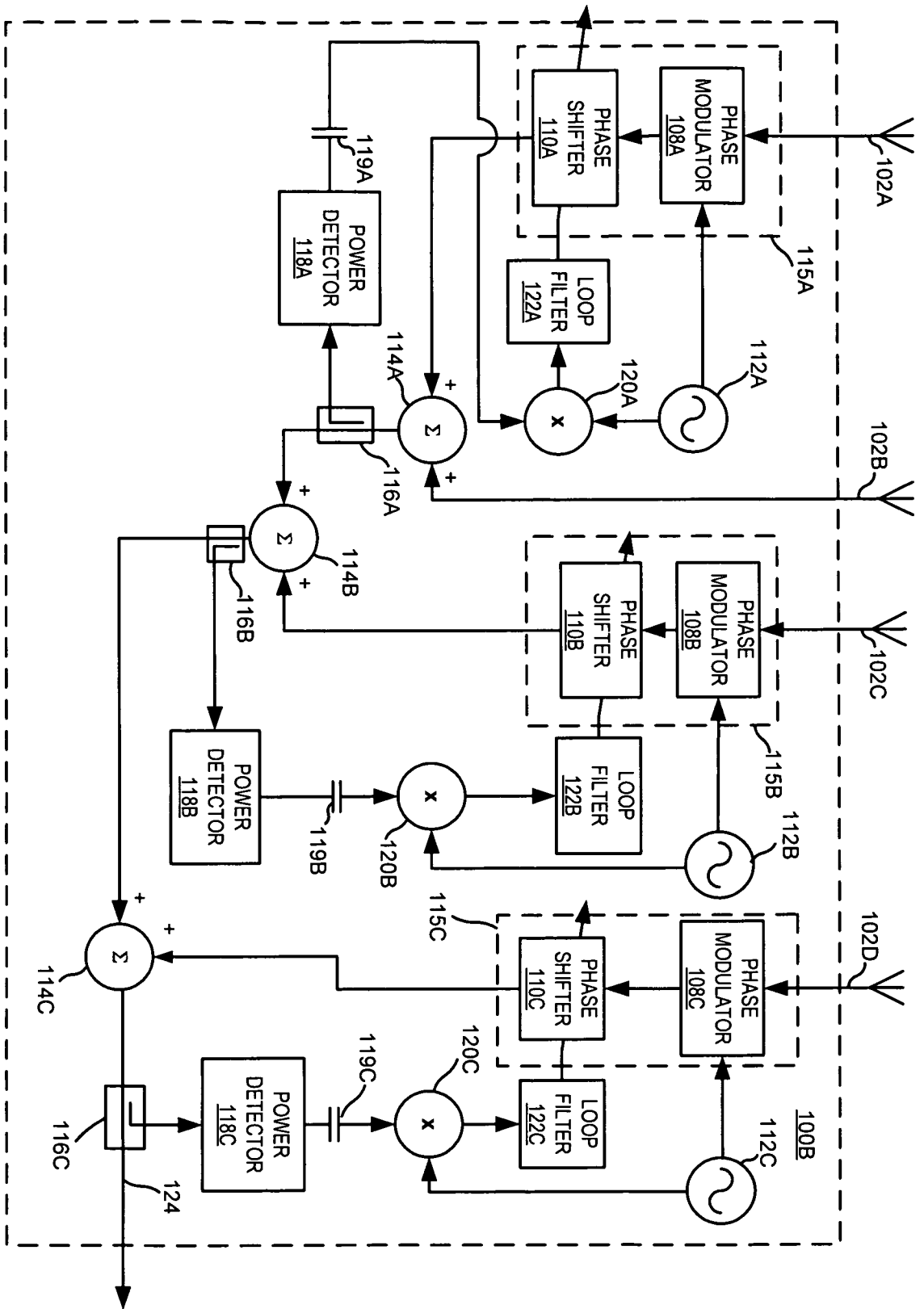


FIGURE 5A

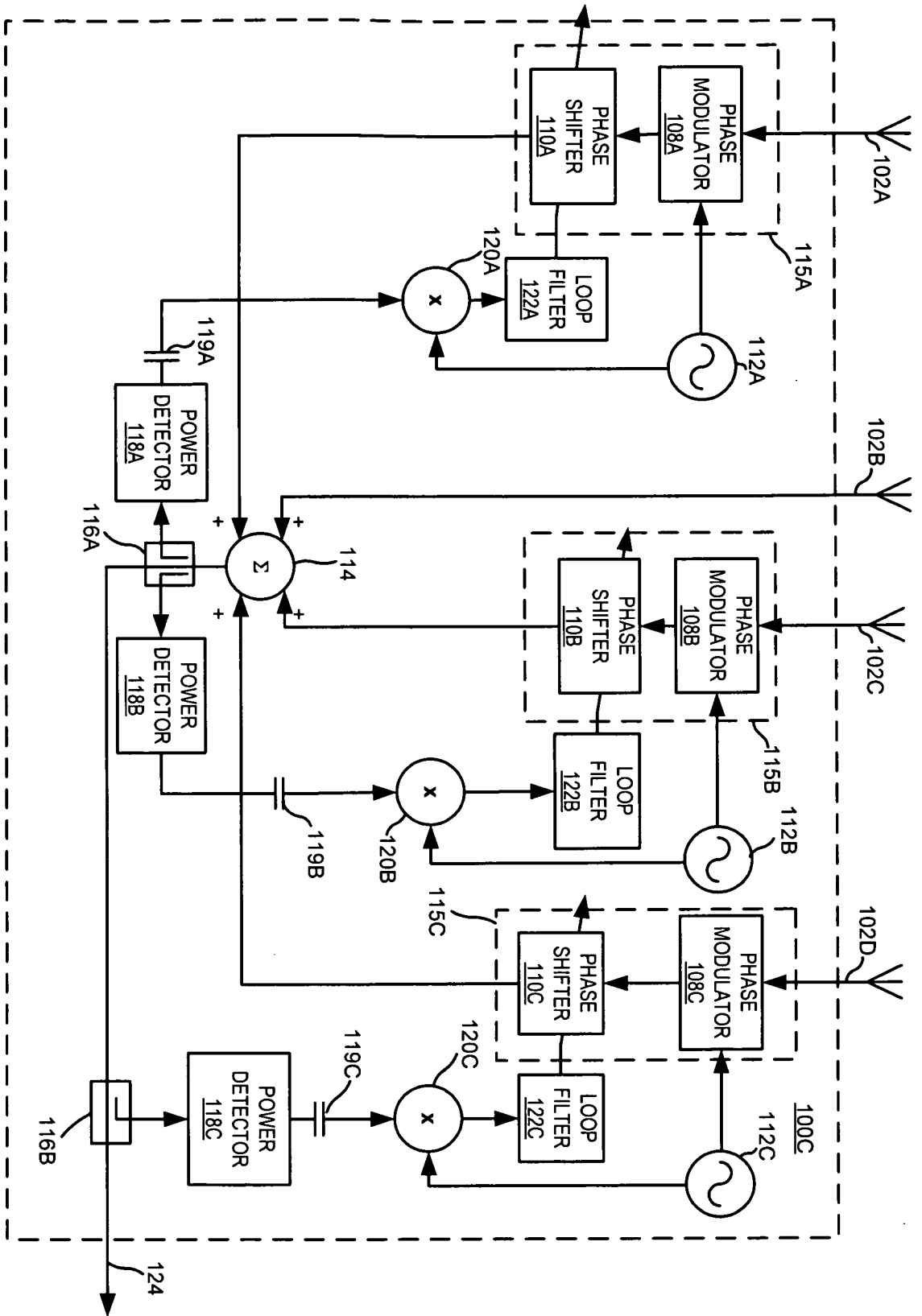
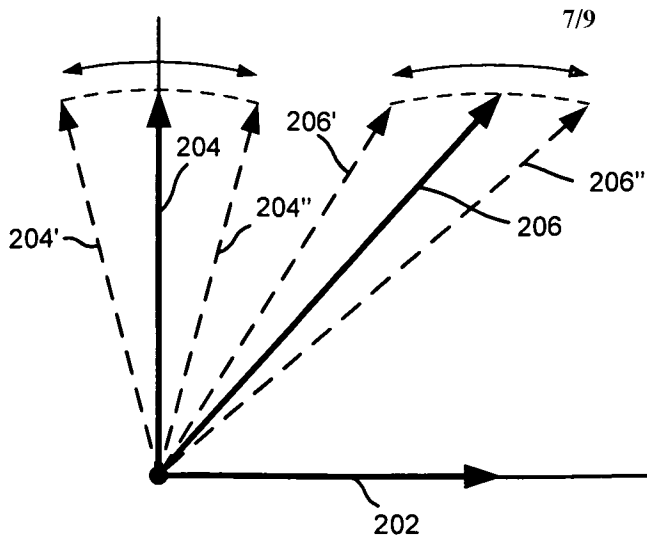
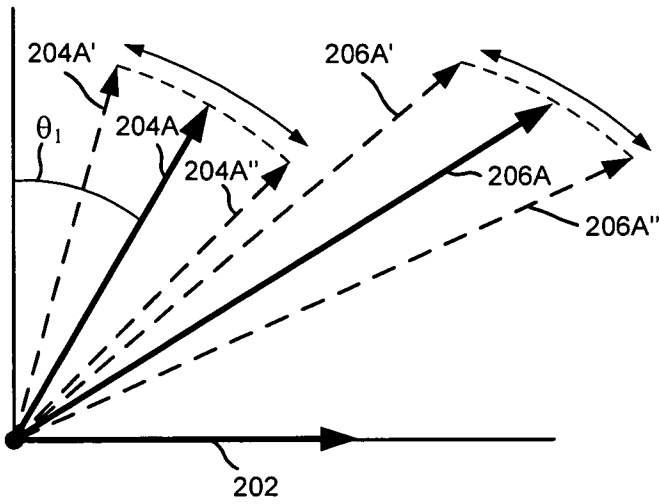


FIGURE 5B

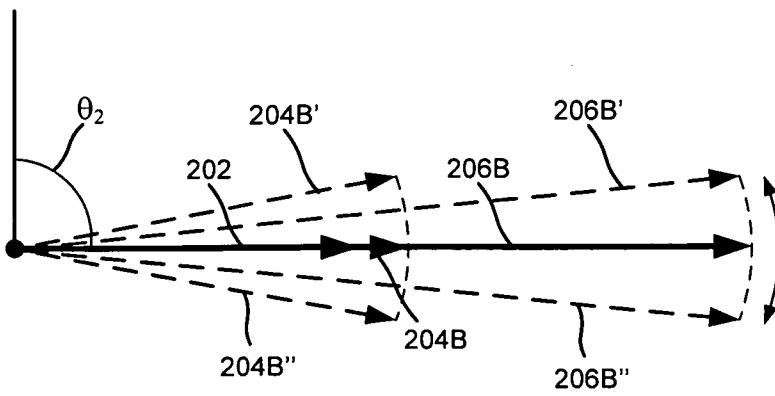




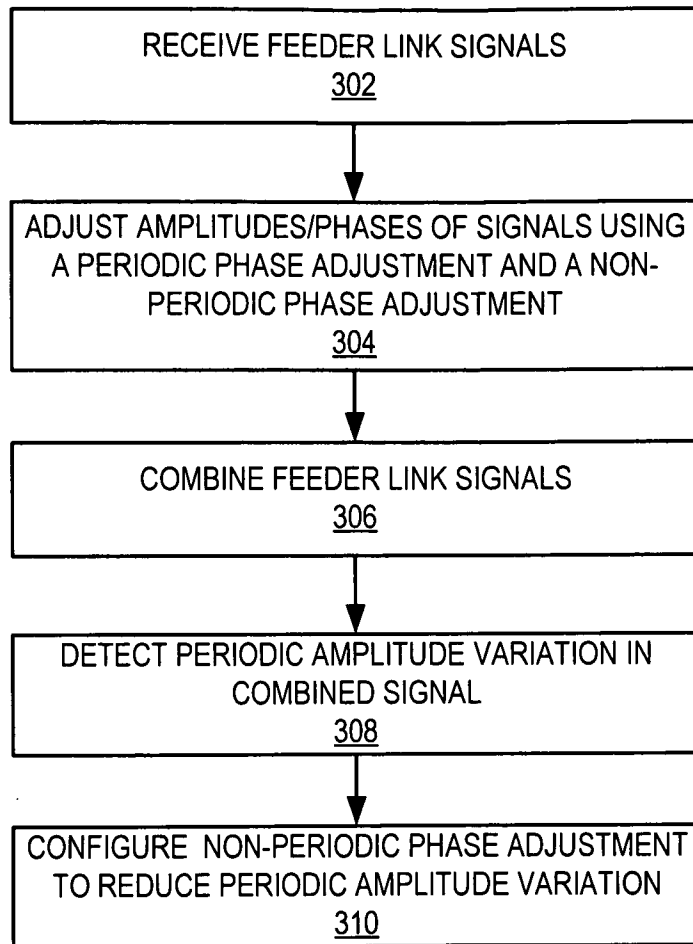
**FIGURE 6A**

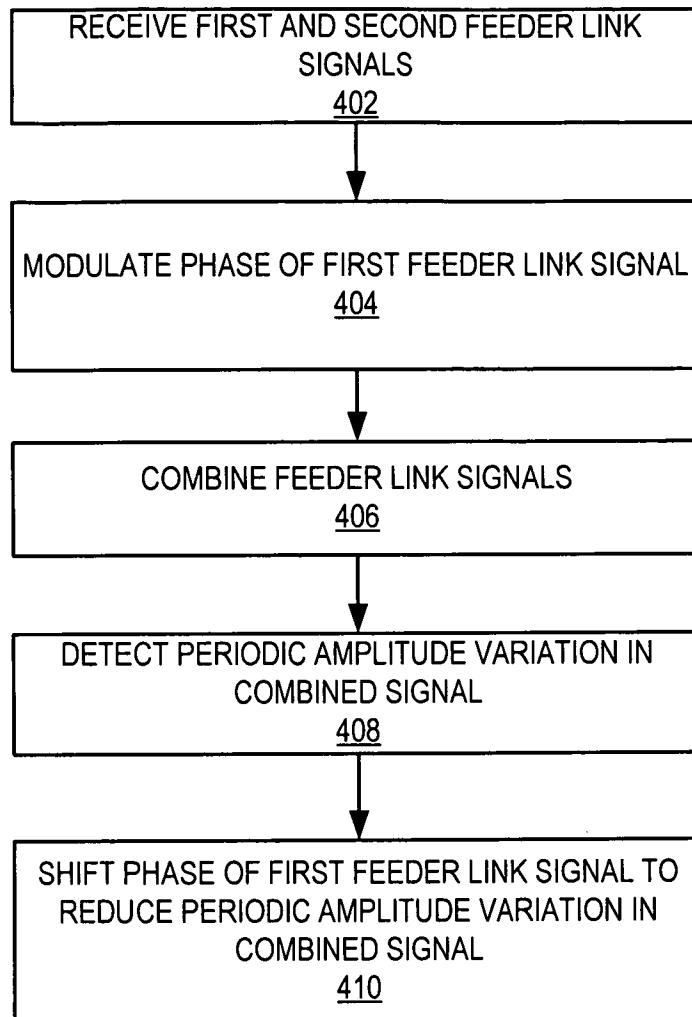


**FIGURE 6B**



**FIGURE 6C**

**FIGURE 7**

**FIGURE 8**

# INTERNATIONAL SEARCH REPORT

International application No

PCT/US2008/007885

**A. CLASSIFICATION OF SUBJECT MATTER**  
 INV. H04B7/185 H04B7/08

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)  
 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 practical, search terms used)

EPO-Internal, INSPEC, 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	KARABINIS P D: "Maximum-power and amplitude-equalizing algorithms for phase control in space diversity combining" BELL SYSTEM TECHNICAL JOURNAL, AT AND T, SHORT HILLS, NY, US, vol. 62, no. 1, 1 January 1983 (1983-01-01), pages 63-89, XP001536882 ISSN: 0005-8580 page 65, line 15 - page 66, line 23 page 70, line 5 - page 73, line 18 figure 1	1-29
Y	WO 2004/114547 A (STICHTING ASTRON [NL]; KEGEL JACOBUS ADRIANUS [NL]) 29 December 2004 (2004-12-29) page 4, line 1 - page 8, line 9 figures 1,2	1-29

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 document 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.
- \*Z\* document member of the same patent family

Date of the actual completion of the international search

4 November 2008

Date of mailing of the international search report

14/11/2008

Name and mailing address of the ISA/  
 European Patent Office, P.B. 5018 Patentlaan 2  
 NL - 2280 HV Rijswijk  
 Tel: (+31-70) 340-2040,  
 Fax: (+31-70) 340-3016

Authorized officer  
 Larcinese, Annamaria

## INTERNATIONAL SEARCH REPORT

International application No  
PCT/US2008/007885

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 354 276 A (KARABINIS PETER D) 12 October 1982 (1982-10-12) column 1, line 1 - line 18 column 2, line 26 - column 5, line 10 column 6, line 26 - line 29 figure 1  -----	1, 13, 22, 26

INTERNATIONAL SEARCH REPORT

International application No  
PCT/US2008/007885

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2004114547	A	29-12-2004	
		AU 2003304230 A1	04-01-2005
		JP 2007521670 T	02-08-2007
		US 2008094276 A1	24-04-2008
US 4354276	A	12-10-1982	NONE