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(71) Applicant *(for all designated States except US)*: **NOKIA CORPORATION** [FI/FI]; Keilalahdentie 4, FIN-02150 Espoo (FI).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: **VARIS, Jukka** [FI/FI]; Lautamiehentie 28, FIN-24800 Halikko (FI).

(74) Agent: **UNGERER, Olaf**; Eisenführ, Speiser & Partner, P.O. Box 31 02 60, 80102 Munich (DE).

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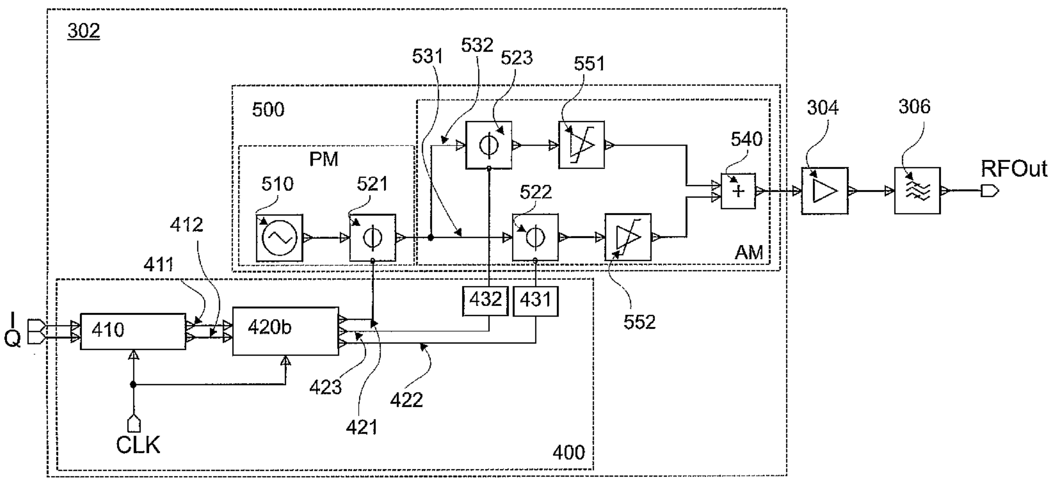
(54) Title: RF MODULATED CARRIER SIGNAL GENERATION WITH BANDPASS PULSE WIDTH MODULATION



(57) Abstract: A modulator and method for generation of a pulse width modulated carrier signal for efficient wireless transmitters for transmission of varying envelope signals is provided. Generally, the new structure of a pulse width modulator consists of serial and separate execution of the required phase and amplitude modulation processes. A first solution with single-edge pulse width modulation is disclosed in which unwanted phase shifting by the amplitude modulation process can be compensated. Further, a second solution with double-edge pulse width modulation is disclosed in which unwanted phase fluctuation by the amplitude modulation process is avoided and thus, efforts for phase correction can be reduced.

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RF modulated carrier signal generation with bandpass pulse width modulation

FIELD OF THE INVENTION

The present invention relates to a modulator for generating a modulated carrier signal from an input signal with a time-varying envelope according to claim 1, respective methods according to claims 20 and 22, and a mobile communications terminal according to claims 24 and 25.

BACKGROUND OF THE INVENTION

The present invention relates generally to a transmitter structure with high efficiency power amplifiers, wherein a bandpass pulse width modulation (BP-PWM) for generation of the modulated carrier signal is used.

It is expected that fourth-generation (4G) standards for wireless mobile phone systems will use quaternary phase-shift keying (QPSK) modulation and code division multiplex access (CDMA) architecture in the up-link. Bandwidth is expected to be higher than 20 MHz to support the demand for multimedia services. QPSK-CDMA systems are usually realized using direct up-conversion transmitters. Compared to many other modulation and multiplexing schemes, a QPSK-CDMA system generates a varying envelope signal, which must be linearly amplified to high power levels for long-range communications.

Therefore, a linear amplifier is required to avoid amplitude as well as phase distortion through AM/PM conversion in the amplified variable envelope modulated signal. However, the requirement for a linear amplification for a variable envelope modulated signal generally results in a less efficient amplifier than in the case of amplifying constant envelope modulated signal. A known approach is to use high efficiency amplifier configurations together with appropriate modulation formats that can provide envelope variation. That is, a high efficiency non-linear amplifier driven by a dedicated control signal results in a high efficiency amplifier, which behaves, quasi-linear. The main concern is the generation of the required driving signal for a switching mode power amplifier (SMPA). For that purpose, pulse width modulation may be a promising approach to provide both efficiency and linearity in power amplification.

Keyzer et al., in "A generation of RF pulse width modulated microwave signals using ΔΣ-modulation", 2002 IEEE MTT-S Digest, disclose a fully digital modulator using pulsewidth and delta-sigma modulations at radio frequency with separately executed phase modulation (PM) and amplitude modulation (AM) processes. Separate modulators for pulse-position modulation (PPM) and pulse-width modulation (PWM) are controlled by respective separate ΔΣ-modulators. Fig. 1 shows schematically the modulator 100, wherein input modulation signals I and Q, e.g. a OQPSK (Offset Quaternary Phase Shift Keying) signal as used in CDMA, are input to a converter 110, which outputs phase and amplitude modulation signals. These phase and amplitude modulation signals are fed to digitally driven ΔΣ-modulators 121 and 122, operated at a carrier frequency fc, e.g. 900MHz for cellular band communication. The carrier frequency fc is derived by frequency dividing means 135 from a local oscillator 130. The local oscillator 130 is for generating a periodic pulse train with a predetermined pulse width and a frequency flo (=8 times fc) that has to be 8 times higher than the carrier frequency fc as output RF-frequency to achieve the used three bit digital resolution. That is the local frequency flo must be approximately 7 GHz. The PM ΔΣ-modulator 121 provides a digital output word corresponding to predetermined digital values for pulse position. The output of the PM ΔΣ-modulator 121 controls a digital pulse delay modulator 140, which acts on the input periodic pulse train to produce a phase modulated output pulse train. Then, this phase modulated pulse train is fed to a pulse width modulator 150, which selects a pulse width value from predetermined digital values, in accordance with the output by the AM ΔΣ-modulator 122. The output of the modulator 100 is a full pulse modulated signal with a constant envelope for driving a switching power amplifier in the output for a quasi-linear amplification of the input signal with time-varying envelope. However, two ΔΣ-modulators are necessary in addition to the pulse position modulator (PPM) and pulse width modulator (PWM). Further, the PPM and PWM modulators 121, 122 require a digital clock, which has to be approximately 7 GHz. Moreover, there is high quantization noise outside the signal band due to the ΔΣ-modulation, which is folded back into the frequency band of interest by residual nonlinearity.

US 6,993,087 of the same inventor as the present application, relates to a switching mode power amplifier using PWM and PPM for bandpass signals, is herewith incorporated by reference. A respective BP-PWM transmitter is shown schematically in Fig. 2, the modulator structure of which is herein described as a parallel BP-PWM as acronym. The transmitter 200 for generating the bandpass RF signal comprises a modulator for the two orthogonal input signals I, Q of a time-varying envelope signal comprises a low frequency portion 201, a high frequency portion 202, a local oscillator 210 for generating the carrier signal, a SMPA 204 for amplifying the modulated carrier signal and a bandpass filter 206 for delivering the respective radio frequency (RF) output signal RFout. The modulator low-frequency portion 201 includes control means 205 for determining amplitude and phase, respectively, related information content of the modulation signal encoded in the input signals I and Q and for generating respective amplitude and phase related control signals. These control signals are used to encode the desired BP-PWM signal. Therefor, the modulator high-frequency RF portion 202 comprises the local oscillator 210 generating a substantially sinusoidal RF frequency signal, which is fed to two identical branches each having respective phase modulators 241 and 242 which are controlled by respective control signals generated from the amplitude and phase related modulation signals. Hence, in each branch the RF signal output from the respective phase modulators 241 and 242 have phase information corresponding to the amplitude and phase related modulation signal. At the output of each branch the respective pulse position modulated (PPM) signals are used for driving the SMPA 204 and at the same time are combined and bandpass filtered by the bandpass filter 206 such that the desired radio frequency (RF) output signal RFout is present. That is, the PM and AM processes are executed simultaneously by means of two parallel and identical branches that are controlled by dedicated control signals. For that reason, the structure of the modulator in Fig. 2 is called herein parallel BP-PWM as acronym. One major problem in this approach is that the two branches, which are used in parallel of the transmitter structure, have to be strictly identical to avoid distortion caused by amplitude and phase imbalances. As a consequence, both branches have to have identical components as identical phase modulators. Further, if phase modulators should be replaced with, for instance, standard FM-synthesizers, additional processing is needed beside two separate and strictly similar synthesizers.

SUMMARY OF THE INVENTION

It is therefore a specific object of the present invention to provide a transmitter structure for generation of a variable envelope modulated signal that overcomes the afore-described problems of currently known modulation methods and apparatus.

According to a first aspect of the invention, it is provided a modulator for generating a pulse width modulated carrier signal from an input signal with time-varying envelope. The modulator comprises control means arranged for generating from said input signal respective modulator control signals related to phase and amplitude information content of the input signal. Generator means provide a carrier signal to first phase modulating means for phase modulation of the carrier signal. The first phase modulating means are controlled by a first phase control signal from the control means. Then, the phase modulated carrier signal is input to a first and a second branch. In said second branch, there are second phase modulating means for additional phase modulation of the phase modulated carrier signal. The second phase modulating means are controlled by a second phase control signal from the control means. Signal combiner means are arranged for combining the phase modulated signal from the first branch and said phase modulated carrier signal from the second branch to provide at a output of the combiner means the pulse width modulated carrier signal.

Preferably, the input signal consists of two orthogonal input signals. These input signals may be orthogonal I- and Q-signals, so called In-phase and Quadrature-phase components of the input signal with time-varying envelope. The modulator further comprises converter means for deriving amplitude and phase information related signals from said orthogonal input signals.

Preferably, the respective amplitude and phase information related signals are input to first control means, which comprise pre-distortion means adapted to pre-distort said amplitude information signal.

According to a first embodiment of the invention, the control means are arranged to generate the first phase control signal as combination of the phase information related signal from said input signals and the pre-distorted amplitude information related signal from said input signals modified by a first compensation factor and to generate the second phase control signal from the pre-distorted amplitude information related signal.

Preferably, the first phase control signal corresponds to the actual value of the phase information related signal reduced by half of the actual value of the pre-distorted amplitude information related signal. That is, the actual value of the phase information related signal of the input signal is reduced by half of the phase that corresponds to the momentary value of the amplitude information related signal.

For delay compensation between the amplitude modulation (AM) process, which is performed by the first phase modulating means for phase modulation of the carrier signal, and the phase modulation (PM) processes, which is performed by the second phase modulating means for the additional phase modulation of the phase modulated carrier signal in the second branch, there may be provided a delay means, such as a signal delay block, for a delay of the respective second phase control signal from said control means. Possible (unequal) delays in PM process, by which the AM process (or the control thereof) has to be delayed can be compensated by the delay means which equalizes for the different signal propagation delays. In other words, the PM and amplitude AM processes can be executed at the same time. However, it is to be noted that the PM and AM processes could as well be implemented in reverse order, so that the PM process is delayed.

According to a second embodiment of the invention, the modulator comprises further in the first branch third phase modulating means for additional phase modulation of the phase modulated carrier signal. The third phase modulating means are controlled by a third phase control signal from the control means. The control means are arranged to generate the first phase control signal from the phase information related signal, the second phase control signal from the pre-distorted amplitude information related signal, and the third phase control signal from the pre-distorted amplitude information related signal modified by a second compensation factor.

Preferably, the first phase control signal corresponds to the actual value of the phase information related signal, the second phase control signal corresponds to the actual value of the pre-distorted amplitude information related signal and the third phase control signal corresponds to the actual value of the pre-distorted amplitude information related signal with reversed sign.

As mentioned above, delay compensation may be needed for equalizing the time differences between PM and AM processes. For delay compensation between the amplitude modulation process, which is performed by the first phase modulating means for phase modulation of the carrier signal, and the phase modulation processes, which is performed by the second phase modulating means for the additional phase modulation of the phase modulated carrier signal in the second branch, there may be provided respective delay means for a delay of the respective second phase control signal from said control means and the respective third phase control signal from said control means, respectively.

In both first and second embodiment of the invention, the generated carrier signal may be a sinusoidal signal and the modulator may consist of substantially analog circuitry. Then, the modulator further comprises signal limiters in the first and second branch before the signal combiner means.

In both first and second embodiment of the invention, the carrier base signal may be a pulse signal and the modulator may consist substantially of digital circuitry.

It is to be noted that it is also possible that parts of the modulator according to the invention consist of digital circuitry as well as analog circuitry. For instance, the control means may be implemented as digital circuitry and the carrier signal generating means together with the respective phase modulators and the combiner may be implemented in analog circuitry.

According to a second aspect of the invention, a method for generating a pulse width modulated carrier signal from a input signal with a time-varying envelope comprises the steps: generating a carrier signal; generating a first modulated carrier signal by phase modulating the carrier signal corresponding to first phase control signal and generating a second modulated carrier signal by phase modulating the first modulated carrier signal corresponding to second control signal; and combining the first modulated carrier signal with the second modulated carrier signal to the pulse width modulated carrier signal.

Preferably, the first phase control signal corresponds to the actual value of the phase information of the input signal reduced by half of the actual value of predistorted amplitude information of the input signal In detail, the actual value of the phase related information of the input signal is reduced by half of the phase that corresponds to the momentary value of the amplitude related information.

According to a third aspect of the invention, a method for generating a pulse width modulated carrier signal from a input signal with a time-varying envelope comprises the steps: generating a carrier signal; generating a first modulated carrier signal by phase modulating the carrier signal corresponding to a first phase control signal and generating a second modulated carrier signal by additionally phase modulating the first phase modulated carrier signal corresponding to a second control signal; generating a third modulated carrier signal by additionally phase modulating the first modulated carrier signal corresponding to a third control signal; and combining the second modulated carrier signal with the third modulated carrier signal to the pulse width modulated carrier signal.

Preferably, the first phase control signal corresponds to the actual value of phase information of the input signal, the second phase control signal corresponds to the actual value of pre-distorted amplitude information of the input signal and the third phase control signal corresponds to the actual value of the pre-distorted amplitude information with reversed sign.

According to a fourth aspect of the invention, a mobile communication terminal comprises a transmitter having a modulator for generating a radio frequency modulated carrier signal for transmission according to the first aspect of the present invention.

According to a fifth aspect of the invention, a mobile communication terminal comprises a transmitter having circuitry arranged for generating a radio frequency modulated carrier signal for transmission by use of a method according to one of the second or third aspect of the present invention.

Other objects and features of the present invention will become apparent from the following detailed description considered in conjunction with the accompanying drawings. It is to be understood, however, that the drawings are designed solely for purposes of illustration and not as a definition of the limits of the invention, for which reference should be made to the appended claims. It should be further understood that the drawings are merely intended to conceptually illustrate the structures and procedures described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a RF pulsewidth modulator utilizing delta-sigma (ΔΣ) modulators in the prior art for generating a BP-PWM signal, in which AM and PM processes are executed separately and controlled by separate ΔΣ-modulators;

Fig. 2 shows a modulator structure of the prior art using PWM and PPM for generating a BP-PWM signal, in which AM and PM processes are executed simultaneously in two parallel and identical branches;

Fig. 3A shows a modulator structure according to a first embodiment of the present invention;

Fig. 3B illustrates the control means of Fig. 3A in more detail;

Fig. 4A shows a modulator structure according to a second embodiment of the present invention; and

Fig. 4B illustrates the control means of Fig. 4A in more detail.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Now, before turning to the drawings and considering the invention in further detail, some general information on the principle of the modulator according to the present invention is provided. As discussed above, SMPAs and other high efficiency power amplifiers that are both reliable and preserve inherent good efficiency have to be controlled using two-state signals. A two-state input signal may typically be a square wave, also called pulse train, where the pulse period is $T = 1/f$ and the frequency f, of which is equal to the desired RF-frequency or a base frequency of the desired RF-frequency. It will be appreciated that square waves present an hypothetical (theoretical) approach to illustrate the main principles; in practice square waves are not possible to achieve due to limited bandwidth.

Also a sinusoidal carrier signal may be used, which when applied to a limiter comes close to the required two-state signal for driving the SMPA. The SMPA does not cause significant phase distortion, but due to its two-state behavior, it is very non-linear as to the amplitude. Thus, it is crucial that the driving signal is processed such that neither phase nor amplitude information of the modulation signal is embedded in the amplitude of the driving signal. Consequently, both phase and amplitude information of the input signal is to be modulated to the transition times, i.e. the edges, of the pulse train for driving the SMPA.

Accordingly, the coding approach of the invention divides the required modulation into a phase modulation (PM) part and an amplitude modulation (AM) part. The PM part may be realized in any of a number of known methods to generate a phase modulated constant envelope signal and for adding the phase information to the carrier signal. The AM part then adds the amplitude information by controlling the width of the resultant pulses of the carrier signal. It is worth noting that the terms PM and AM are related to the information content of the original modulation signal, i.e. the respective phase and amplitude information related content. The essence of these so-called outphasing techniques lies in the realization that any envelope and phase-modulated signal can be represented by the summation of two components with fixed envelope but varying in phase. That is, the basic principle behind BW-PWM signals is that the durations of individual pulses are proportional to the amplitude of the modulated signal, and that the locations of the individual pulses are pulse-position modulated (PPM) according to the phase content of the modulated signal.

Now reference is made to Fig. 3A and Fig. 4A, the basically similarities of which are described first. Accordingly, the modulator structures 301 and 302 comprise a low frequency part 400 and a high frequency part 500 by which the modulated carrier signal is provided to an amplifier 304. Then, at the output of a bandpass filter 306, which lets the desired frequency band for transmission pass through, the BP-PWM carrier signal RFout is present.

In a certain embodiment, depending on the used signal combiner, the output can be a two-state signal or tri-state signal. In an ideal case, the tri-state signal does not contain spectral components in the vicinity of DC, since the time average of the pulses is zero. Thus, the bandpass filter (BPF) may be replaced by a low pass filter (LPF). However, in case another than the first harmonic frequency of the local frequency is to be modulated, the BPF may be required.

The amplifier 304 may be a switching mode power amplifier, which may be supplied by a switching mode power supply based on a DC-to-DC converter design and used to control the output power of the transmitter. The limited minimum width of pulses may cause dynamic range degeneration. Thus, tuning the supply voltage(s) of the amplifier 304 may be used for control of output power. The SMPA may be of any now-known amplifier configuration for future-developed amplifiers having operational properties to carry out the intended functions of the present invention. Preferably, the SMPA is a high efficiency amplifier design such as class-D, class-E or class-S. However, the invention is not limited to such configurations and may also include, for example, class-C or saturated class-B amplifiers.

The input signal with a time-varying envelope is input to the low frequency part 400. Preferably, said input signals consist of two orthogonal signals, an In-phase input signal I and a Quadrature-phase input signal Q, which present the In-phase and Quadrature-phase components of the input modulation signal. A converter 410 derives the amplitude and phase information related content from the I-input signal and the Q-input signal. In other words, the converter 410 performs a conversion from Cartesian coordinates I and Q into polar coordinates represented by amplitude and phase information. The phase information related signal is provided at 411 and the amplitude information related signal is provided at 412.

Now reference is made to Fig. 3A, which shows a first embodiment of the present invention. In the low frequency part 400, the amplitude and phase information signals at 411, 412 are delivered to a first control unit 420a for generating respective first and second control signals provided at 421 and 422. Preferably, both the converter 410 and first control unit 420a are built with digital circuitry and thus controlled by a common clock signal CLK provided by any now-known clock signal generation means (not shown in Fig. 3A). The first phase control signal at 421 and second phase control signal at 422 are input to the high frequency part 500 of the modulator 301. The generation of the first and second phase control signal will be explained in more detail below.

Now turning to the high frequency part 500, in which a generator 510 is provided for generating a carrier signal, which may be at the center frequency of the required RF-frequency or a base frequency thereof. The generator 510 may be realized as any now-known local oscillator which may also be incorporated as a modulator sub-block, for example in the first phase modulator 521, which will be described below. Also any known analog circuitry as well as digital circuitry for implementation of an oscillator may be used. For instance, in "CMOS Wireless Phase-Shifted Transmitter", IEEE Journal of solid-state circuits, vol. 39, no. 8, August 2004, which is herewith incorporated by reference, S. Hamedi-Hagh at al. disclose a possible implementation for an analog local oscillator.

The carrier signal generated by the generator 510 is input to the first phase modulator 521 for a phase modulation of the carrier signal in accordance to the first phase control signal provided by the first control unit 420a in the low frequency part 400 at 421. Then the phase modulated carrier signal is output from the first phase modulator 521 and split into a first and a second branch 531 and 532. In the second branch 532, there is a second phase modulator 522 for an additional phase modulation of the already phase modulated carrier signal by the first phase modulator 521. The second phase modulator 522 carries out an additional phase modulation in accordance to the second phase control signal provided from the first control unit 420a. Then, both the phase modulated carrier signal of the first branch 531 and the twice phase modulated carrier signal of the second branch 532 are combined to the desired pulse width modulated carrier signal by a signal combiner 540, whose output corresponds to the output of the high frequency part 500 of the modulator 301.

When the generated carrier signal is a digital signal, that is the digital signals are pulse-position modulated, which is equivalent to the phase-modulation of a sinusoidal signal. Accordingly, mainly digital circuitry can be used and the combination of the phase modulated carrier signal of the first branch and the twice phase modulated carrier signal of the second branch 531, 532 can be got either by using arithmetic operations alike subtraction or summation or logical operations alike AND-, OR-, or XOR-operations and their linear counterparts. It would also be possible to use sequential circuits as RS- and T-flip-flops. Preferred combining method depends on the specific application.

Additionally, in the first and second branch 531, 532 of the high frequency part 500 there may be provided respective limiters 551, 552 which are to be used, if the generated carrier signal is a analog, in particular a sinusoidal, signal, for instance, provided by an analog local oscillator. Since the input signals for the combiner 540 has to be digital in any case, such limiters 551, 552 are preferably located before the signal combiner 540.

However, limiters 551, 552 may also be used to enhance the operation of the used amplifier 304 and/or the signal combiner 540. The combined signals of the first and second branch 531, 532 constitute the desired radio frequency modulated carrier signal for transmission, which has a varying duty-cycle and is then power amplified by the amplifier 304. Preferred power amplifier arrangements depend on the specific application. For instance, in US 2004/0251962 of the same inventor as the present application, which is related to a "Power Control for Switching Mode Power Amplifier" and incorporated herewith by reference, a possible configuration for a SMPA with power control is provided that may also be used together with the modulator of the present invention.

However, for instance, the above-mentioned class-E power amplifiers are critical with signals having a varying duty-cycle. Here it is to be noted that it would also be possible to have respective power amplifiers in the first branch 531 as well as the second branch 532 located before the signal combiner 540 instead of the location of the amplifier 304 or in addition to the amplifier 304. In the afore-mentioned document "CMOS Wireless Phase-Shifted Transmitter", IEEE Journal of solid-state circuits, vol. 39, no. 8, August 2004, also a possible implementation is disclosed for applicable power amplifiers together with the realization of a signal combiner as well as a bandpass filter circuit. In case, the signals in the first and second branch 531, 532 are digital signals and the respective power amplifiers are located before combination of the signals of the first and second branch 531, 532, then the signals passing the respective amplifiers have constant duty-cycle. Thus, class-E power amplifiers with very high gain can be used and can be driven in switching mode without strictly pulsed control.

For sake of completeness, it is to be noted that for power control of the pulse width modulated carrier signal it is, depending on the application, also possible to utilize the existing variable gain amplifiers and linear power amplifiers. Further, there are several methods that can be used to control the modulated output power, including tuning of the I-and Q-signals, tuning pulse positions in connection with pulse width modulation or tuning pulse widths in connection with pulse position modulation, tuning the supply voltage of the power amplifier switches using a (slow) DC/DC-converter, and using a tunable attenuator after the power amplifier.

Now the first control unit 420a of the low frequency part 400 in the modulator 301 according to the present invention will be described in more detail. Therefore, reference is made to Fig. 3B. Accordingly, the phase information related signal at 411 and the amplitude information related signal at 412 are input to the first control unit 420a provided by the converter 410. The amplitude information related signal is pre-distorted by a pre-distortion circuit 424a. The respective pre-distorted amplitude information signal is used as the second phase control signal at 422. Further, the pre-distorted amplitude information signal or second phase control signal at 422, respectively, is modified by a compensation circuit 426a and then combined with the phase information related signal at 411 by a signal combiner 428 which provides as output the first phase control signal at 421. If the low frequency part 400 is implemented as digital circuitry, the combiner may be as mentioned above, for instance, an arithmetic summation circuit.

As a result, it becomes clear that with the modulator of the present invention for generating the modulated carrier signal as a bandpass pulse width modulated signal, the required phase modulation (PM) and amplitude modulation (AM) processes are performed separately in a serial manner, wherein in a first part of the high frequency section 500 the generated carrier signal is phase modulated in a respective phase modulation section PM and then with respect to the resultant BP-PWM carrier signal, in the amplitude modulation section AM a “single-edge” pulse width modulation is performed by only pulse position modulation in the second branch 532. Finally, by combining the signals from the first and second branch 531, 532 the desired pulse width modulated signal is formed.

An important feature of the present invention is the avoidance of unwanted phase modulation due to the fact that only one edge of pulses are modulated by only modulating the carrier signal in the second branch 532 in accordance with the second control signal, i.e. the amplitude information signal. That is a shift of the middle points of the pulses in the resultant signal would be present after the combining means 540. Such unwanted phase shifting or phase modulation, respectively, is entirely compensated according to the present invention by shifting the “original” phase modulated pulses by half of the momentary pulse width. Hence, the middle points of the resultant pulse width modulated signal after the combiner 540 do not drift according to the amplitude modulation any more.

Now reference is made to Fig. 4A which shows a second embodiment of the serial BP-PWM according to the present invention. It is to be noted that only differences of the second embodiment to the first embodiment have to be described in detail. Further, alike components are designated same reference signs. Again, the modulator 302 according to the second embodiment consists of the low frequency part 400 and a high frequency part 500, which provides the desired bandpass pulse width modulated signal to the respective amplifier 304 and bandpass filter 306 at the output of which the desired radio frequency bandpass pulse width modulated signal RFout is provided.

The main difference between the first and second embodiment is that in the amplitude modulation section AM of the high frequency part 500, additionally a third phase modulator 523 for phase modulation of the phase modulated carrier signal is provided in the first branch 531. The third modulator 523 is controlled by a third phase control signal provided by the second control unit 420b of the low frequency part 400. It is noted that in the second embodiment the first control unit 420a is replaced by a second control unit 420b, which is described in more detail with reference to Fig. 4B in the following.

Once again, the second control unit 420b has as input signals the phase information signal at 411 and the amplitude information signal at 412 provided by the converter 410 described above. The second control unit 420b is arranged to generate the first phase control signal at 421 from the phase information signal. Preferably, the first phase control signal at 421 corresponds to the actual value of the phase information signal at 411. Further, the second control unit 420b is arranged to generate the second phase control signal at 422 from the amplitude information signal at 412 pre-distorted by a respective pre-distortion circuit 424b. Preferably, the second phase control signal at 422 corresponds to the actual value of the pre-distorted amplitude information signal at 412. Further, the second control unit 420b is arranged to generate the third phase control signal at 423 from the actual value of the pre-distorted amplitude information signal by modification with a second compensation factor applied by a compensation circuit 426b. Preferably, the second phase control signal at 422 corresponds to the actual value of the pre-distorted amplitude information signal and the third phase control signal at 423 corresponds to the actual value of the pre-distorted amplitude information signal with reversed sign, i.e. the pre-distorted amplitude information signal is multiplied with –1.

As result, according to the second embodiment of the present invention in the amplitude modulation section AM the pulse width modulation of the pulses of the carrier signal is performed by a “double-edge” pulse width modulation. Basically, the PWM process is realized by respective pulse position modulations (PPM) in both the first and second branch 531, 532 of the amplitude modulation section AM. For this double-edge pulse width modulation for the required amplitude modulation the third phase modulator 523 is needed in the amplitude modulation section AM. However, advantageously the amplitude modulation section AM is now symmetrically. In other words, the two PPM processes in the first and second branch 531, 532 allow effectively two amplitude modulation controls: one for controlling the leading-edges, in the second branch 532 of the amplitude modulation section AM, and another for controlling the trailing-edges, in the first branch 531 of the amplitude modulation section AM. Thus, the edges are shifted to opposite directions causing symmetrical double-edge modulation. As result, both edges are symmetrically modulated and phase fluctuation caused by amplitude modulation does not exist any more and phase correction is not needed.

Finally yet importantly, as mentioned above due to the serial structure of the BP-PWM modulator according to the present invention time compensation means between the PM and AM processes may be necessary. This may be easily effected to the first embodiment (Fig. 3A) and second embodiment (Fig. 4A) of the invention by implementation of respective delay blocks 431 and 432, respectively, to the respective AM process phase control signal lines 422 and 423, respectively.

The BP-PWM according to the present invention provides several advantages vis-à-vis the prior art solutions. Since phase modulation and amplitude modulation processes are executed separately, the phase modulators have not to be identical any more. Moreover, the first phase modulating means 521 may be implemented separately, e.g. using an IQ-modulator or included in the frequency generator 510, i.e. merely, for example, a FM-synthesizer is needed.

Further, since amplitude related control is continuous and bounded such that $0 \leq a*(t) \leq \pi$, the second phase modulator 522 in the first embodiment (Fig. 3A) can be replaced with a phase shifter, for example a passive delay-line type phase modulator.

If the double-edge pulse width modulation according to the second embodiment (Fig. 4A) is used, the control range will be $0 \leq a*(t) \leq \pi/2$. The second and third phase modulators 522, 523 in the second embodiment (Fig. 4A) can be replaced with phase shifters. In "CMOS Wireless Phase-Shifted Transmitter", IEEE Journal of solid-state circuits, vol. 39, no. 8, August 2004, also a solution for applicable phase shifters is disclosed.

As a further advantage over the prior art solutions the maximum needed local frequency generated by the frequency generation means 510 can be equal or lower than the desired center frequency of the generated modulated carrier signal. It is also possible to modulate directly other than the first pulse width modulation harmonic, which is explained in more detail in US 6,993,087 of the same inventor, which is incorporated herewith by reference.

Accordingly, with the modulator of the present invention it is possible to utilize higher harmonics of the modulator output as well. Since the amplitude of the n-th harmonic is proportional to $\sin(n \cdot \Phi)$, where Φ denotes a parameter related to the first harmonic, by dividing in the pre-distortion part of the control units 420a or 420b, respectively, the pre-distorted amplitude by n, a distortion less amplitude can be arranged for the n-th harmonic. Likewise, it is also that the angle of the n-th harmonic of a sinusoidal signal passing a non-linear device exhibits similar expansion, that is, it will be multiplied by n. By diving the angle related to the input IQsignals by n, it is possible to arrange the correct phase modulation for the n-th harmonic.

Therefore, it is possible to use the modulator at a lower frequency then would otherwise be possible. The benefit is exceptionally high for a fully digital modulator by allowing a lower clock frequency. Further, the use of sub-harmonics can be used to advantageously avoid mixing of the transmitting signal with the local oscillator. Further, the amplifier 304 still preserves the good efficiency provided that the unwanted harmonics may be terminated with high impedance to gain good power efficiency. Other harmonics could also be filtered to meet spurious emission requirements. When using an n-th harmonic, where $n \geq 3$, the strong first harmonic should be filtered to produce an acceptable modulated output signal.

Compared to the RF pulse widths modulator using ΔΣ-modulators of the prior art no extra ΔΣ-modulators are needed. Consequently, ΣΔ-type quantization noise "shoulders" outside the signal band do not exist at all and also no local frequency clock being more times higher than the required radio frequency is needed.

The serial structure of the bandpass pulse width modulator according to the present invention offers many possible embodiments to practical implementations. For instance, the modulator structure provided by the present invention can advantageously be used in mobile communication terminals where high power efficiency is mandatory to realize long battery life.

Finally yet importantly, a modulator and method for generation of a bandpass pulse width modulated carrier signal for efficient wireless transmitters for transmission of varying envelope signals has been provided. Generally, the new structure of the BP-PWM consists of the serial and separate execution of the required phase and amplitude modulation processes which could be provided in any order, i.e., amplitude modulation process after phase modulation process or vice versa. A first solution with single-edge pulse width modulation has been disclosed in which unwanted phase shifting by the amplitude modulation process is entirely compensated by appropriate shifting of the original phase modulated signal by half of the momentary pulse width in the amplitude modulation process. Further, a second solution with double-edge pulse width modulation has been disclosed in which unwanted phase fluctuation by the amplitude modulation process is totally avoided by controlling leading-edges and trailing-edges such that edges of the resultant signal are shifted to opposite directions and any phase correction not needed at all.

While there have been shown and described and pointed out fundamental features of the invention as applied to the preferred embodiments thereof, it will be understood that various omissions and substitutions and changes in the form and details of the devices and methods described may be made by those skilled in the art without departing from the present invention. For example, it is expressly intended that all combinations of those elements and/or method steps, which perform substantially the same function in substantially the same way to achieve the same results, be within the scope of the invention. Moreover, it should be recognized that structures and/or elements and/or method steps shown and/or described in connection with any disclosed form or embodiment of the invention may be incorporated in any other disclosed or described or suggested form or embodiment as a general matter of designed choice. It is the intention, therefore, to be limited only as indicated by the scope of the claims appended hereto.

Claims

1. Modulator for generating a modulated carrier signal from a input signal with a time-varying envelope, said modulator comprising:

   - control means being arranged for generating from said input signal respective control signals related to phase and amplitude information content of said input signal;
   - generator means for providing a carrier signal to first phase modulating means for phase modulation of said carrier signal, said first phase modulating means being controlled by a first phase control signal from said control means, and for inputting said phase modulated carrier signal to a first and a second branch;
   - second phase modulating means in said second branch for phase modulation of said phase modulated carrier signal, said second phase modulating means being controlled by a second phase control signal from said control means; and
   - signal combiner means arranged for combining said phase modulated carrier signal from said first branch and said phase modulated carrier signal from said second branch.

2. Modulator according to claim 1, wherein said input signal consists of two orthogonal signals and said control means further comprise converter means for deriving an amplitude related information signal and a phase related information signal from said input signal.

3. Modulator according to claim 2, wherein said respective amplitude and phase related information signals are input to first control means, which comprise pre-distortion means adapted to pre-distort said amplitude related information signal.

4. Modulator according to claim 3, wherein said control means are arranged to generate said first phase control signal from a combination of said phase related information signal and said pre-distorted amplitude related information signal modified by a first compensation factor and to generate said second phase control signal from said pre-distorted amplitude related information signal.

5. Modulator according to claim 4, wherein said first phase control signal corresponds to the actual phase related information signal reduced by half of the actual value of said pre-distorted amplitude related information signal.

6. Modulator according to claim 3, further comprising third phase modulating means in said first branch for phase modulation of said phase modulated carrier signal, said third phase modulating means being controlled by a third phase control signal from said control means.

7. Modulator according to claim 6, wherein said first control means are arranged to generate said first phase control signal from said phase related information signal, said second phase control signal from said pre-distorted amplitude related information signal, and said third phase control signal from said pre-distorted amplitude related information signal modified by a second compensation factor.

8. Modulator according to claim 7, wherein said second phase control signal corresponds to the actual value of said pre-distorted amplitude related information signal and said third phase control signal corresponds the actual value of said pre-distorted amplitude related information signal with reversed sign.

9. Modulator according to claim 5 or 8, wherein said generated carrier signal is a sinusoidal signal and said modulator comprises analog circuitry.

10. Modulator according to claim 9, further comprising signal limiters in said first and second branch before said signal combiner means.

11. Modulator according to claim 10, further comprising amplifier means after said signal combiner means for amplifying the said modulated carrier signal.

12. Modulator according to claim 11, wherein said respective amplifier means are one of a class-D, class-E, class-S, class-C or saturated class-B amplifier.

13. Modulator according to claim 10, further comprising respective amplifier means in said first and said second branch before said signal combiner means for amplifying said respective said phase modulated carrier signal from said first branch and said phase modulated carrier signal.

14. Modulator according to claim 13, wherein said respective amplifier means are one of a class-D, class-E, class-S, class-C or saturated class-B amplifier.

15. Modulator according to claim 5 or 8, wherein said carrier base signal is pulse signal and said modulator comprises digital circuitry.

16. Modulator according to claim 15, further comprising amplifier means after said signal combiner means for amplifying the said modulated carrier signal.

17. Modulator according to claim 16, wherein said respective amplifier means are one of a class-D, class-E, class-S, class-C or saturated class-B amplifier.

18. Modulator according to claim 15, further comprising respective amplifier means in said first and said second branch before said signal combiner means for amplifying said respective said phase modulated carrier signal from said first branch and said phase modulated carrier signal.

19. Modulator according to claim 18, wherein said respective amplifier means are one of a class-D, class-E, class-S, class-C or saturated class-B amplifier.

20. Modulator according to claim 1, wherein there is a delay means for a delay of the respective second phase control signal from said control means.

21. Modulator according to claim 6, wherein there are respective delay means for a delay of the respective second phase control signal from said control means and the respective third phase control signal from said control means, respectively.

22. Modulator according to claim 1, wherein said combiner means for combining of the phase modulated carrier signal of the first branch and the twice phase modulated carrier signal of the second branch is provided by an arithmetic operation or a logical operation.

23. Modulator according to claim 22, wherein said arithmetic operation is one of a subtraction or summation.

24. Modulator according to claim 23, wherein said logical operation comprises at least one one of AND-, OR-, and XOR-operations or linear counterparts thereof.

25. Modulator according to claim 1, wherein a control for modulated output power is provided by at least one of respective tuning of input signals, tuning pulse positions in connection with pulse width modulation or tuning pulse widths in connection with pulse position modulation, tuning the supply voltage of the power amplifier switches by means of a DC/DC-converter, and tuning an attenuator provided after the power amplifier.

26. Method for generating a pulse width modulated carrier signal from a input signal with a time-varying envelope, said method comprising the steps:

- generating a carrier signal;
- generating a first modulated carrier signal by phase modulating said carrier signal corresponding to a first control signal;
- generating a second modulated carrier signal by phase modulating said first modulated carrier signal corresponding to a second control signal; and
- combining said first modulated carrier signal with said second modulated carrier signal to said pulse width modulated carrier signal.

27. Method according to claim 26, wherein said first phase control signal corresponds to the actual value of phase related information of said input signal reduced by half of the actual value of a pre-distorted amplitude related information of said input signal and said second phase control signal corresponds to the actual value of said pre-distorted amplitude related information of said input signal.

28. Method according to claim 27, further comprising delaying the second control signal in accordance to the delay caused by said generating of the first modulated carrier signal.

29. Method for generating a pulse width modulated carrier signal from a input signal with a time-varying envelope, said method comprising the steps:

- generating a carrier signal;

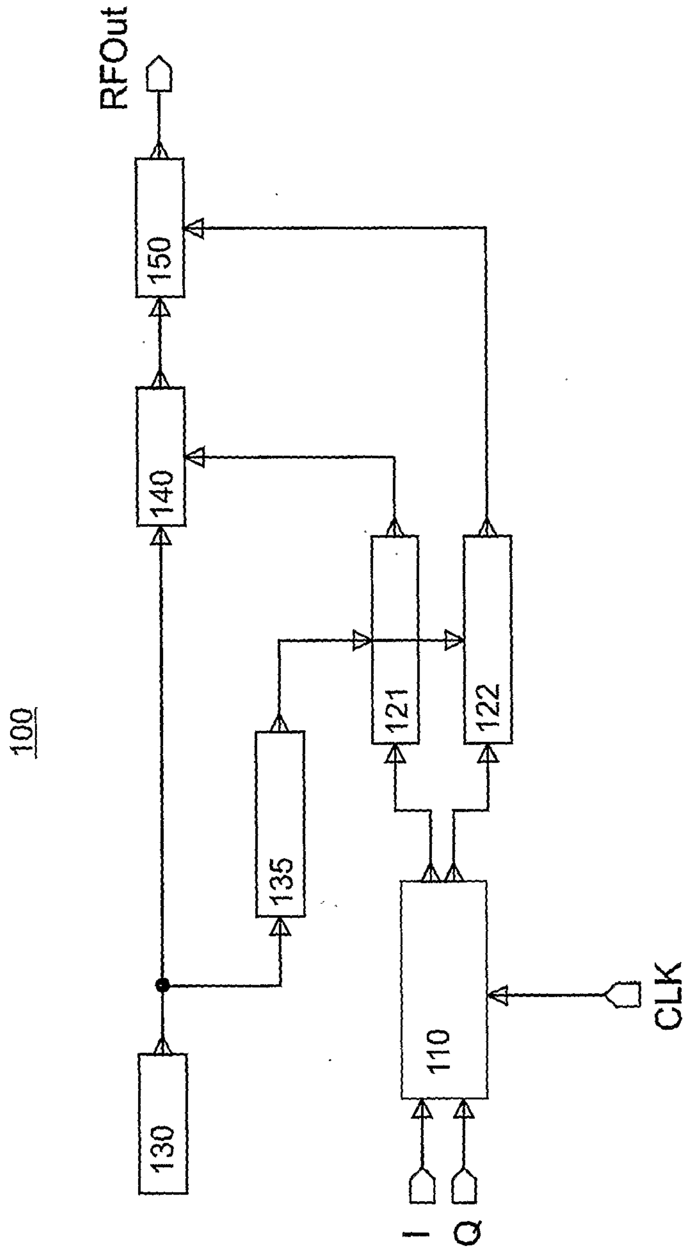
- generating a first modulated carrier signal by phase modulating said carrier signal corresponding to a first control signal;
- generating a second modulated carrier signal by phase modulating said first phase modulated carrier signal corresponding to a second control signal;
- generating a third modulated carrier signal by phase modulating said first phase modulated carrier signal corresponding to third control signal; and
- combining said second modulated carrier signal with said third modulated carrier signal to said pulse width modulated carrier signal.

30. Method according to claim 29, wherein said first phase control signal corresponds to the actual value of phase related information of said input signal, said second phase control signal corresponds to the actual value of pre-distorted amplitude related information of said input signal and said third phase control signal corresponds the actual value of said pre-distorted amplitude related information with reversed sign.

31. Method according to claim 29, further comprising delaying of the respective second control signal from said control means and the respective third control signal from said control means, respectively in accordance to the delay caused by said generating of the first modulated carrier signal.

32. Mobile communication terminal comprising a transmitter, said transmitter having a modulator for generating a radio frequency bandpass carrier signal for transmission according to one of the claims 1 to 25.

33. Mobile communication terminal comprising transmitter having digital circuitry arranged for generating a radio frequency bandpass carrier signal for transmission by use of a method according to one of the claims 26 to 31.



(Prior Art) Fig. 1

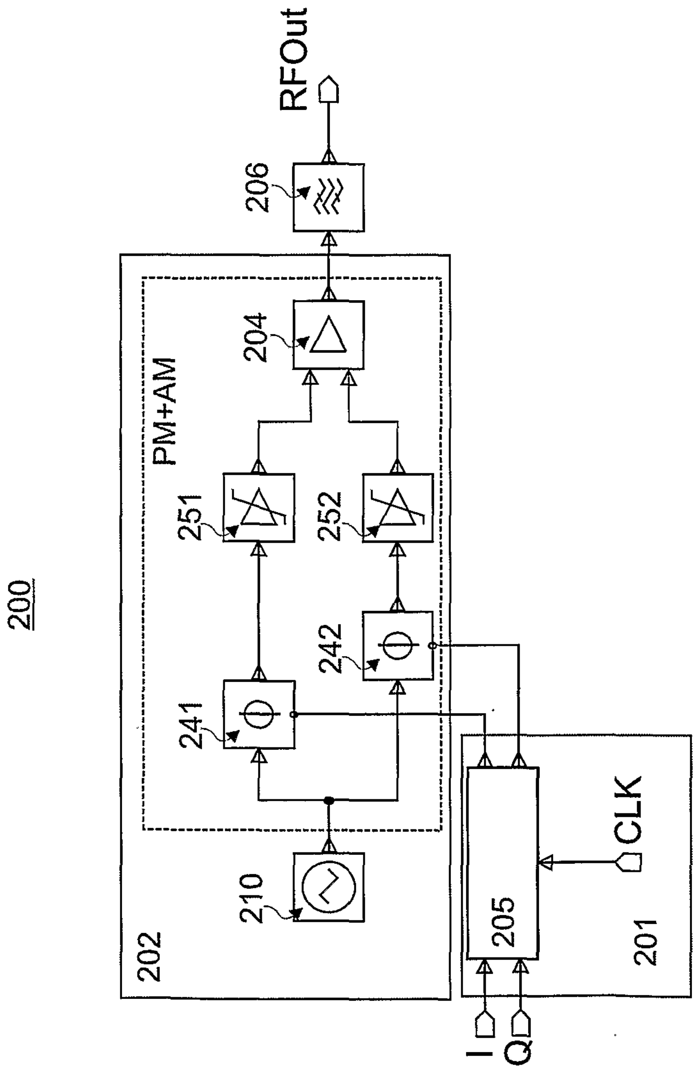


Fig. 2 (Prior Art)

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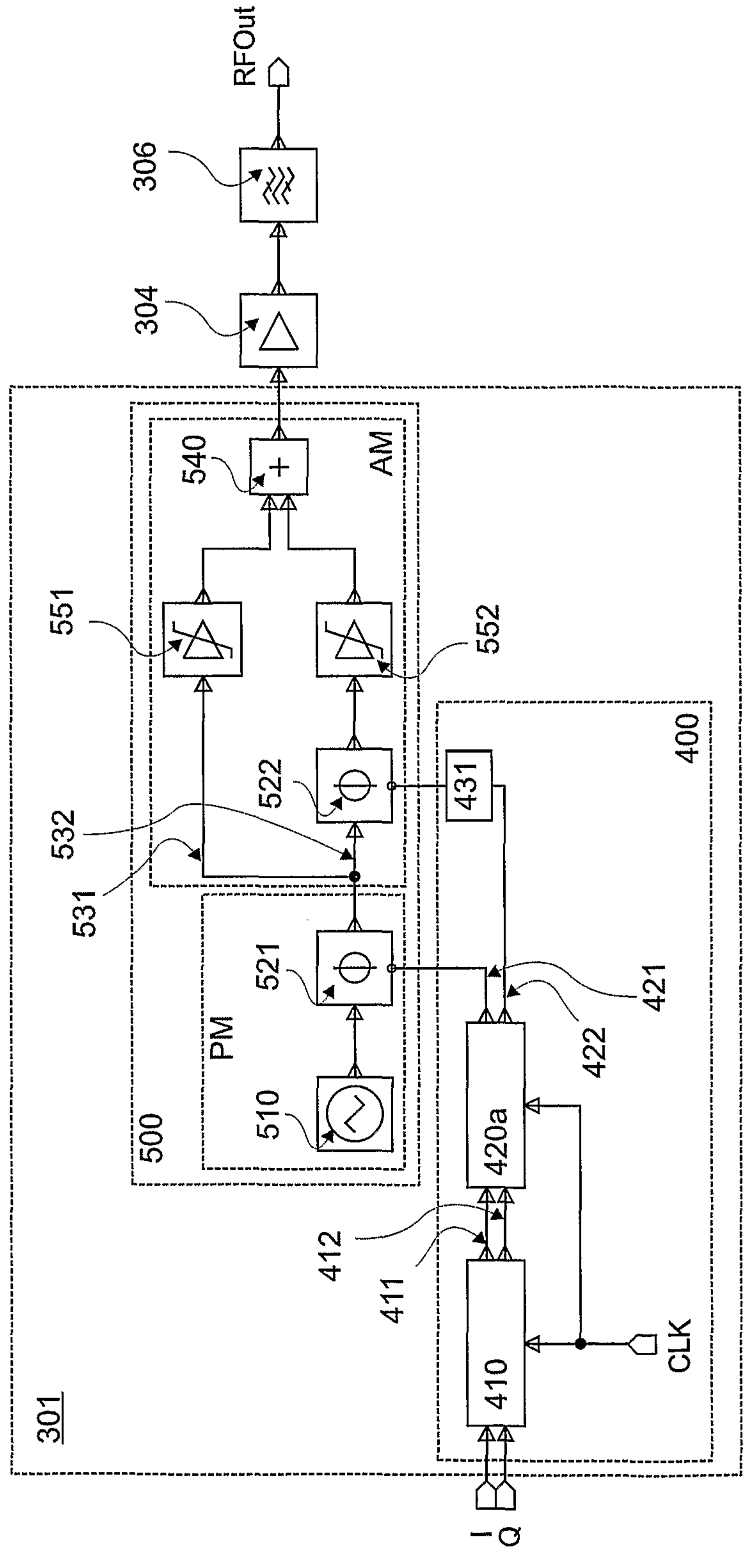
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Fig. 3A

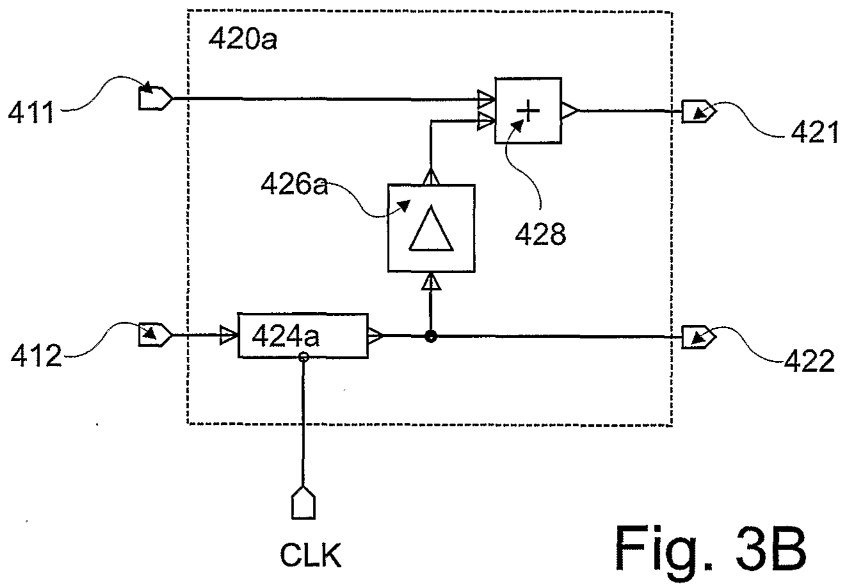

Fig. 3B

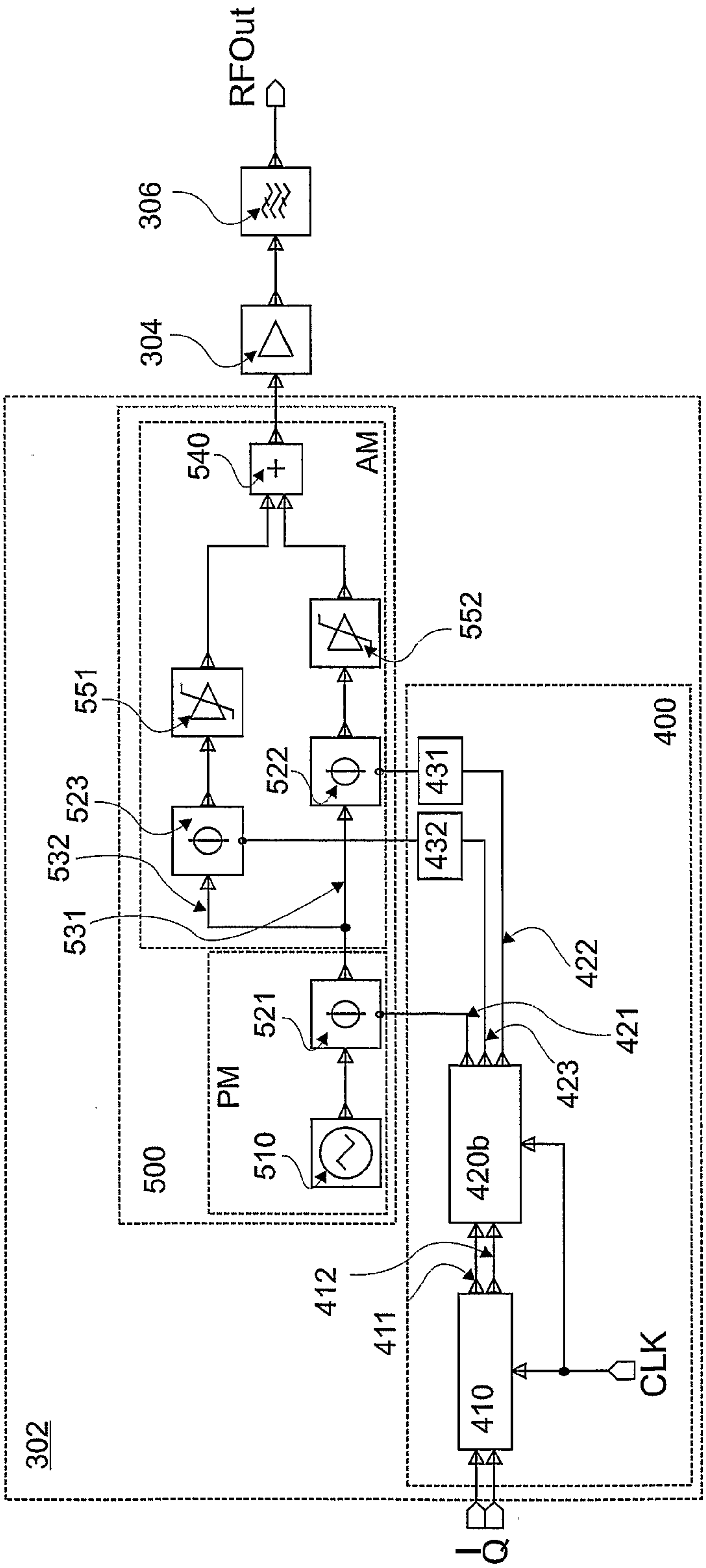
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Fig. 4A

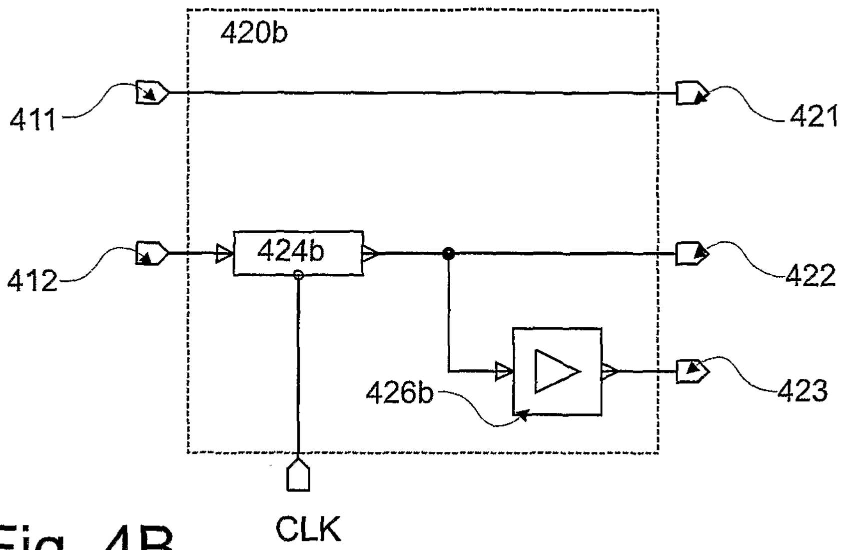

Fig. 4B