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(54) **Title**: SUPPRESSION OF SPURIOUS HARMONICS GENERATED IN TX DRIVER AMPLIFIERS

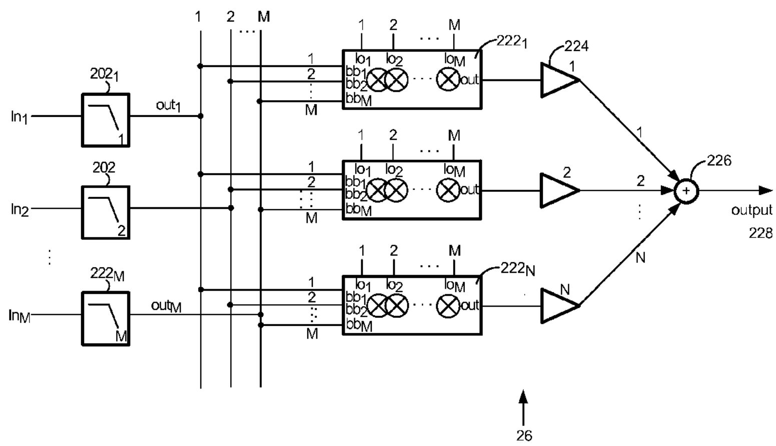

FIG. 2B

(57) **Abstract**: The transmission path of a communication device includes, in part, N upconverters each of which receives M phases of a signal to be transmitted. Each upconverter further receives one of N sets of phases of a LO signal. Each of the N sets includes M phases of the LO signal. The communication device further includes at least one combiner, and N amplifiers each responsive to a different one of the N upconverters to generate N amplified signals. The combiner combines the N amplified signals to generate an output signal. By selecting the gain of one of the amplifiers to be different than the gain of the remaining amplifiers, the undesired harmonics of the signal to be transmitted, caused by non-linearity of the amplifiers, is reduced. Each upconverter optionally includes a multitude of upconverters whose outputs are combined to further reduce the spurious harmonic upconversion products and the counter-intermodulation distortion (IM3).

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SUPPRESSION OF SPURIOUS HARMONICS GENERATED IN TX DRIVER AMPLIFIERS

CLAIM OF PRIORITY

This application claims the priority of U.S. non-Provisional Application Serial No. 13/949,736 entitled "SUPPRESSION OF SPURIOUS HARMONICS GENERATED IN TX DRIVER AMPLIFIERS" and filed on July 24, 2013, which is assigned to the assignee hereof and hereby expressly incorporated by reference herein.

BACKGROUND

[0001] The present disclosure relates to electronic circuits, and more particularly to a transmitter used in such circuits.

[0002] A wireless communication device, such as a cellular phone, includes a transmitter for transmitting signals and a receiver for receiving signals. The receiver often downconverts an analog radio frequency (RF) signal to an intermediate frequency (IF) signal which is filtered, amplified, and converted to a baseband signal. The transmitter converts a baseband digital signal to an analog signal, which is filtered and upconverted to an RF signal before being transmitted.

[0003] Non-linearity in the circuit blocks coupled to the output of the upconversion mixers, such as power amplifiers (PA) and driver amplifiers, often generate harmonics of the transmitted signal. Such harmonics, particularly the third and fifth harmonics, are undesired and should be kept below a certain threshold in order to meet the emission requirements. In the long term evolution (LTE) standard, such harmonics may couple to and desensitize an aggregated receiver associated with a different band when carrier aggregation is employed. Controlling the transmitter harmonics remains a challenge.

BRIEF SUMMARY

[0004] A communication device, in accordance with one embodiment of the present invention includes, in part, N upconverters, N amplifiers and at least one combiner. Each upconverter, made up of either M single balanced upconversion mixers or M/2 double-balanced upconversion mixers, receives M phases of a baseband signal to be transmitted. Each upconverter further receives a different one of N sets of phases of a local oscillator (LO) signal. Each of the N sets includes M different phases of the LO signal. Each amplifier is responsive to a different one of the upconverters to generate an amplified upconverted signal. The combiner combines the N amplified upconverted signals to generate an output signal. Undesired upconverted signal component at a frequency equal to a multiple of a sum of the LO signal frequency and the baseband signal frequency, or a multiple of a difference between the LO signal frequency and the baseband signal frequency is substantially suppressed from the output signal by selecting a gain of at least one of the amplifiers to be different from the gain of the remaining amplifiers. N and M are integers greater than 1.

[0005] In one embodiment, the communication device further includes, in part, a first filter receiving a baseband in-phase signal to generate a first set of filtered in-phase baseband signals to be transmitted, and a second filter receiving a baseband quadrature-phase signal to generate a second set of filtered quadrature-phase of the signals to be transmitted. In one embodiment, the baseband in-phase signal includes a first pair of complementary signals and the baseband quadrature-phase signal includes a second pair of complementary signals. In one embodiment N is 3 and M is 4.

[0006] In one embodiment, to eliminate a third harmonic, first and second amplifiers are selected to have an equal gain and a third amplifier is selected to have a gain larger than the gain of the first and second amplifiers. In one embodiment, the gain of the third amplifier is substantially $2^{\frac{1}{6}}$ times the gain of the first and second amplifiers. In one embodiment, the gain of the third amplifier is substantially $2^{\frac{1}{10}}$ times the gain of the first and second amplifiers.

[0007] In one embodiment, the four phases of the LO signal in a first set lead corresponding four phases of the LO signal in a second set by 45°. In one embodiment, the four phases of the LO signal in a third set lag corresponding four phases of the LO signal in the second set by 45°. In one embodiment, the four phases of the LO signal in the first are at 315, 135, 45, 225 degrees, the 4 phases of the LO signal in the second set are at 0, 180, 90, 270 degrees, and the 4 phases of the LO signal in the third set are at 45, 225, 135, 315 degrees.

[0008] A communication device, in accordance with another embodiment of the present invention includes, in part, N sets of upconverters and N sets of combiners. Each of the N set of upconverters includes Q upconverters. Each of the Q upconverters in each of the N sets receives M phases of a signal to be transmitted. Each of the Q upconverters in each of the N sets further receives one of Q*N sets of phases of a LO signal. Each of the Q*N sets includes M phases of the LO signal. In response, each of the Q upconverters generates an upconverted in-phase signal and an upconverted inverse signal. Each set of combiners is associated with a different one of the N sets of upconverters. A first combiner in each such set combines the N in-phase signals the first combiner receives from its associated upconverters. A second combiner in each set combines the N inverse signals the second combiner receives from its associated upconverters. Undesired upconverted signal component at a frequency equal to a multiple of a sum of the LO signal frequency and the baseband signal frequency, or a multiple of a difference between the LO signal frequency and the baseband signal frequency is substantially suppressed from the combined in-phase and inverse signals, Q, M and N are positive integers.

[0009] In one embodiment, the communication device further includes, in part, a first filter receiving a baseband in-phase signal to generate a first set of in-phase signals to be transmitted, and a second filter receiving a baseband quadrature-phase signal to generate a second set of filtered quadrature-phase of the signals to be transmitted. In one embodiment, the baseband in-phase signal includes a first pair of complementary signals and the baseband quadrature-phase signal includes a second pair of complementary signals. In one embodiment, N and Q are equal to three. In one embodiment, N×Q sets of phases of the LO signal includes 5 distinct sets, and M is equal to 4.

[0010] In one embodiment, the communication device further includes, in part, N amplifiers each associated with a different one of the N sets of combiners. Each amplifier amplifies the upconverted signal and its inverse it receives from its associated set of combiners. In one embodiment, the gain of at least one of the amplifiers is substantially $2^{\frac{1}{6}}$ times the gain of the remaining amplifiers. In one embodiment, the gain of at least one of the amplifiers is substantially $2^{\frac{1}{10}}$ times the gain of the remaining amplifiers.

[0011] In one embodiment, the four phases of the LO signal in a first set lead corresponding four phases of the LO signal in a second set by 45°. In one embodiment, the four phases of the LO signal in a third set lag corresponding four phases of the LO signal in the second set by 45°. In one embodiment, the four phases of the LO signal in the first are at 315, 135, 45, 225 degrees, the 4 phases of the LO signal in the second set are at 0, 180, 90, 270 degrees, and the 4 phases of the LO signal in the third set are at 45, 225, 135, 315 degrees.

[0012] A method of communication, in accordance with one embodiment of the present invention includes, in part, applying M phases of a baseband signal to be transmitted to N upconverters, and applying a different one of N sets of phases of a LO signal to each of the N upconverters. Each of the N sets includes a different one of M phases of the LO signal. The method further includes, in part, applying an output signal of each of the N upconverters to a different one of N associated amplifiers to generate N amplified signals, selecting a gain of at least a first one of the N amplifiers to be different from a gain of a remaining one of the N amplifiers, and combining the N amplified signals to generate an output signal. N and M are integers greater than 1.

[0013] A method of communication, in accordance with another embodiment of the present invention includes, includes, in part, applying M phases of a baseband signal to be transmitted to N sets of upconverters, each set comprising Q upconverters. The M phases of the baseband signal are applied to each of the Q upconverters of each of the N sets. The method further includes, in part, applying to each of the Q upconverters of each of the N sets one of Q*N sets of phases of a LO signal. Each of the Q*N sets includes M phases of the LO signal. Each of the Q upconverters generates an upconverted signal and its inverse signal. The method further includes, in part, combining the N in-phase signals generated by the Q converters of each of the N sets thereby to generate N combined in-phase signals, and combining the N inverse signals generated by the Q converters of each of the N sets thereby to generate N combined inverse signals. Undesired upconverted signal component at a frequency equal to a multiple of a sum of the LO signal frequency and the baseband signal frequency, or a multiple of a difference between the LO signal frequency and the baseband signal frequency is substantially suppressed from the combined in-phase and inverse signals. Q, M and N are positive integers.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] Aspects of the disclosure are illustrated by way of example. In the accompanying figures, like reference numbers indicate similar elements, and:

[0015] Figure 1 is a block diagram of a wireless communication device, in accordance with one embodiment of the present invention.

[0016] Figure 2A is a block diagram of a number of components disposed in a transmit chain of a transmitter, in accordance with one exemplary embodiment of the present invention.

[0017] Figure 2B is a generalized block diagram of the transmit chain illustrated in Figure 2A, in accordance with one exemplary embodiment of the present invention.

[0018] Figure 3A shows the phasors corresponding to a number of signals of Figure 2A at a fundamental frequency of (LO+BB) defined by the local oscillator frequency of LO and baseband frequency of BB), in accordance with one embodiment of the present invention.

[0019] Figure 3B shows the phasors corresponding to the signals of Figure 3A at the third harmonic frequency of 3*(LO+BB), in accordance with one embodiment of the present invention.

[0020] Figure 3C shows the phasors corresponding to the signals of Figure 3A at the fifth harmonic frequency of 5*(LO+BB), in accordance with one embodiment of the present invention.

[0021] Figure 4A is a block diagram of a number of components disposed in the transmit chain of a transmitter, in accordance with one exemplary embodiment of the present invention.

[0022] Figure 4B is a generalized block diagram of the transmit chain illustrated in Figure 4A, in accordance with one exemplary embodiment of the present invention.

[0023] Figures 5A-5C show the phasors corresponding to a number of transmit signals of Figure 4A at a fundamental frequency of (LO+BB) defined by the local oscillator frequency of LO and baseband frequency of BB), in accordance with one embodiment of the present invention.

[0024] Figures 6A-6C show the phasors corresponding to the signals of Figures 5A-5C at the third order spurious upconversion product frequency of (3*LO-BB), in accordance with one embodiment of the present invention.

[0025] Figures 7A-7C show the phasors corresponding to the signals of Figures 5A-5C at the fifth order spurious upconversion product frequency of (5*LO+BB), in accordance with one embodiment of the present invention.

[0026] Figure 8 is a flowchart for transmitting a signal, in accordance with one embodiment of the present invention.

[0027] Figure 9 is a flowchart for transmitting a signal, in accordance with another embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0028] Several illustrative embodiments will now be described with respect to the accompanying drawings, which form a part hereof. While particular embodiments, in which one or more aspects of the disclosure may be implemented, are described below, other embodiments may be used and various modifications may be made without departing from the scope of the disclosure.

[0029] Figure 1 is a block diagram of a wireless communication device 50 (hereinafter alternatively referred to as device) used in a wireless communication system, in accordance with one embodiment of the present invention. Device 50 may be a cellular phone, a personal digital assistant (PDA), a modem, a handheld device, a laptop computer, and the like.

[0030] Device 50 may communicate with one or more base stations on the downlink (DL) and/or uplink (UL) at any given time. The downlink (or forward link) refers to the communication link from a base station to the device. The uplink (or reverse link) refers to the communication link from the device to the base station.

[0031] A wireless communication system may be a multiple-access system capable of supporting communication with multiple users by sharing the available system resources (e.g., bandwidth and transmit power). Examples of such systems include code division multiple access (CDMA) systems, time division multiple access (TDMA) systems, frequency division multiple access (FDMA) systems, orthogonal frequency division multiple access (OFDMA) systems, spatial division multiple access (SDMA) systems, and the long term evolution (LTE) systems.

[0032] Device 50 is shown as including, in part, frequency upconverter/modulator 10, digital to analog converter (DAC) 12, filter 14 and amplifier 16, which collectively form a transmission channel. Incoming digital signal 22 is first applied to DAC 12. The converted analog signal is filtered by filter 14, frequency upconverted with upconverter/modulator 10 and its output further amplified by amplifier 16. The amplified signal generated by amplifier 16 may be optionally further amplified using a power amplifier 18 before being transmitted by antenna 20. In certain embodiments, the amplified signal at the output of each of the driver amplifier 16 and/or power amplifier 18 may also be filtered (not shown) before passing through other blocks.

[0033] Figure 2A is a block diagram of a number of components disposed in a transmit chain 24, in accordance with one exemplary embodiment of the present invention. Transmit chain 24 is shown as including, in part, filters 102, 104, quadrature upconverters 120, 122, 124, driver amplifiers 130, 132, 134, and combiners 140, 142. Transmit chain 24 is adapted to upconvert the frequency of the signals it receives and suppress spurious harmonics generated in driver amplifiers 130, 132, and 134, as described further below.

[0034] Filter 102 filters out undesired signals from the I-channel baseband signals I_{bb} and IB_{bb} to generate filtered baseband signals I_{bb}_F and IB_{bb}_F. Signals I_{bb} and IB_{bb} are inverse (complement) of one another. Likewise, filter 104 filters out undesired signals from Q-channel baseband signals Q_{bb} and QB_{bb} to generate filtered baseband signals Q_{bb}_F and QB_{bb}_F. The four filtered baseband signals I_{bb}_F, IB_{bb}_F, Q_{bb}_F and QB_{bb}_F that are 90° phase shifted with respect to one another are applied to each of the quadrature upconverters 120, 122, 124. As shown, quadrature upconverter 120 receives four phases 315, 135, 45, 225 of a local oscillator (not shown). Quadrature upconverter 122 receives four phases 0, 180, 90, 270 of the local oscillator. Quadrature upconverter 124 receives four phases 45, 225, 135, 315 of the local oscillator. Accordingly, the four phases of the LO signal received by quadrature upconverter 120 lead the corresponding phases of the LO signal received by quadrature upconverter 122 by 45°. Likewise, the four phases of the LO signal received by quadrature upconverter 124 lag the corresponding phases of the LO signal received by quadrature upconverter 122 by 45°.

[0035] Quadrature upconverter 120 performs frequency upconversion to generate RF signals I_1, Q_1; quadrature upconverter 122 performs frequency upconversion to generate

RF signals I_2, Q_2; and quadrature upconverter 124 performs frequency upconversion to generate RF signals I_3, Q_3. Amplifier 130 amplifies signals I_1/Q_1 to generate a pair of complementary signals A and AB; amplifier 132 amplifies signals I_2/Q_2 to generate a pair of complementary signals B and BB; and amplifier 134 amplifies signals I_3/Q_3 to generate a pair of complementary signals C and CB.

[0036] Since the four phases of the local oscillator signal applied to quadrature upconverter 120 lead the corresponding phases of the local oscillator signal applied to quadrature upconverter 122 by 45°, signal I_1 leads signal I_2 by 45° and signal Q_1 leads signal Q_2 by 45°. Therefore, signal A leads signal C by 45° and signal AB leads signal CB by 45°. Likewise, because the four phases of the local oscillator signal applied to quadrature upconverter 124 lag the corresponding phases of the local oscillator signal applied to quadrature upconverter 122 by 45°, signal B lags signal C by 45° and signal BB lags signal CB by 45°.

[0037] Figure 2B is a generalized block diagram of the transmit chain illustrated in Figure 2A, in accordance with one exemplary embodiment of the present invention. As illustrated, in general, the transmit chain 26 may include M filters 202 each receiving one of the M input signals and output one of the output signals out_1 through out_M. Each output signal (e.g., out_1) may include a signal and its inverse. The output signals may enter the generalized upconverters 222_1 through 222_N. Each of the generalized upconverters 222 may include M/2 double balanced mixers. Output of the N upconverters 222 may be amplified with N amplifiers 224_1 through 224_N. The amplified signals may then be combined with the generalized combiner 226 to generate output 228.

[0038] Figure 3A shows three phasors corresponding to signals A, B and C having a fundamental frequency defined by the local oscillator (LO) frequency of LO and baseband frequency of BB, namely LO+BB. As seen in Figure 3A, at this fundamental frequency, signal A leads signal C by 45° and signal B lags signal C by 45°. Figures 3B and 3C show the same three phasors respectively at the third harmonic frequency of 3*(LO+BB), and fifth harmonic frequency of 5*(LO+BB). For the third harmonic, the difference between phases of signals C and A, or C and B is 3*45°=135°. For the fifth harmonic, the difference between phases of signals C and A, or C and B is 5*45°=225°.

[0039] Referring to Figure 3A, it is seen that the three phasors corresponding to signals A, B, and C at the fundamental and desired frequency of LO+BB reinforce one another. Therefore, the output signal Outp of combiner 140, which is generated by combining/adding signals A, B , C, is enhanced at the fundamental frequency.

[0040] Referring to Figure 3B, it is seen that in order to substantially suppress the third harmonic, the sum of the projections (magnitudes) of phasors A and B along the x-axis has to be equal to the magnitude of phasor C along the same axis. Assuming phasors A and B have a length of 1, because the angle between phasors C and A as well as the angle between phasors C and B is 135°, the x-component of each of phasors A and B has a length (value) of $\frac{\sqrt{2}}{2}$. Therefore, the sum of the x-components of signals A and B at the third harmonic frequency is equal to $\sqrt{2}$. Consequently, to substantially eliminate the third harmonic, phasor C is selected to have a length that is $\sqrt{2}$ times the lengths of phasors A and B. This causes the three phasors to cancel each other along both the x and y axes. In order for phasor C to have a length (size) that is $\sqrt{2}$ times the length of phasors A and B, amplifier 132 is selected to have a gain that is $2^{\frac{1}{6}}$ times the gains of amplifiers 130, 134. Consequently, if amplifiers 130, 134 have a gain of G, amplifier 132 has a gain of $2^{\frac{1}{6}}$*G.

[0041] When amplifier 132 is selected to have a gain of $2^{\frac{1}{6}}$*G, the third harmonic of signals I_2 and Q_2 is amplified by a factor of $(2^{\frac{1}{6}})^3$--which is equal to $\sqrt{2}$. In other words, because amplifiers 130, 134 have a gain of G, whereas amplifier 132 has a gain of $(2^{\frac{1}{6}})$, the third harmonic of signal C has a magnitude that is greater than that of signals A and B by a factor of $(2^{\frac{1}{6}})^3$ which is equal to $\sqrt{2}$. Likewise, the third harmonic of signal CB has a magnitude that is larger than that of signals AB and BB by a factor of $\sqrt{2}$. Accordingly, as described above, output signal Outp that is generated by combining/adding signals A, B, C, has a substantially reduced component at the third harmonic frequency of 3*(LO+BB). Likewise, output signal Outn that is generated by combining/adding signals AB, BB, CB, has a substantially reduced component at the third harmonic frequency of 3*(LO+BB).

[0042] Referring to Figure 3C, it is seen that the y-components of signals A and B cancel one another. Therefore, in order to substantially suppress the fifth harmonic, the sum of the x-components of phasors A and B has to be equal to the x-component of phasor C. Assuming phasors A and B have a length of 1, because the angle between phasors C and A as well as the angle between phasors C and B is 225°, the magnitude of each of phasors A and B along the x-axis is $\frac{\sqrt{2}}{2}$. Consequently, to substantially eliminate the fifth harmonic, phasor C is selected to have a length that is $\sqrt{2}$ times the length of phasors A and B. This causes the three phasors to cancel each other along both the x and y axes. For phasor C to have a length that is $\sqrt{2}$ times the length of phasors A and B, amplifier 132 is selected to have a gain that is $2^{\frac{1}{10}}$ times the gains of amplifiers 130, 134. Consequently, if amplifiers 130, 134 have a gain of G, amplifier 132 has a gain of $2^{\frac{1}{10}}$*G.

[0043] When amplifier 132 is selected to have a gain of $2^{\frac{1}{10}}$*G, the fifth harmonic of signals I_2 and Q_2 is amplified by a factor of $(2^{\frac{1}{10}})^5$--which is equal to $\sqrt{2}$. In other words, because amplifiers 130, 134 have a gain of G, whereas amplifier 132 has a gain of ($2^{\frac{1}{10}}$), the fifth harmonic of signal C has a magnitude that is larger than that of signals A and B by a factor of $(2^{\frac{1}{10}})^5$ which is equal to $\sqrt{2}$. Likewise, the fifth harmonic of signal CB has a magnitude that is larger than that of signals AB and BB by a factor of $\sqrt{2}$. Accordingly, output signal Outp that is generated by combining/adding signals A, B, C (using combiner 140) has a substantially reduced component at the fifth harmonic frequency of 5*(LO+BB). Likewise, output signal Outn that is generated by combining/adding signals AB, BB, CB (using combiner 142) has a substantially reduced component at the fifth harmonic frequency of 5*(LO+BB). Consequently, in accordance with the present invention, by adjusting the gain of amplifier 132 relative to the gains of amplifiers 130 and 134, the undesired harmonics caused by non-linearity of the amplifiers is substantially suppressed.

[0044] In one embodiment, each of the frequency upconverters 120, 122, 124 may be a composite harmonic-rejective frequency upconverter that, in turn, includes a multitude of upconverters. Figure 4A is a block diagram of another exemplary embodiment of a frequency upconverter. Transmit chain 24 of Figure 4A is shown as including, in part, filters 102, 104, quadrature upconverters 120_1, 120_2, 120_3 collectively forming upconverter 120, quadrature upconverters 122_1, 122_2, 122_3 collectively forming upconverter 122, quadrature upconverters 124_1, 124_2, 124_3 collectively forming upconverter 124, driver amplifiers 130, 132, 134, and combiners 202, 204, 206, 208, 210, 212, 140, 142.

[0045] Transmit chain 24 of Figure 4A is adapted to upconvert the frequency of the signals it receives and suppress the third harmonic frequency of 3*(LO+BB) or fifth harmonic frequency of 5*(LO+BB), as described above in reference to Figures 2 and 3A-3C. Transmit chain 24 of Figure 4A is further adapted to suppress the third order spurious mixing product of 3*LO-BB caused by the upconverters, the fifth order spurious mixing product of 5*LO+BB caused by the upconverters, as well as the undesired counter-IM3 product of LO-3*BB caused by the driver amplifiers. While the embodiment of Figure 4A is described with reference to a frequency upconversion circuit having 3 sets of upconverters 120, 122, 124 each set having 3 upconverters (for a total of 9 upconverters), it is understood that other embodiments may have N sets of upconverters with each set including Q upconverters, where N and Q are positive integers. Furthermore, while the frequency upconversion circuit of Figure 4A is shown as receiving 9 sets of phases of the LO signal with each set including 4 different phases of the LO signal, it is understood that other embodiments may receive N×Q sets of phases of a LO signal with each set including M different phases of the LO signal, where N, Q and M are positive integers. For certain embodiments, some of the N×Q sets of phases of the LO signal may be distinct and some of the sets may be similar to one another. For example, if N=3 and Q=3, out of 9 sets of phases of the LO signal, 5 sets may be distinct and 4 sets may be duplicate of the other sets.

[0046] Filter 102 filters out undesired signals from the I-channel baseband signals I_{bb} and IB_{bb} to generate filtered baseband signals I_{bb}_F and IB_{bb}_F. Signals I_{bb} and IB_{bb} are inverse of one another. Likewise, filter 104 filters out undesired signals from Q-channel baseband signals Q_{bb} and QB_{bb} to generate filtered baseband signals Q_{bb}_F and QB_{bb}_F. The four filtered baseband signals I_{bb}_F, IB_{bb}_F, Q_{bb}_F and QB_{bb}_F that are 90° phase shifted with respect to one another are applied to each of the quadrature upconverters 120_1, 120_2, 120_3, 122_1, 122_2, 122_3, 124_1, 124_2, 124_3.

[0047] As shown, upconverter 120_1 receives four phases 270, 90, 0, 180 of the local oscillator; upconverter 120_2 receives four phases 315, 135, 45, 225 of the local oscillator; upconverter 120_3 receives four phases 0, 180, 90, 270, of the local oscillator;

upconverter 122_1 receives four phases 315, 135, 45, 225 of the local oscillator; upconverter 122_2 receives four phases 0, 180, 90, 270 of the local oscillator; upconverter 122_3 receives four phases 45, 225, 135, 315 of the local oscillator; upconverter 124_1 receives four phases 0, 180, 90, 270 of the local oscillator; upconverter 124_2 receives four phases 45, 225, 135, 315 of the local oscillator; and upconverter 124_3 receives four phases 90, 270, 180, 0 of the local oscillator (LO).

[0048] Accordingly, the four phases of the LO signal received by upconverter 120_1 lead the corresponding phases of the LO signal received by upconverter 120_2 by 45°, and the four phases of the LO signal received by upconverter 120_3 lag the corresponding phases of the LO signal received by quadrature upconverter 120_2 by 45°. Similarly, the four phases of the LO signal received by upconverter 122_1 lead the corresponding phases of the LO signal received by upconverter 122_2 by 45°, and the four phases of the LO signal received by upconverter 122_3 lag the corresponding phases of the LO signal received by quadrature upconverter 122_2 by 45°. Likewise, the four phases of the LO signal received by upconverter 124_1 lead the corresponding phases of the LO signal received by upconverter 124_2 by 45°, and the four phases of the LO signal received by upconverter 124_3 lag the corresponding phases of the LO signal received by quadrature upconverter 124_2 by 45°.

[0049] Furthermore, the four phases of the LO signal received by upconverter 120_i lead the corresponding phases of the LO signal received by quadrature upconverter 122_i by 45°, where i is an integer varying from 1 to 3 in this exemplary embodiment. For example, the four phases 315, 135, 45, 225 of the LO signal received by upconverter 120_2 lead the corresponding four phases 0, 180, 90, 270 of the LO signal received by quadrature upconverter 122_2 by 45°. Likewise, the four phases of the LO signal received by upconverter 124_i lag the corresponding phases of the LO signal received by quadrature upconverter 122_i by 45°. For example, the four phases 45, 225, 135, 315 of the LO signal received by upconverter 124_2 lag the corresponding phases 0, 180, 90, 270 of the LO signal received by quadrature upconverter 122_2 by 45°.

[0050] Upconverter 120_1 performs frequency upconversion to generate upconverted in-phase and inverse RF signals G_1, G_2; upconverter 120_2 performs frequency upconversion to generate upconverted in-phase and inverse RF signals H_1, H_2; upconverter 120_3 performs frequency upconversion to generate upconverted in-phase and its inverse RF signals I_1, I_2; upconverter 122_1 performs frequency upconversion to generate upconverted in-phase and inverse RF signals D_1, D_2; upconverter 122_2 performs frequency upconversion to generate upconverted in-phase and inverse RF signals E_1, E_2; upconverter 122_3 performs frequency upconversion to generate upconverted in-phase and inverse RF signals F_1, F_2; upconverter 124_1 performs frequency upconversion to generate upconverted in-phase and inverse RF signals J_1, J_2; upconverter 124_2 performs frequency upconversion to generate upconverted in-phase and inverse RF signals K_1, K_2; and upconverter 124_3 performs frequency upconversion to generate upconverted in-phase and inverse RF signals L_1, L_2.

[0051] Combiner 202 is adapted to add/combine signals G_1, H_1, I_1 to generate signal M; combiner 204 is adapted to add/combine signals G_2, H_2, I_2 to generate signal N; combiner 206 is adapted to add/combine signals D_1, E_1, F_1 to generate signal O; combiner 208 is adapted to add/combine signals D_2, E_2, F_2 to generate signal p; combiner 210 is adapted to add/combine signals J_1, K_1, L_1 to generate signal S; and combiner 212 is adapted to add/combine signals J_2, K_2, L_2 to generate signal T. Amplifier 130 amplifies signals M and N to generate a pair of complementary signals A and AB; amplifier 132 amplifies signals O and P to generate a pair of complementary signals B and BB; and amplifier 134 amplifies signals S and T to generate a pair of complementary signals C and CB.

[0052] Since the four phases of the local oscillator signal applied to quadrature upconverter 120_1 lead the corresponding phases of the local oscillator signal applied to quadrature upconverter 120_2 by 45°, signals G_1 and G_2 respectively lead signals H_1 and H_2 by 45°. Likewise, because the four phases of the local oscillator signal applied to quadrature upconverter 120_3 lag the corresponding phases of the local oscillator signal applied to quadrature upconverter 120_2 by 45°, signals I_1 and I_2 respectively lag signals H_1 and H_2 by 45°. For the same reason, signals D_1 and D_2 respectively lead signals E_1 and E_2 by 45°, and signals F_1 and F_2 respectively lag signals E_1 and E_2 by 45°. Likewise, signals J_1 and J_2 respectively lead signals K_1 and K_2 by 45°, and signals L_1 and L_2 respectively lag signals K_1 and K_2 by 45°.

[0053] Figure 4B is a generalized block diagram of the transmit chain illustrated in Figure 4A, in accordance with one exemplary embodiment of the present invention. As illustrated, in general, the transmit chain 28 may include M filters 202 each receiving one of the M input signals and output one of the output signals out_1 through out_M. Each output signal (e.g., out_1) may include a signal and its inverse. The output signals may enter each of the N sets of the generalized upconverters (e.g., 440_1 through 440_Q). Each of the generalized upconverters 440 may include M/2 double balanced mixers or M single balanced mixers. Output of the Q upconverters 440 may be combined with combiner 450 before being amplified with amplifier 224_1. Outputs of the N amplifiers 224_1 through 224_N may then be combined with the generalized combiner 226 to generate output 228.

[0054] Figure 5A shows three phasors associated with signals I_1, G_1 and H_1 having a fundamental frequency defined by the local oscillator (LO) frequency of LO and baseband frequency of BB, namely LO+BB. As seen in Figure 5A, at this fundamental frequency, signal G_1 leads signal H_1 by 45° and signal I_1 lags signal H_1 by 45°. Figure 5B shows three phasors associated with signals E_1, F_1 and D_1 having a fundamental frequency of LO+BB. As seen in Figure 5B, at this fundamental frequency, signal D_1 leads signal E_1 by 45° and signal F_1 lags signal E_1 by 45°. Figure 5C shows three phasors associated with signals J_1, K_1 and L_1 having a fundamental frequency of LO+BB. As seen in Figure 5C, at this fundamental frequency, signal J_1 leads signal K_1 by 45° and signal L_1 lags signal K_1 by 45°.

[0055] Figure 6A shows the three phasors associated with signals G_1, H_1, I_1 at the spurious upconversion mixing product frequency of (3*LO-BB). The value (amplitude) of signal H_1 is selected to be $\sqrt{2}$ times greater than the value of each of signals G_1 and I_1. Thus, the y-component of signal H_1 cancels signal G_1, and the x-component of signal H_1 cancels signal I_1. Figure 6B shows the three phasors associated with signals D_1, E_1, F_1 at the spurious upconversion mixing product frequency of (3*LO-BB). The value of signal E_1 is selected to be $\sqrt{2}$ times greater than the value of each of signals D_1 and F_1. Thus, the y-components of signals D_1 and F_1 cancel each other. Furthermore, the sum of the x-components of signals D_1 and F_1 cancel signal E_1. Figure 7C shows the three phasors associated with signals J_1, K1, L_1 at the spurious upconversion mixing product frequency of (3*LO-BB). The value of signal K_1 is selected to be $\sqrt{2}$ times greater than the value of each of signals L_1 and J_1. Thus, the x-component of signal K_1 cancels signal J_1, and the y-component of signals K_1 cancels signal L_1. Accordingly, the spurious upconversion mixing product at frequency (3*LO-BB) is substantially reduced at (i) the outputs M and N of combiners 202, 204, (ii) the outputs O and P of combiners 206, 208;

and (iii) the outputs S, T of combiners 201, 212. In other words, in accordance with one aspect of the present invention, the spurious upconversion mixing products at frequency (3*LO-BB) is canceled or substantially reduced at the outputs of combiners, i.e., at the inputs of amplifiers 130, 132, 134.

[0056] Figure 7A shows the three phasors associated with signals G_1, H_1, I_1 at the spurious upconversion product frequency of (5*LO+BB). The value of signal H_1 is selected to be √2 times greater than the value of each of signals G_1 and H_1. Thus, the y-component of signal H_1 cancels signal G_1, and the x-component of signal H_1 cancels signal I_1. Figure 7B shows the three phasors associated with signals D_1, E_1, F_1 at the spurious upconversion product frequency of (5*LO+BB). The value of signal E_1 is selected to be √2 times greater than the value of each of signals D_1 and F_1. Thus, the y-components of signals D_1 and F_1 cancel each other. Furthermore, the sum of the x-components of signals D_1 and F_1 cancel signal E_1.

[0057] Figure 7C shows the three phasors associated with signals J_1, K1, L_1 at the spurious upconversion product frequency of (5*LO+BB). The value of signal K_1 is selected to be √2 times greater than the value of each of signals L_1 and J_1. Thus, the x-component of signal K_1 cancels signal J_1, and the y-component of signals K_1 cancels signal L_1. Accordingly, the spurious upconversion products at frequency (5*LO+BB) is substantially canceled at (i) the outputs M and N of combiners 202, 204, (ii) the outputs O and P of combiners 206, 208; and (iii) the outputs S, T of combiners 201, 212. In other words, in accordance with one aspect of the present invention, the spurious upconversion product at frequency (5*LO+BB) is canceled or substantially reduced at the outputs of combiners, i.e., at the inputs of the amplifiers.

[0058] It should be noted that the proposed method also rejects undesired components at frequency LO-3BB. The undesired components at frequency LO-3BB are generated because of the presence of third order nonlinearity in amplifiers 130,132,134 as a result of intermodulation of input signals with spectral components at LO+BB and 3*LO-BB. The embodiment as illustrated in Figure 4A, rejects 3*LO-BB components by design at the combiner outputs 202, 204, 206, 208, 210 and 212. As a result of this rejection of the 3*LO-BB component, no substantial LO-3*BB product can be generated at the outputs of amplifiers 130, 132, 134.

[0059] Figure 8 is a flowchart 200 for a communication method, in accordance with one embodiment of the present invention. To perform the communication, M phases of a signal to be transmitted are applied 202 to N upconverters. One of N sets of phases of a LO signal are also applied 204 to each of the N upconverters. Each of the N sets of phases includes a different one of M phases of the LO signal. The output of each upconverter is applied 206 to an associated amplifier to generate N amplified signals. The gain of at least one of the amplifiers is set 208 to a value that is different from the gain of the remaining amplifiers. The amplified signals are combined 216 to generate an output signal that has a substantially reduced harmonics of the upconverted signal to be transmitted.

[0060] Figure 9 is a flowchart 200 for a communication method, in accordance with one embodiment of the present invention. To perform the communication, M phases of a signal to be transmitted are applied 304 to N sets of upconverters. Each of the N sets includes Q upconverters. As illustrated, the M phases of the signal are applied to each of the Q upconverters of each of the N sets. One of N×Q sets of phases of a local oscillator signal are also applied 306 to each of the N×Q upconverters. Each of the N×Q sets includes M phases of the LO signal. Each of the Q upconverters generates an upconverted in-phase signal and an upconverted inverse signal in response. Thereafter, the Q in-phase signals generated by the Q upconverters of each of the N sets are combined 308 to generate N combined in-phase signals. The Q inverse signals generated by the Q upconverters of each of the N sets are also combined 310 to generate N combined inverse signals.

[0061] The above embodiments of the present invention are illustrative and not limitative. The embodiments of the present invention are not limited by the number of upconverters, the number of sets of LO phases, or the number of LO phases in each such set. Nor are the embodiments of the present invention limited by any particular phases of the local oscillator used in each set. Other additions, subtractions or modifications are obvious in view of the present disclosure and are intended to fall within the scope of the appended claims.

WHAT IS CLAIMED IS:

CLAIMS

1. A communication device having a transmission path comprising:

N upconverters each receiving M phases of a baseband signal to be transmitted, each upconverter further receiving a different one of N sets of phases of a local oscillator (LO) signal, each of the N sets comprising M different phases of the LO signal;

N amplifiers each responsive to a different one of the N upconverters to generate N amplified signals; and

at least one combiner adapted to combine the N amplified signals to generate an output signal, wherein a frequency component falling at a multiple of a sum of a LO signal frequency and a baseband signal frequency, or a multiple of a difference between the LO signal frequency and the baseband signal frequency is substantially suppressed from the output signal by selecting a gain of at least a first one of the N amplifiers to be different from a gain of a remaining one of the N amplifiers, wherein N and M are integers greater than 1.

2. The communication device of claim 1 further comprising:

a first filter receiving a baseband in-phase signal to generate a first filtered in-phase signal to be transmitted; and

a second filter receiving a baseband quadrature-phase signal to generate a second filtered quadrature-phase of the signal to be transmitted.

3. The communication device of claim 2 wherein said baseband in-phase signal comprises a first pair of complementary signals and wherein said baseband quadrature-phase signal comprises a second pair of complementary signals.

4. The communication device of claim 1 wherein N is 3 and M is 4.

5. The communication device of claim 4 wherein to eliminate a third harmonic, first and second amplifiers are selected to have an equal gain and a third amplifier is selected to have a gain larger than the gain of the first and second amplifiers.

6. The communication device of claim 5 wherein the gain of the third amplifier is substantially $2^{\frac{1}{6}}$ times the gain of the first and second amplifiers.

7. The communication device of claim 5 wherein the gain of the third amplifier is substantially $2^{\frac{1}{10}}$ times the gain of the first and second amplifiers.

8. The communication device of claim 5 wherein the four phases of the LO signal in a first set lead corresponding four phases of the LO signal in a second set by 45°.

9. The communication device of claim 8 wherein the four phases of the LO signal in a third set lag corresponding four phases of the LO signal in the second set by 45°.

10. The communication device of claim 9 wherein the 4 phases of the LO signal in the first are 315, 135, 45, 225 degrees the 4 phases of the LO signal in the second set are 0, 180, 90, 270 degrees and the 4 phases of the LO signal in the third set are 45, 225, 135, 315 degrees.

11 A communication device having a transmission path comprising:

N sets of upconverters each set comprising Q upconverters, each of the Q upconverters in each of the N sets receiving M phases of a baseband signal to be transmitted, each of the Q upconverters in each of the N sets further receiving one of N×Q sets of phases of a local oscillator (LO) signal, each of the N×Q sets comprising M phases of the LO signal, each of the Q upconverters generating an upconverted in-phase signal and an upconverted inverse signal; and

N sets of combiners each set associated with a different one of the N sets of upconverters, wherein a first combiner in each set combines the Q in-phase signals the first combiner receives from its associated upconverters, and wherein a second combiner in each set combines the Q inverse signals the second combiner receives from its associated upconverters, wherein Q, M and N are positive integers, wherein a frequency component falling at a multiple of a sum of the LO signal and the baseband signal, or a multiple of a difference between the LO signal and the baseband signal is substantially suppressed from combined in-phase and inverse signals.

12. The communication device of claim 11 further comprising:

a first filter receiving a baseband in-phase signal to generate a first filtered in-phase signal to be transmitted; and

a second filter receiving a baseband quadrature-phase signal to generate a second filtered quadrature-phase of the signal to be transmitted.

13. The communication device of claim 12 wherein said baseband in-phase signal comprises a first pair of complementary signals and wherein said baseband quadrature-phase signal comprises a second pair of complementary signals.

14. The communication device of claim 11 wherein each of N and Q are equal to three.

15. The communication device of claim 14 wherein N×Q sets of phases of the LO signal comprise 5 distinct sets, and M is equal to 4.

16. The communication device of claim 11 further comprising:

N amplifiers each associated with a different one of the N sets of combiners, each amplifier adapted to amplify the signal and its inverse that it receives from its associated set of combiners.

17. The communication device of claim 16 wherein a gain of at least one of the amplifier is substantially $2^{\frac{1}{6}}$ times the gain of remaining (N-1) amplifiers.

18. The communication device of claim 16 wherein a gain of at least one of the amplifier is substantially $2^{\frac{1}{10}}$ times the gain of remaining (N-1) amplifiers.

19. The communication device of claim 14 wherein the 4 phases of the LO signal received by a first upconverter in each of the N sets lead corresponding 4 phases of the LO signal received by a second upconverter in the set by 45°, and the 4 phases of the LO signal received by a third upconverter in each of the N sets lag the corresponding 4 phases of the LO signal received by the second upconverter in the set by 45°.

20. The communication device of claim 19 wherein the 4 phases of the LO signal in the first set are 270, 90, 0, 180 degrees, the 4 phases of the LO signal in the

second set are 315, 135, 45, 225 degrees, the 4 phases of the LO signal in the third are 0, 180, 90, 270 degrees, the 4 phases of the LO signal in the fourth set are 45, 225, 135, 315 degrees, and the 4 phases of the LO signal in the fifth set are 90, 270, 180, 0 degrees.

21. A method of communication comprising:

applying M phases of a baseband signal to be transmitted to N upconverters;

applying a different one of N sets of phases of a local oscillator (LO) signal to each of the N upconverters, each of the N sets comprising M different phases of the LO signal;

applying an output signal of each of the N upconverters to a different one of N associated amplifiers to generate N amplified signals;

selecting a gain of at least a first one of the N amplifiers to be different from a gain of a remaining one of the N amplifiers; and

combining the N amplified signals to generate an output signal, wherein a frequency component falling at a multiple of a sum of a LO signal frequency and a baseband signal frequency, or a multiple of a difference between the LO signal frequency and the baseband signal frequency is substantially suppressed from the output signal, and wherein N and M are integers greater than 1.

22. The method of claim 21 further comprising:

filtering a baseband in-phase signal to generate a first filtered in-phase signal to be transmitted; and

filtering a baseband quadrature-phase signal to generate a second filtered quadrature-phase signal to be transmitted.

23. The method of claim 22 wherein said baseband in-phase signal comprises a first pair of complementary signals and wherein said baseband quadrature-phase signal comprises a second pair of complementary signals.

24. The method of claim 21 wherein N is 3 and M is 4.

25. The method of claim 24 wherein to eliminate a third harmonic, first and second amplifiers are selected to have equal gains and a third amplifier is selected to have a gain larger than the gain of the first and second amplifiers.

26. The method of claim 25 wherein the gain of third amplifier is selected to be substantially $2^{\frac{1}{6}}$ times the gain of the first and second amplifiers.

27. The method of claim 25 wherein the gain of third amplifier is selected to be substantially $2^{1/10}$ times the gain of the first and second amplifiers.

28. The method of claim 25 wherein the 4 phases of the LO signal in a first set lead corresponding phases of the LO signal in a second set by 45°.

29. The method of claim 28 wherein the 4 phases of the LO signal in a third set lag corresponding phases of the LO signal in the second set by 45°.

30 The method of claim 29 wherein the 4 phases of the LO signal in the first set are 315, 135, 45, 225 degrees, the 4 phases of the LO signal in the second set are 0, 180, 90, 270 degrees, and the 4 phases of the LO signal in the third set are 45, 225, 135, 315 degrees.

31. A method of communication comprising:

applying M phases of a baseband signal to be transmitted to N sets of upconverters, each set comprising Q upconverters, wherein the M phases of the baseband signal are applied to each of the Q upconverters of each of the N sets;

applying to each of the Q upconverters of each of the N sets one of N×Q sets of phases of a local oscillator (LO) signal, each of the N×Q sets comprising M phases of the LO signal, each of the Q upconverters generating upconverted signal and inverse signal;

combining the Q in-phase upconverted signals generated by the Q converters of each of the N sets thereby to generate N combined in-phase upconverted signals; and

combining the Q inverse signals generated by the Q converters of each of the N sets thereby to generate N combined inverse signals, wherein a frequency component falling at a multiple of a sum of a LO signal frequency and a baseband signal frequency, or a multiple of a difference between the LO signal frequency and the baseband signal frequency is substantially suppressed from the combined in-phase and inverse signals, wherein Q, M and N are positive integers.

32. The method of claim 31 further comprising:

filtering a baseband in-phase signal to generate a first filtered in-phase signal to be transmitted; and

filtering a baseband quadrature-phase signal to generate a second quadrature -phase signal to be transmitted.

33. The method of claim 32 wherein said baseband in-phase signal comprises a first pair of complementary signals and wherein said baseband quadrature-phase signal comprises a second pair of complementary signals.

34. The method of claim 33 wherein each of N and Q are equal to three.

35. The method of claim 34 wherein N×Q sets of phases of the LO signal comprise 5 distinct sets, and M is equal to 4.

36. The method of claim 31 further comprising:

amplifying each of the N combined in-phase signals; and

amplifying each of the N combined inverse signals.

37. The method of claim 36 wherein at least one of the amplifications is substantially $2^{\frac{1}{6}}$ times the remaining amplifications.

38. The method of claim 36 wherein at least one of the amplifications is substantially $2^{\frac{1}{10}}$ times the remaining amplifications.

39. The method of claim 34 wherein the 4 phases of the LO signal received by a first upconverter in each of the N (3) sets lead corresponding 4 phases of the LO signal received by a second upconverter in the set by 45°, and the 4 phases of the LO signal received by a third upconverter in each of the N (3) sets lag the corresponding 4 phases of the LO signal received by the second upconverter in the set by 45°.

40. The method of claim 39 wherein the 4 phases of the LO signal in the first are 270, 90, 0, 180 degrees, the 4 phases of the LO signal in the second set are 315, 135, 45, 225 degrees, the 4 phases of the LO signal in the third are 0, 180, 90, 270 degrees, the 4 phases of the LO signal in the fourth set are 45, 225, 135, 315 degrees, and the 4 phases of the LO signal in the fifth set are 90, 270, 180, 0 degrees.

41. A communication device comprising:

means for applying M phases of a baseband signal to be transmitted to N upconverters;

means for applying a different one of N sets of phases of a local oscillator (LO) signal to each of the N upconverters, each of the N sets comprising M different phases of the LO signal;

means for applying an output signal of each of the N upconverters to a different one of N associated amplifiers to generate N amplified signals;

means for selecting a gain of at least a first one of the N amplifiers to be different from a gain of a remaining one of the N amplifiers; and

means for combining the N amplified signals to generate an output signal, wherein a frequency component falling at a multiple of a sum of a LO signal frequency and a baseband signal frequency, or a multiple of a difference between the LO signal frequency and the baseband signal frequency is substantially suppressed from the output signal, and wherein N and M are integers greater than 1.

42. The communication device of claim 41 further comprising:

means for filtering a baseband in-phase signal to generate a first filtered in-phase signal to be transmitted; and

means for filtering a baseband quadrature-phase signal to generate a second filtered quadrature-phase signal to be transmitted.

43. The communication device of claim 42 wherein said baseband in-phase signal comprises a first pair of complementary signals and wherein said baseband quadrature-phase signal comprises a second pair of complementary signals.

44. The communication device of claim 41 wherein N is 3 and M is 4.

45. The communication device of claim 44 wherein to eliminate a third harmonic, first and second amplifiers are selected to have equal gains and a third amplifier is selected to have a gain larger than the gain of the first and second amplifiers.

46. The communication device of claim 45 wherein the gain of third amplifier is selected to be substantially $2^{\frac{1}{6}}$ times the gain of the first and second amplifiers.

47. The communication device of claim 45 wherein the gain of third amplifier is selected to be substantially $2^{\frac{1}{10}}$ times the gain of the first and second amplifiers.

48. The communication device of claim 45 wherein the 4 phases of the LO signal in a first set lead corresponding 4 phases of the LO signal in a second set by 45°.

49. The communication device of claim 48 wherein the 4 phases of the LO signal in a third set lag corresponding 4 phases of the LO signal in the second set by 45°.

50. The communication device of claim 49 wherein the 4 phases of the LO signal in the first set are 315, 135, 45, 225 degrees, the 4 phases of the LO signal in the second set are 0, 180, 90, 270 degrees, and the 4 phases of the LO signal in the third set are 45, 225, 135, 315 degrees.

51. A communication device comprising:

means for applying M phases of a baseband signal to be transmitted to N sets of upconverters, each set comprising Q upconverters, wherein the M phases of the baseband signal are applied to each of the Q upconverters of each of the N sets;

means for applying to each of the Q upconverters of each of the N sets one of N×Q sets of phases of a local oscillator (LO) signal, each of the N×Q sets comprising M phases of the LO signal, each of the Q upconverters generating an upconverted in-phase signal and an upconverted inverse signal;

means for combining the Q in-phase signals generated by the Q converters of each of the N sets thereby to generate N combined in-phase signals; and

means for combining the Q inverse signals generated by the Q converters of each of the N sets thereby to generate N combined inverse signals, wherein a frequency component falling at a multiple of a sum of a LO signal frequency and a baseband signal frequency, or a multiple of a difference between the LO signal frequency and the baseband signal frequency is substantially suppressed from the combined in-phase and inverse signals, wherein Q, M and N are positive integers.

52. The communication device of claim 51 further comprising:

means for filtering a baseband in-phase signal to generate a first filtered in-phase signal to be transmitted; and

means for filtering a baseband quadrature-phase signal to generate a second filtered quadrature-phase signal to be transmitted.

53. The communication device of claim 52 wherein said baseband in-phase signal comprises a first pair of complementary signals and wherein said baseband quadrature-phase signal comprises a second pair of complementary signals.

54. The communication device of claim 53 wherein each of N and Q are equal to three.

55. The communication device of claim 54 wherein N×Q sets of phases of the LO signal comprise 5 distinct sets, and M is equal to 4.

56. The communication device of claim 51 further comprising:

means for amplifying each of the N combined in-phase signals; and

means for amplifying each of the N combined inverse signals.

57. The communication device of claim 56 wherein at least one of the amplifications is substantially $2^{\frac{1}{6}}$ times the remaining amplifications.

58. The communication device of claim 56 wherein at least one of the amplifications is substantially $2^{\frac{1}{10}}$ times the remaining amplifications.

59. The communication device of claim 54 wherein the 4 phases of the LO signal received by a first upconverter in each of the N sets lead corresponding 4 phases of the LO signal received by a second upconverter in the set by 45°, and the 4 phases of the LO signal received by a third upconverter in each of the N sets lag the corresponding 4 phases of the LO signal received by the second upconverter in the set by 45°.

60. The communication device of claim 59 wherein the 4 phases of the LO signal in the first are 270, 90, 0, 180, the 4 phases of the LO signal in the second set are 315, 135, 45, 225, the 4 phases of the LO signal in the third are 0, 180, 90, 270 degrees, the 4 phases of the LO signal in the fourth set are 45, 225, 135, 315 degrees, and the 4 phases of the LO signal in the fifth set are 90, 270, 180, 0 degrees.

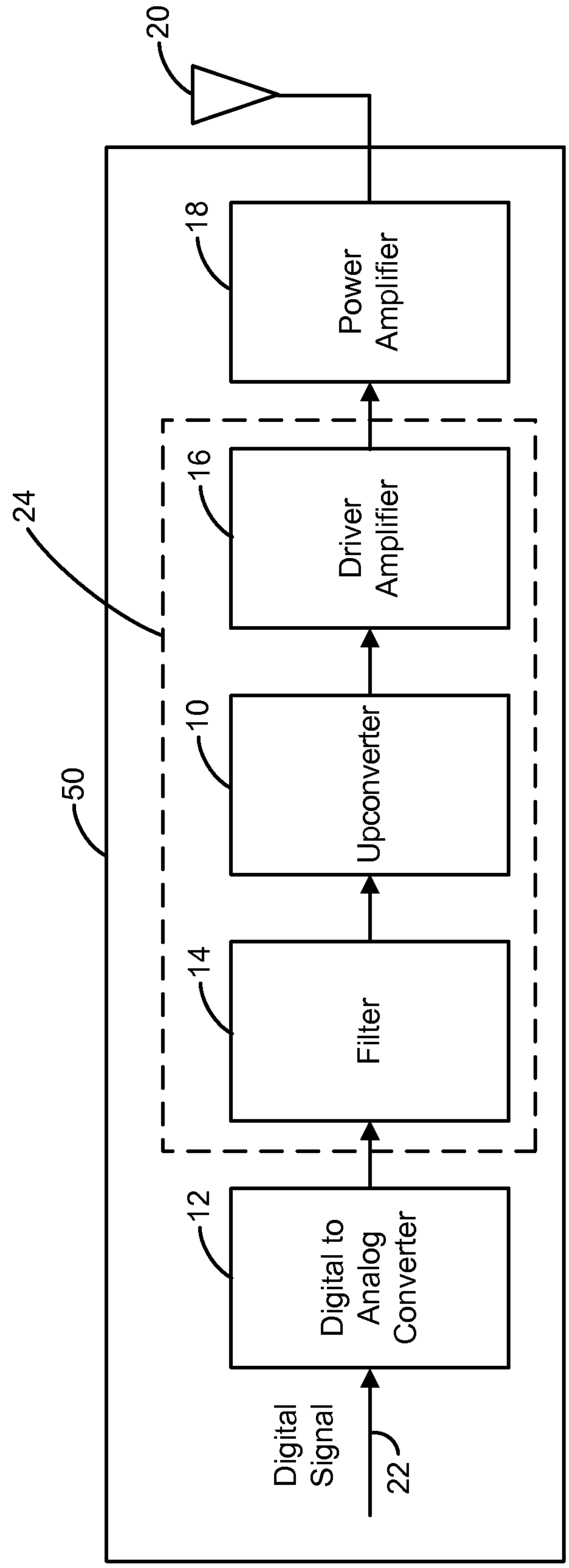

20
18
Power Amplifier
16
Driver Amplifier
24
10
Upconverter
50
14
Filter
12
Digital to Analog Converter
Digital Signal
22

FIG. 1

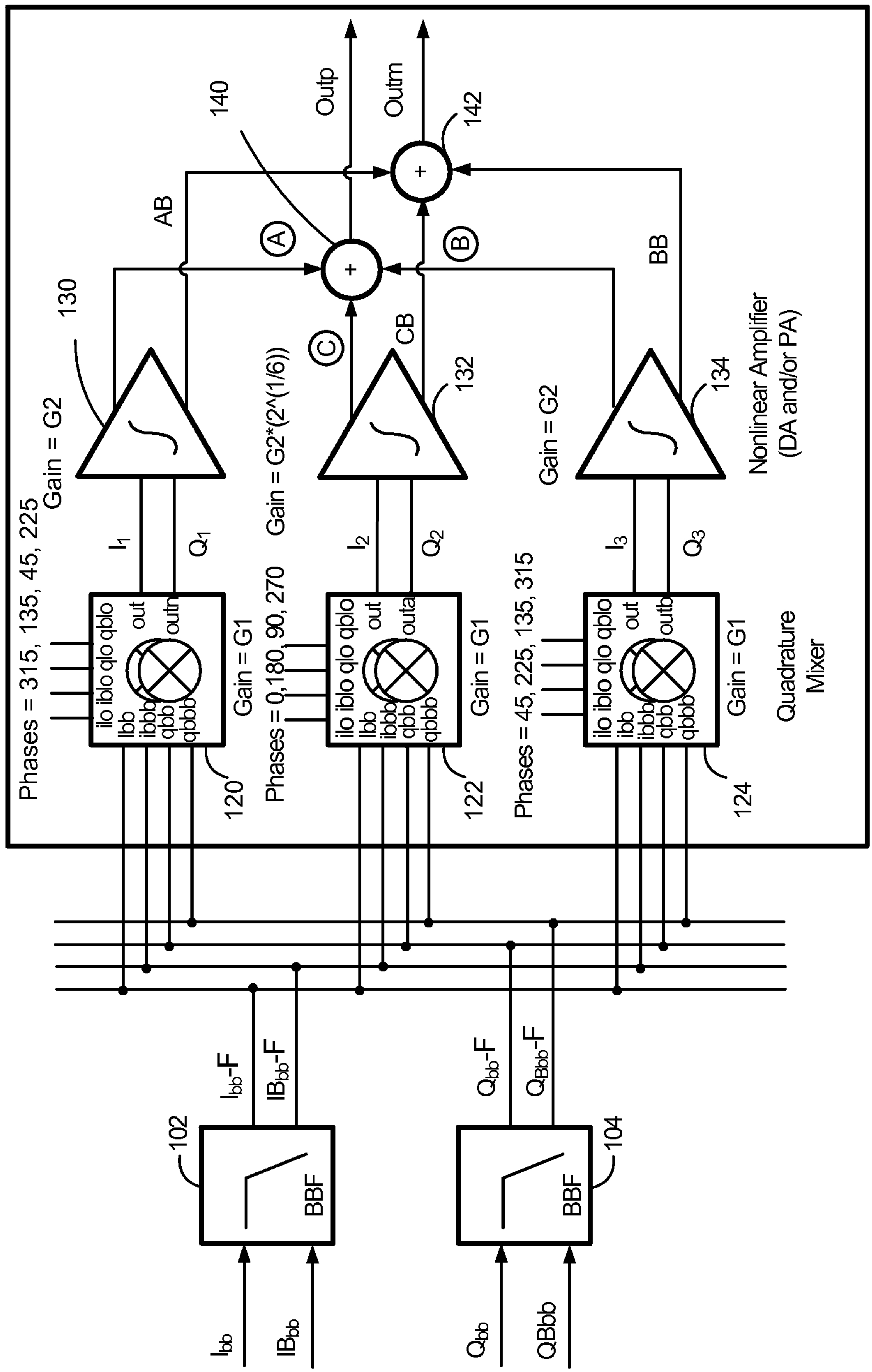

Outp
Outm
140
142
AB
A
B
C
BB
CB
130
132
134
Gain = G2
Gain = G2*(2^(1/6))
Gain = G2
Nonlinear Amplifier
(DA and/or PA)
Phases = 315, 135, 45, 225
Phases = 0,180, 90, 270
Phases = 45, 225, 135, 315
I1
Q1
I2
Q2
I3
Q3
ilo iblo qlo qblo
Ibb
ibbb
qbb
qbbb
out
outn
outa
outb
Gain = G1
Quadrature
Mixer
120
122
124
Ibb-F
IBbb-F
Qbb-F
QBbb-F
102
104
BBF
BBF
Ibb
IBbb
Qbb
QBbb

FIG. 2A

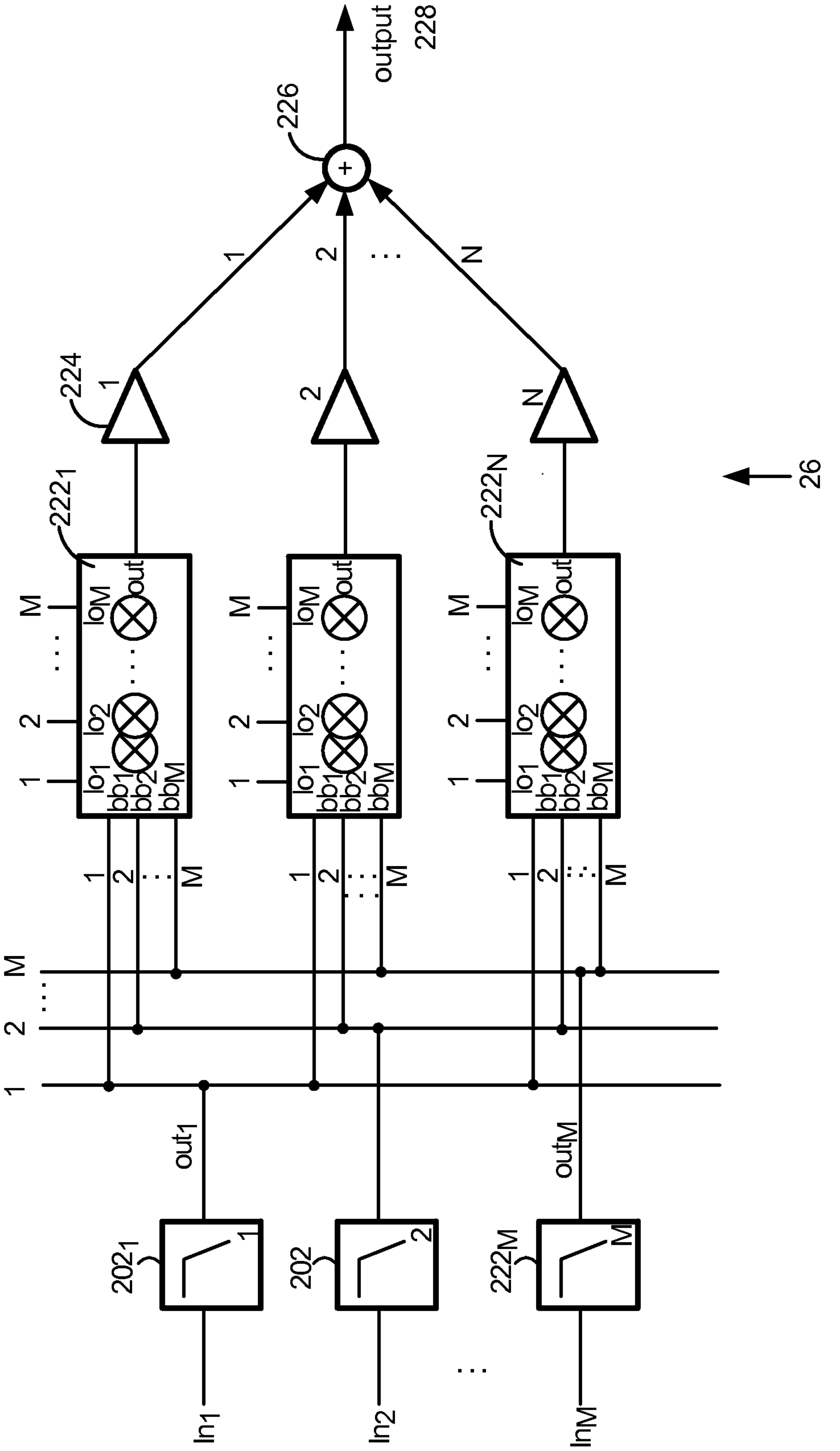

output
228
226
+
1
2
...
N
224
1
2
N
222_1
222_N
26
lo1
lo2
loM
out
bb1
bb2
bbM
M
2
1
out1
outM
202_1
202
222_M
In1
In2
InM
...

FIG. 2B

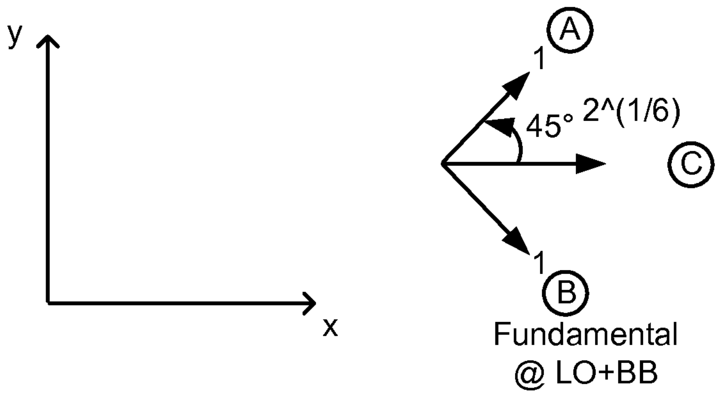


FIG. 3A

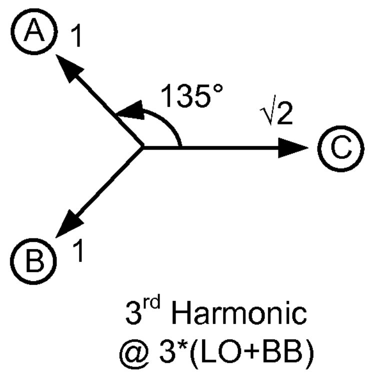


FIG. 3B

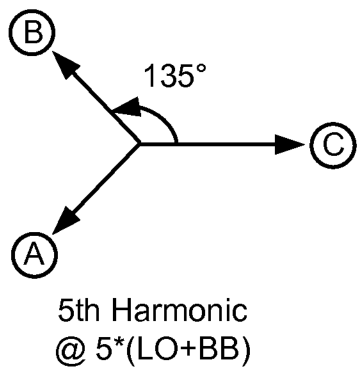


FIG. 3C

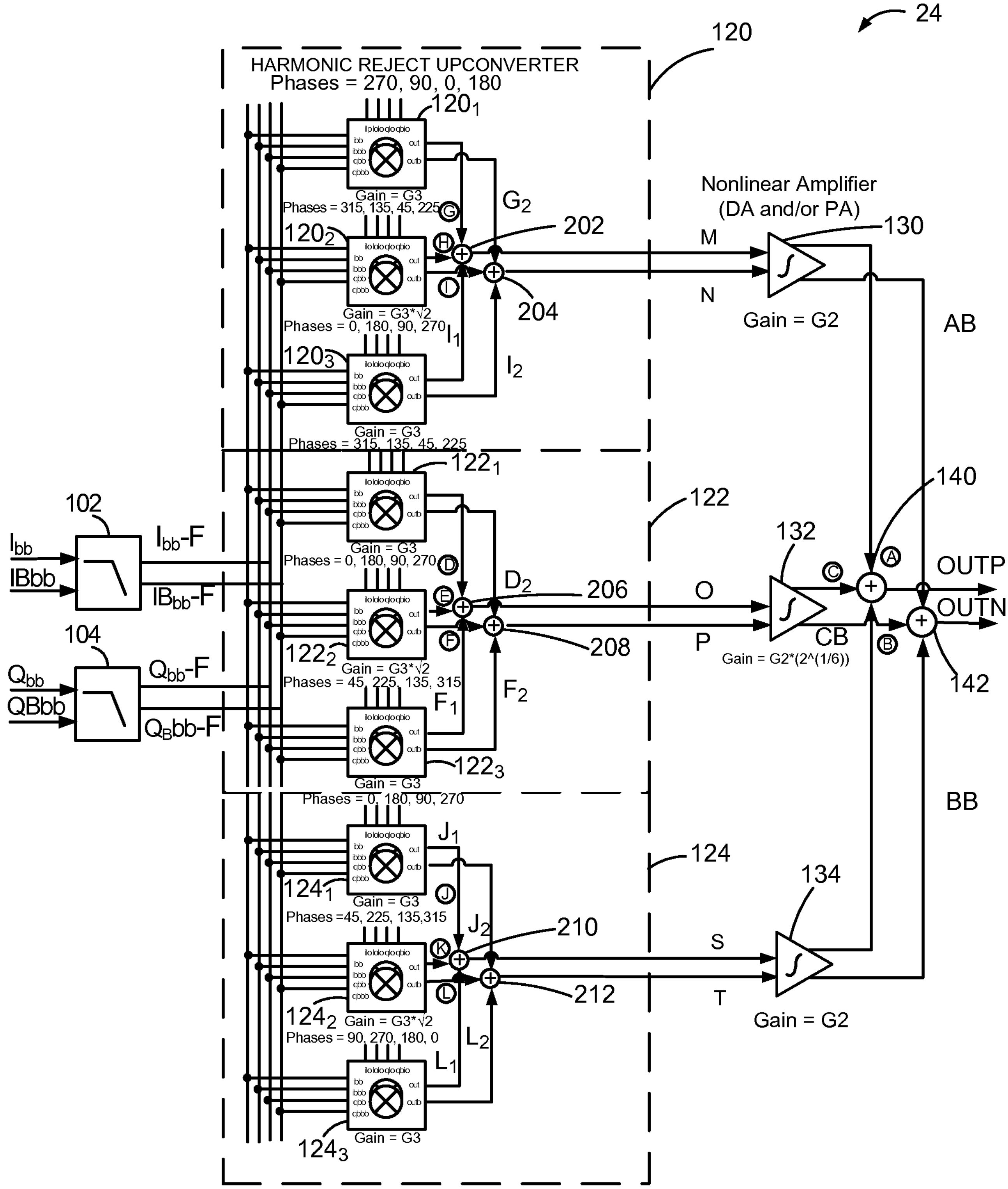
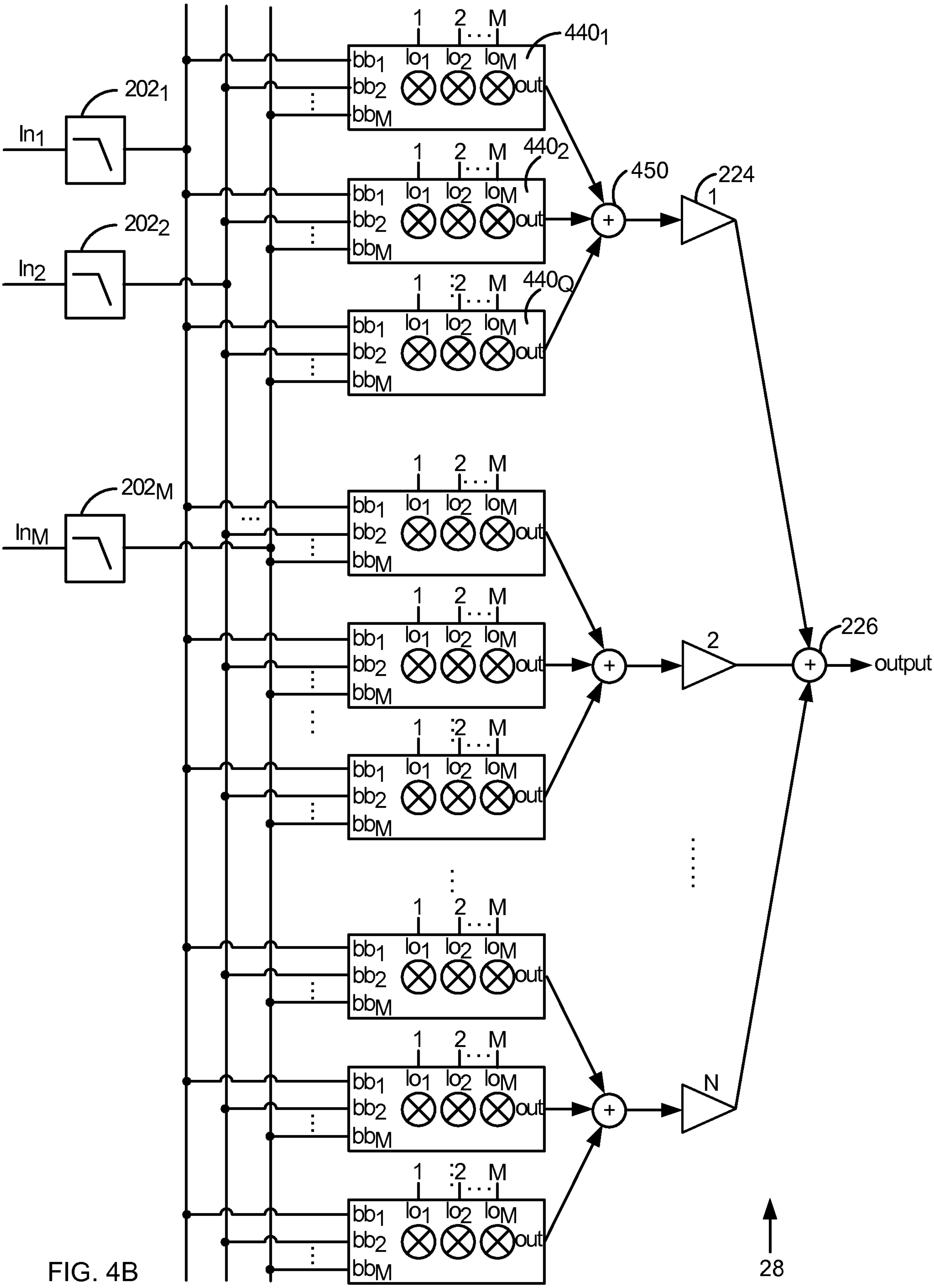

24
120
HARMONIC REJECT UPCONVERTER
Phases = 270, 90, 0, 180
120_1
Gain = G3
Phases = 315, 135, 45, 225
G
G_2
202
120_2
H
I
204
Gain = G3*√2
Phases = 0, 180, 90, 270
I_1
120_3
I_2
Gain = G3
Phases = 315, 135, 45, 225
122_1
Nonlinear Amplifier
(DA and/or PA)
130
M
N
Gain = G2
AB
140
122
102
I_bb
IB_bb
I_bb-F
IB_bb-F
Gain = G3
Phases = 0, 180, 90, 270
D
D_2
206
E
F
208
O
P
132
C
A
OUTP
OUTN
CB
B
Gain = G2*(2^(1/6))
142
104
Q_bb
QB_bb
Q_bb-F
Q_Bbb-F
122_2
Gain = G3*√2
Phases = 45, 225, 135, 315
F_1
F_2
122_3
Gain = G3
Phases = 0, 180, 90, 270
BB
J_1
124
124_1
Gain = G3
J
Phases =45, 225, 135,315
134
J_2
210
K
L
212
S
T
124_2
Gain = G3*√2
Phases = 90, 270, 180, 0
L_2
L_1
Gain = G2
124_3
Gain = G3

FIG. 4A



In1
In2
InM
2021
2022
202M
4401
4402
440Q
450
224
226
1
2
N
bb1
bb2
bbM
lo1
lo2
loM
out
M
output
28

FIG. 4B

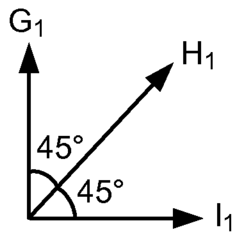


FIG. 5A

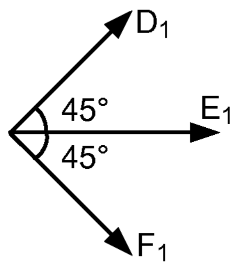


FIG. 5B

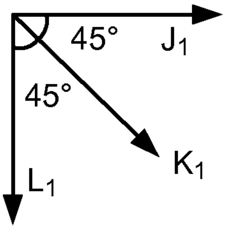


FIG. 5C

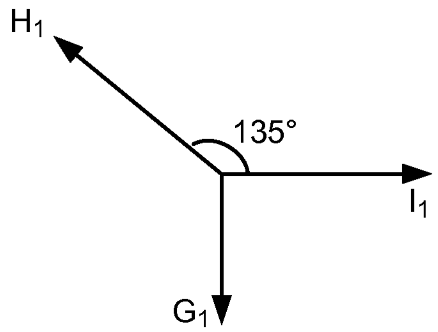


FIG. 6A

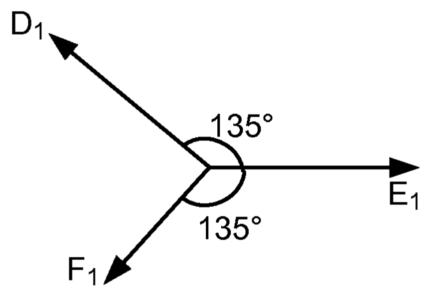


FIG. 6B

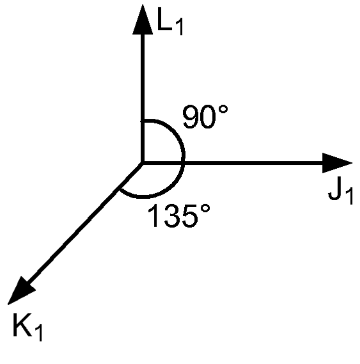


FIG. 6C

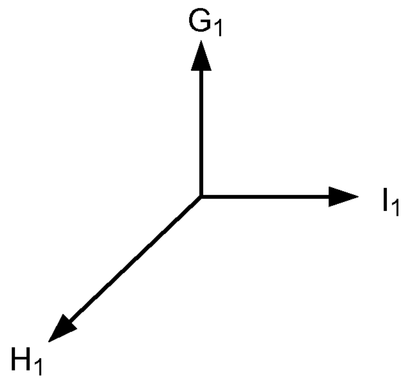


FIG. 7A

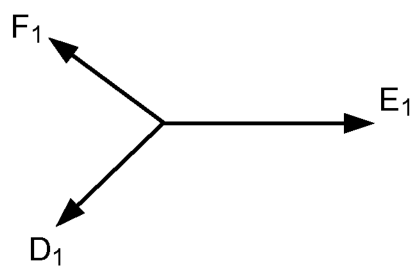


FIG. 7B

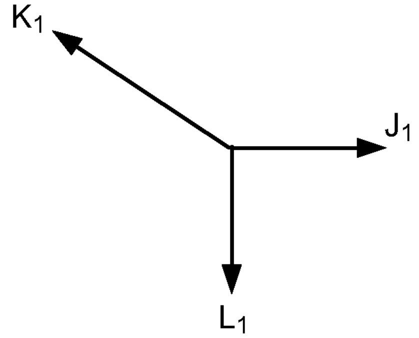


FIG. 7C

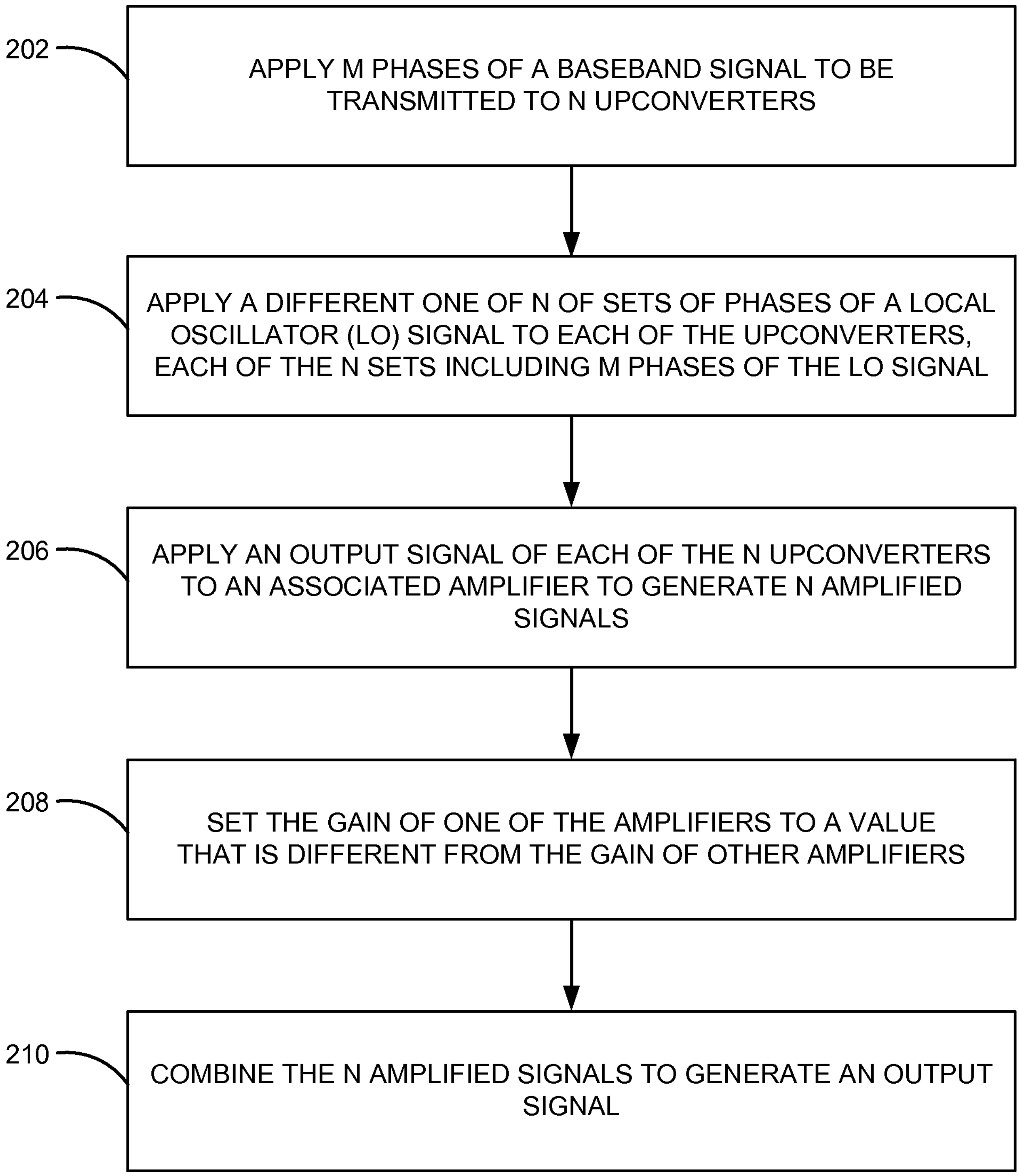
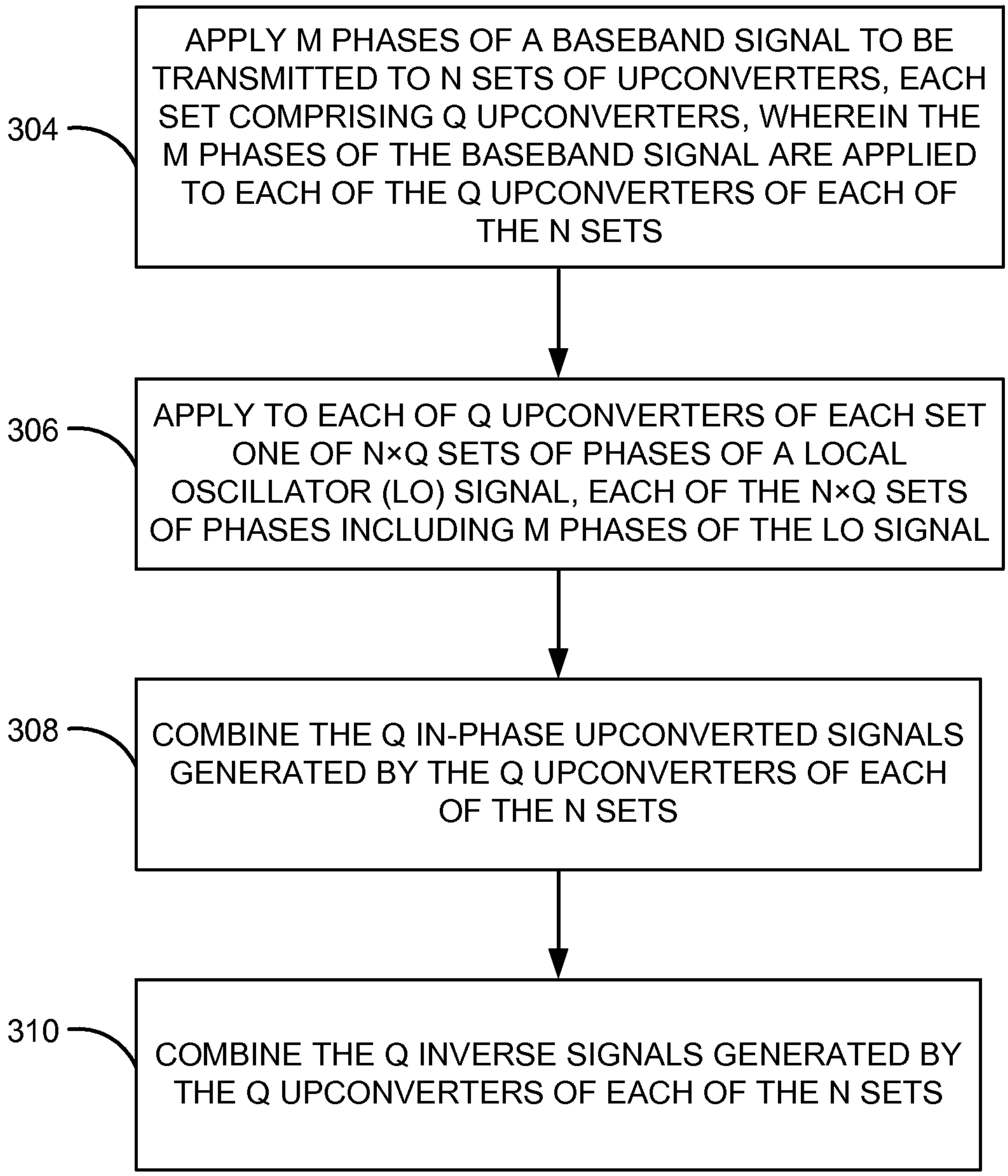

202
APPLY M PHASES OF A BASEBAND SIGNAL TO BE TRANSMITTED TO N UPCONVERTERS
204
APPLY A DIFFERENT ONE OF N OF SETS OF PHASES OF A LOCAL OSCILLATOR (LO) SIGNAL TO EACH OF THE UPCONVERTERS, EACH OF THE N SETS INCLUDING M PHASES OF THE LO SIGNAL
206
APPLY AN OUTPUT SIGNAL OF EACH OF THE N UPCONVERTERS TO AN ASSOCIATED AMPLIFIER TO GENERATE N AMPLIFIED SIGNALS
208
SET THE GAIN OF ONE OF THE AMPLIFIERS TO A VALUE THAT IS DIFFERENT FROM THE GAIN OF OTHER AMPLIFIERS
210
COMBINE THE N AMPLIFIED SIGNALS TO GENERATE AN OUTPUT SIGNAL

FIG. 8



304
APPLY M PHASES OF A BASEBAND SIGNAL TO BE TRANSMITTED TO N SETS OF UPCONVERTERS, EACH SET COMPRISING Q UPCONVERTERS, WHEREIN THE M PHASES OF THE BASEBAND SIGNAL ARE APPLIED TO EACH OF THE Q UPCONVERTERS OF EACH OF THE N SETS
306
APPLY TO EACH OF Q UPCONVERTERS OF EACH SET ONE OF N×Q SETS OF PHASES OF A LOCAL OSCILLATOR (LO) SIGNAL, EACH OF THE N×Q SETS OF PHASES INCLUDING M PHASES OF THE LO SIGNAL
308
COMBINE THE Q IN-PHASE UPCONVERTED SIGNALS GENERATED BY THE Q UPCONVERTERS OF EACH OF THE N SETS
310
COMBINE THE Q INVERSE SIGNALS GENERATED BY THE Q UPCONVERTERS OF EACH OF THE N SETS

FIG. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2014/047160

A. CLASSIFICATION OF SUBJECT MATTER
INV. H03F1/32 H03D7/14 H03F3/189 H03F3/24 H03F3/60
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H03F H03D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2010/089700 A1 (NXP BV [NL]; RU ZHIYU [NL]; KLUMPERINK ERIC A M [NL]; NAUTA BRAM [NL];) 12 August 2010 (2010-08-12)	1,21,41
A	page 5, line 15 - line 30; figure 6 page 11, line 1 - line 22; figure 13 -----	11,31,51
A	WO 2006/063358 A1 (MAXLINEAR INC [US]; SEENDRIPU KISHORE [US]; MONTEMAYOR RAYMOND [US]; Y) 15 June 2006 (2006-06-15) paragraph [0070] - paragraph [0075]; figures 2,4 -----	1,2,11, 12,21, 22,31, 32,41, 42,51,52

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
1 October 2014	15/10/2014

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Kurzbauer, Werner

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2014/047160

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	ALYOSHA MOLNAR ET AL: "Impedance, filtering and noise in n-phase passive CMOS mixers", CUSTOM INTEGRATED CIRCUITS CONFERENCE (CICC), 2012 IEEE, IEEE, 9 September 2012 (2012-09-09), pages 1-8, XP032251851, DOI: 10.1109/CICC.2012.6330616 ISBN: 978-1-4673-1555-5 page 1, left-hand column, line 1 - right-hand column, line 30; figure 1	1,11,21, 31,41,51
A	US 2009/143031 A1 (SHAH PETER [US]) 4 June 2009 (2009-06-04) the whole document	1-60
A	US 7 130 604 B1 (WONG HEE [US] ET AL) 31 October 2006 (2006-10-31) the whole document	1-60
A	US 2006/205370 A1 (HAYASHI TAKAYUKI [US] ET AL) 14 September 2006 (2006-09-14) the whole document	1-60

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2014/047160

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US 2009143031 A1	04-06-2009	NONE	
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