MULTI-MODE MODULATION APPARATUS

Abstract: The present invention relates to a multi-mode modulation apparatus and a method of modulating a carrier signal by a baseband signal in at least two modulation modes. The phase of the carrier signal is modulated in response to a first control signal derived from the baseband signal to obtain a first phase-modulated signal, and the phase of the carrier signal is additionally modulated in response to a second control signal derived from the baseband signal to obtain a second phase-modulated signal, wherein combination of the first and second phase-modulated signals is controlled to select one of the at least two modulation modes. Thereby, information of different components (e.g. phase and envelope) of the baseband signal can be phase-modulated and combined in a suitable manner, so that over-sampling and highly linear triangular or saw-tooth signals are no longer required. Moreover, the controlled combination provides a flexible multi-mode modulation scheme.
For two-letter codes and other abbreviations, refer to the “Guidance Notes on Codes and Abbreviations” appearing at the beginning of each regular issue of the PCT Gazette.
Multi-mode modulation apparatus

The present invention relates to a multi-mode modulation apparatus and method of modulating a carrier signal by a baseband signal in at least two modulation modes.

Modulation systems are known for modulating a carrier signal based on a baseband signal, for instance for modulating a radio frequency (RF) carrier based on information which is to be transmitted in a cellular communication system.

Due to increasing requirements on spectral efficiency, variable envelope modulation methods have become more and more popular. However, variable envelope modulation methods are disadvantageous in that conventional power amplifiers (PA) may cause heat and/or operation time problems in the transmitter equipment, in particular in thermally limited equipment like terminal devices. To alleviate these problems, switching mode PAs have been developed to increase power efficiency. These switching mode PAs are however extremely non-linear and may thus lead to increased distortions.

D.C. Cox, "Linear Amplification with Non-linear Components", IEEE Transactions on Communications, COM-22, pp. 1942 to 1945, December 1974, describes a variable envelope modulation systems which makes use of switching mode PAs as LINC (Linear Amplification with Non-linear Components) system in which any arbitrary bandpass signal, which has both amplitude and phase variations is represented by means of two signals which are of constant amplitude and have only phase variations. These two angle-modulated signals can be amplified separately using power efficient non-linear amplifiers. The outputs of these amplifiers are then combined by a summing unit in order to produce the desired variable amplitude signal. A problem of this system is the combination of two non-coherent amplified signals.

In pulse-width modulation (PWM) systems, the original signal is coded to a two-level signal that has pulses of varying width. The mean value of the two-level signal follows the desired output signal and can be extracted by filtering. Pulse density modulation (PDM) is an alternative way to accomplish the same task. Another pulse modulation method, which resembles the above-described PWM systems, is enabled by a sigma-delta modulation system. A bandpass sigma-delta modulator can be employed for transforming a modulated sinusoidal carrier to a two-level signal.
Furthermore, in polar modulation systems, an amplitude-modulated (AM) component and a phase-modulated (PM) component are separately processed and combined at the PA. There are several ways to control the PA. One class of prior art polar-modulation solutions are those where the AM component is added via modulation of the supply voltage of the PA. In order to achieve high power efficiency, this supply voltage modulation should be done via an efficient switching Direct Current-Direct Current (DC-DC) converter. It is however difficult to achieve high modulation bandwidth and to get rid of the switching ripple. A second class of prior-art polar-modulation solutions are those where the input of a switching PA is driven with a two-level PWM signal which is generated by comparing the AM and PM modulated carrier signal with a triangular (or saw-tooth) signal which fundamental frequency is at least twice the carrier frequency. This solution leads to a high PA switching frequency (over-sampling) and severe linearity requirements for the triangular (or saw-tooth) signal. Besides, the carrier already should have been linearly AM modulated before PWM conversion takes place. A third class of prior-art polar-modulation solutions are those where the input of the switching PA is driven with a two-level pulse-density signal which is generated by a bandpass sigma-delta converter. However, this solution requires an even higher PA switching frequency and thus a significant over-sampling ratio.

US 2004/0246060 A1 discloses a modulation system which provides a two-level signal with a desired modulation suited to be amplified by a switching mode PA. This prior art proceeds from the idea that the known LINC system can be redesigned to provide a two-level constant envelope signal. The information which is to be represented by a final modulation, e.g. amplitude and/or phase of an analog control signal, is coded into two control signals controlling the modulation applied by two constant envelope modulators. The modulation may comprise a phase modulation in case the output constant envelope signals are sinusoidal signals, and a modulation of transition times in case the output constant envelope signals are pulsed signals. The two constant envelope signals are then combined to a single two-level constant envelope signal. Hence, a single constant envelope signal is provided in the form of a two-level signal which can be amplified using a single non-linear amplifier, e.g. a switching mode amplifier. Thereby, the non-coherent power combining of the traditional LINC system can be avoided. Moreover, contrary to the delta-sigma modulation, the width of the resulting pulses is not discrete, so that quantization noise can be reduced.
It is an object of the present invention to provide a multi-mode modulation apparatus and method, by means of which different modulation types, such as PWM and linear modulation, can be provided without any need for over-sampling and linear triangular or saw-tooth signals.

The invention is defined by the independent claim. Dependent claims describe advantageous embodiments. Accordingly, phase-modulated outputs of two oscillator means controlled based on first and second control signals, which are derived from the baseband signal, are selectively combined to obtain a predetermined type or mode of modulation. This provides the advantage that over-sampling and a highly linear triangular or saw-tooth signals normally used for generating PWM signals are not required. Only one additional controlled oscillator means is required to generate a phase modulation.

Moreover, highly flexible usefulness as multi-mode modulator is provided by the selective combination. Conventional AM-PM RF carriers can be generated by linear addition of sine wave or sinusoidal voltage controlled oscillator (VCO) signals, and even polar modulation is possible when the RF carrier is only phase-modulated and the supply of the PA is directly fed with the envelope or amplitude component. In case of phase-modulated signals, the amplitude modulation of the fundamental frequency of the phase-modulated PWM signal can be used as power control. Such a power control scheme can be used in combination with any conventional way of power control by simply adapting the power supply of the PA. This combination will result in an even higher dynamic range for the power control.

With the suggested two-phase modulated output signals it is even possible to build a PA concept based on the LINC technique. In this case, the two phase-modulated (constant envelope) signals are fed to two switching PAs from which the output signals can be combined to generate a phase and amplitude modulated signal.

The combining means may comprise a logic gate (e.g. OR-gate, AND-gate, NOR-gate, etc. or any combination thereof) for logically combining respective binary square-wave signals generated from the first and second phase-modulated output signals to obtain the modulated output signal in accordance with a pulse-width modulation as a first one of the at least two modulation modes. Additionally, the combining means may comprise adding means for adding the first and second phase-modulated output signals to obtain the modulated output signal in accordance with a linear modulation as a second one of the at
least two modulation modes. Thereby, quite simple combination elements can be used to
obtain PWM and linear modulated output signals.

According to a specific example, the at least one logical gate may comprise a
NOR-gate and an AND-gate for logically combining the respective binary square-wave
signals to obtain push-pull signals for a balanced power amplifier, e.g., in a switched
operation mode for a two-level modulation mode (such as the PWM modulation mode).
Furthermore, the combining means may comprise inverter means for inverting said
modulated output signal to obtain push-pull signals for a balanced power amplifier, e.g., in a
linear operation mode for a linear modulation mode. The provision of such a balanced PWM
output signal provides the advantage that a cleaner spectrum is achieved at the output of the
balanced power amplifier.

The control means may comprise switching means for switching between
respective output signals of the OR-gate and the adding means. Again, flexible multi-mode
modulation can be obtained in a simple manner by switching between the respective output
signals of the combining means.

Furthermore, predistortion means may be provided for applying a
predetermined predistortion to at least one of a phase-related component and an amplitude-
related component of said baseband signal in response to said selective modulation mode,
wherein the first control signal is generated by adding the phase-related and amplitude-
related components in a summing means and the second control signal is generated by
subtracting the phase-related and amplitude-related components in a subtracting means.
Thereby, the selective predistortion provides the advantage that the modulated output signal
is optimized based on the selected modulation mode. In particular, the predistortion means
may be adapted to selectively either remove a sin(x)/x distortion or generate an amplitude-
modulated carrier, in response to the selected modulation mode.

The first and second controlled oscillator means may be phase-locked by
respective phase-locked loop circuits which are connected to a reference oscillator. Thus, the
transmitting or RF frequency may easily be changed by simply controlling the reference
frequency supplied by the reference oscillator.

The present invention will now be described based on a preferred embodiment
with reference to the accompanying drawings, in which:
Fig. 1 shows a schematic block diagram of a PLL multi-mode modulator according to the preferred embodiment;

Fig. 2 shows signal waveforms of the preferred embodiment as obtained by an AM component;

Fig. 3 shows a waveform of a symmetrical PWM signal at different timings;

Fig. 4 shows signal waveforms of the preferred embodiment as obtained by a PM component;

Fig. 5 shows a schematic circuit diagram of an alternative example of a signal combination portion of Fig. 1 suitable for driving a balanced PA;

Fig. 6A shows an output spectrum in the PWM mode in case of AM only;

Fig. 6B shows a time signal corresponding to the output spectrum of Fig. 6A;

Fig. 7 shows an output spectrum of the preferred embodiment in the PWM mode in case of a PM only;

Fig. 8 shows an output spectrum of the preferred embodiment in the PWM mode in case of AM and PM;

Fig. 9A shows an output spectrum of the preferred embodiment in the linear mode in case of AM only; and

Fig. 9B shows a time signal corresponding to the output spectrum of Fig. 9A.

In the following, the preferred embodiment will be described in connection with a phase-locked loop (PLL) multi-mode modulator which can be applied to achieve efficient modulation in transmitters for Wireless Local Area Networks (WLANs), WPANs (Wireless Personal Area Networks), Bluetooth systems, Orthogonal Frequency Division Multiplex (OFDM) systems, Global System for Mobile communication (GSM), Universal Mobile Telecommunications System (UMTS), Code Division Multiple Access (CDMA) systems, low-power mobile communication devices, etc.

Fig. 1 shows a schematic block diagram of the PLL modulation apparatus according to the preferred embodiment. An amplitude component \( A(t) \) and a phase component \( \Phi_p(t) \) of a baseband signal are supplied to a baseband processing circuit 10 which comprises a selective predistortion unit 110 controlled by a control signal which depends on the selected modulation mode, e.g., PWM or linear modulation. At the output of the baseband processing circuit 10 an amplitude-related phase modulation component \( \Phi_M(0) \) and a phase-related phase modulation signal \( \Phi_p(t) \) are obtained which are supplied to respective summing
nodes 27, 37 of two PLL circuits. The PLL circuits comprise a first VCO 26 and a second VCO 36, which are phase-locked by their respective PLL circuit. The phase-related phase modulation signal $\Phi_p(t)$ is directly supplied to both summing nodes 27 and 37, while the amplitude-related phase modulation signal $\Phi_M(0)$ is directly supplied to the first summing node 27 of the first PLL circuit and via an inverter 40 to the second summing node 37 of the second PLL circuit. Thereby, the first summing node 27 acts to add the phase-related and amplitude-related phase modulation signals $\Phi_p(t)$ and $\Phi_M(0)$, while the second summing node 37 acts to subtract the phase-related and amplitude-related phase modulation signals $\Phi_p(t)$ and $\Phi_M(t)$.

The first PLL circuit comprises a PLL loop in which a reference frequency with a reference phase $\theta_{ref}$ is supplied to a phase detector 22 where it is compared to an output frequency of the first VCO 26, which has been frequency-divided by a first divider circuit 24. The output of the first phase detector 22 is supplied to a loop filter 28 which supplies the filtered control signal to the first VCO 26 in order to control the phase of the output signal of the first VCO 26 based on the reference phase $\theta_{ref}$ of the reference oscillator 50. The modulation is achieved by a third summing node 25 where the summed phase modulation signals $\Phi_p(t)$ and $\Phi_M(0)$ are added to the output of the first phase detector 22 in order to control the phase of the output signal of the first VCO 26.

Similarly, the second PLL circuit comprises a second phase detector 32, a second loop filter 38 and a second divider circuit 34. It operates in a similar manner and comprises a fourth summing node 35 to which the difference of the two phase modulation signals $\Phi_p(t)$ and $\Phi_M(t)$ is supplied and which adds it to the output of the second phase detector 32.

The phase-modulated output signal $\Phi_1$ of the first VCO 26 and the phase-modulated output signal $\Phi_2$ of the second VCO 36 are connected to an adding circuit 70 where they are added and supplied to a first terminal of a switch 80. Additionally, the phase-modulated output signals $\Phi_1$ and $\Phi_2$ of the first and second VCOs 26, 36 are supplied to sign circuits 60 where the sinusoidal signals are converted to binary two-level signals corresponding to the sign of the sinus amplitude. The binary sign signals are then supplied to an OR-gate 62 where they are logically combined (i.e. OR-ed) and supplied to a second terminal of the switch 80.
The binary output signal of the OR-gate 62 has a first logical value "1" if at least one of the two input signals has a first logical value "1". If both input signals have the second logical value, i.e. "0", the OR-gate 62 generates the logical output value "0".

The switch 80, which may be any electronic switching device, such as a passive or active semiconductor switching element, is controlled by a control signal for selecting the modulation mode, which is also supplied to the baseband processing circuit 10. Based on this control signal, one of the outputs of the OR-gate 62 and the adding circuit 70 is selected and supplied as a modulation output $S_{RF}(t)$ to a PA 90. The power-amplified modulation output may then be supplied e.g. to a transmission antenna via a bandpass filter.

In the present example of Fig. 1, the baseband processing circuit 10 comprises only one predistortion unit 110 for applying a predistortion to the amplitude component $A(t)$ in order to generate the amplitude-related phase modulation signal $\Phi_{M}(t)$. However, a suitable predistortion may as well be supplied to the phase-related phase modulation signal $\Phi_{P}(t)$, if desired.

Thus, according to the preferred embodiment, the fundamental of a two-level PWM RF output signal can be amplitude-modulated and phase-modulated to generate a suitable signal for an efficient switching PA 90. The baseband envelope and phase information is modulated on two locked PLL circuits which are running at RF frequency. OR-gating of the two square-wave VCO output signals will then result in the wanted AM-PM two-level PWM signal. For this modulation method there is no need for over-sampling and no need for a highly linear triangular or saw-tooth signal which is normally used for generating PWM signals. Only one additional PLL circuit is required to generate the phase modulation in case of two-level RF carriers. In addition, conventional AM-PM RF carriers can be generated by selecting linear modulation and thus linear addition of the sine wave VCO signals, and even polar modulation is possible when the RF carrier is only phase-modulated and the supply of the PA 90 is directly fed with the envelope. In case of phase-modulated signals, the amplitude modulation of the fundamental frequency of the phase-modulated PWM signal can be used for power control.

According to Fig. 1, the first and second VCOs 26, 36 are phase-locked to the same reference frequency by means of two PLLs. If the PWM modulation mode is selected, the two square-wave output VCO signals are fed to the OR-gate 62, which results in an unmodulated square-wave output signal with a 50% duty cycle. In case of the linear modulation mode, two sine wave VCO signals are added at the adding circuit 70, which results in case of no modulation in a sine wave equal to the reference frequency. The two
PLL circuits can be provided with an extra divider to extend the range of the phase detectors 22, 32.

In case of modulation, both VCOs 26, 36 will become phase-modulated by adding a modulation signal at their loop filter circuits 28, 38. The loop bandwidth of the PLL circuits is sufficient to follow the desired phase modulation which is injected to the loop filter 28, 38. In the PWM modulation mode RF-modulated carriers (two-level signal) can be generated to be suitable for switched-mode PA concepts (class D), while in the linear modulation mode RF signals are generated to be used for conventional PA concepts.

In the PWM modulation mode, a corresponding phase predistortion is selected at the predistortion unit 110, and in addition the output of the OR-gate 62 is selected. The predistorted amplitude-related phase modulation signal $\Phi_M(0)$ which represents the envelope or the amplitude information of the baseband signal results in an amplitude modulation of the fundamental of the PWM signal. The first VCO 26 will be phase-modulated with a positive modulation signal $+\Delta\Phi_M$ and the second VCO 36 will be phase-modulated with a negative modulation signal $-\Delta\Phi_M$.

Fig. 2 shows signal waveforms of the preferred embodiment resulting from the effects of the amplitude-related phase modulation signal $\Phi_M(0)$. The upper waveform indicates the modulation output $s_{RF}(0)$ if the amplitude-related phase modulation is zero. The second and third waveforms indicate effects of a change of the amplitude-related phase modulation signal by $\Delta\Phi_M$. The change $\Delta\Phi_M$ leads to a shift of the output signal $\theta lo(t)$ of the first VCO 26 to the left and of the output signal $\theta o(t)$ of the second VCO 36 to the right. Thus, the fundamental of the PWM is amplitude-modulated by a differential predistorted amplitude-related phase modulation signal $\Phi_M(0)$.

It has been shown that the fundamental of the PWM carrier can be amplitude-modulated by predistortion of the duty-cycle by removing the $\sin(x)/x$ distortion. The fourth waveform of Fig. 2 shows a modulation output $s_{RF}(0)$ for the circuitry of Fig. 1 with increased pulse width and thus lower amplitude of the fundamental frequency of this rectangular signal. For 50% duty cycle the amplitude of the fundamental has the largest value and a further increase in pulse width will result in a lower amplitude of the fundamental.

As alternatives to the exemplary circuitry of Fig. 1, the combining of the two VCO output signals $\theta lo(t)$ and $\theta o(t)$ could as well be implemented by other logic gates, such as an AND gate, a NOR gate, etc. The lowest two curves of Fig. 2 show modulation outputs
If the OR-gate 62 is replaced by an AND-gate and a NOR-gate, respectively. Still, a suitable AM modulation is obtained.

Fig. 3 shows a waveform diagram indicating the change of the pulse width between a first time \( t = t_1 \) and a second time \( t = t_2 \), i.e., between the upper and lowest waveforms of Fig. 2.

In the following, the needed predistortion at the predistortion unit 110 for the PWM modulation mode is described in the following.

If the modulation frequency is much lower than the carrier frequency the quasi stationary approach can be used. For the amplitude of the fundamental of the PWM signal as shown in Fig. 3, the following equation applies:

\[
A(\tau) = \frac{\tau}{T_0} \sin\left(\frac{2\pi f_0}{2} \frac{\tau}{2}\right)
\]

wherein \( T_0 \) indicates the time period of the PWM signal and \( f_0 = f_0 \) denotes the corresponding frequency.

The duty cycle of the signal is given by \( d(\tau) = \tau/T_0 \), which results in the following modified expressions:

\[
A = d \frac{\bar{n}(nd)}{nd} \quad d(\tau) = \frac{\arcsin(M(\tau))}{\pi}
\]

This expression gives the relation between the desired amplitude (amplitude modulation) of the fundamental frequency of the PWM signal and the duty cycle. The maximum level of the carrier follows for a zero phase modulation (duty cycle 50%) and the minimum level for a phase modulation of 90° (duty cycle 0 or 100%). This results in the following expression for the phase modulating signal:

\[
\Phi M = \frac{\pi}{2} \quad \Phi M(t) = (l-2d(t)) \Phi M
\]

The effects of the phase-related phase modulation signal \( \Phi_p(t) \), which represents the phase of the baseband signal, lead to a direct modulation (common mode) at
both loop filters 28, 38 of the first and second PLL circuits, which results in a phase modulation of the fundamental frequency of the PWM signal.

Fig. 4 shows signal waveforms similar to Fig. 2 but for the case of a phase-related phase modulation signal $\Phi_p(t)$ only. Here, both output signal $\theta_1$ and $\theta_2$ of the first and second VCOs 26, 36 are shifted in the same direction by the amount of phase-related phase modulation $\Delta \Phi_p(t)$, and thus lead to a phase modulation of the modulation output $S_{RF}(t)$.

If the linear modulation mode is selected, another phase predistortion is selected at the predistortion unit 110, and the output of the linear adding circuit 70 for the output sine waves of the first and second VCOs 26, 36 is selected. The predistortion applied to the amplitude-related phase modulation signal $I_{M}(O)$, which represents the envelope information of the baseband signal, must be changed to get an amplitude-modulated output carrier.

The desired envelope can be expressed as follows:

$$A(t) = a + m \sin(\omega t)$$

A normal amplitude-modulated signal can be expressed by:

$$s_{AM}(t) = A(t) \cos(\omega_0 t)$$

The signals generated by the first and second VCOs 26, 36 are given by:

$$\theta_1(t) = \cos(\omega_0 t + \Phi_M(t))$$

$$\theta_2(t) = \cos(\omega_0 t - \Phi_M(t))$$

Addition of both signals results in an amplitude-modulated carrier, which can be expressed as follows:

$$s_{AM}(t) = \theta_1(t) + \theta_2(t) = \cos(\omega_0 t + \Phi_M(t)) + \cos(\omega_0 t - \Phi_M(t))$$

$$s_{AM}(t) = 2 \cos(\Phi_M(t)) \cos(\omega_0 t)$$
Comparing the desired signal with the generated signal and leaving out the amplitude scaling (factor 2) gives the predistortion of the phase modulation to obtain an amplitude-modulated carrier which can be expressed as follows:

\[ s^2 \text{AM}(t) = \text{SAM}_{00}, \text{ which gives: } \Phi_M(t) = \arccos(A(t)) \]

In the linear modulation mode, the phase modulation is done with a common mode phase modulation, so that the total output signals of the first and second VCOs 26, 36 with amplitude and phase modulation can be expressed as follows:

\[
\begin{align*}
\Theta_1(t) &= \cos(\omega_1 t + \arccos(A(t)) + \Phi_p(t)) \\
\Theta_2(t) &= \cos(\omega_2 t - \arccos(A(t)) + \Phi_p(t)) 
\end{align*}
\]

The linear addition of the two VCO signals \( \Theta_1 \) and \( \Theta_2 \) at the adding circuit results in an AM-PM modulated signal, which can be expressed as follows:

\[
\text{SAM-PM}(t) = \Theta_1(t) + \Theta_2(t) = 2A(t)\cos(\omega_1 t + \Phi_p(t)).
\]

Fig. 5 shows a schematic circuit diagram of an alternative example of the combination portion of Fig. 1 for combining the VCO output signals \( \Theta_1 \) and \( \Theta_2 \) in a manner suitable for driving a PA 90 which is now in a balanced configuration. To achieve this, push-pull signals \( s_1(t) \) and \( s_2(t) \) with basically opposite phase (linear modulation mode) or logical state (PWM modulation mode) have to be applied to respective control terminals (e.g. base terminals) of a balanced transistor pair, while the balanced PWM output signal is then obtained between the respective output terminals (e.g. collector terminals) of the transistor pair. Such a balanced PWM output signal provides the advantage that all even harmonics of the fundamental carrier with their sidebands are cancelled, so that a cleaner spectrum is achieved at the output of the balanced PA 90.

In the PWM modulation mode, the opposite logical state of the push-pull signals \( s_1(t) \) and \( s_2(t) \) can be achieved e.g. by replacing the OR-gate 62 of Fig. 1 by a combination of a NOR gate 63 and an AND gate 64 after the sign circuits 60. The respective output terminals of the NOR-gate 63 and the AND-gate 64 are then selectively connected in parallel by the switch 80 to the respective control terminals of the balanced PA 90.
In the linear modulation mode, the opposite phase of the push-pull signals $s_1(t)$ and $s_2(t)$ can be achieved e.g. by adding an inverter circuit 72 at the output of the adding circuit 70 of Fig. 1. The respective output terminals of the adding circuit 70 and the inverter circuit 72 are then selectively connected in parallel by the switch 80 to the respective control terminals of the balanced PA 90.

Of course, other suitable logical or linear combination circuits can provided for combining the VCO output signals in a desired manner to obtain one or a plurality of suitable driving signal(s) of the PA 90.

In the following, simulation results obtained by the circuit of Fig. 1 are shown for the PWM modulation mode and the linear modulation mode. The following simulation results are based on a scaled version (factor $\pi$) of the envelope used in the above equations.

Fig. 6A shows an output spectrum in case of a sole amplitude modulation in the PWM modulation mode. The three central spectral lines show the carrier and the two sideband frequencies of a typical amplitude modulation, while harmonics caused by the rectangular shape of the carrier signal start at higher sideband frequencies.

Fig. 6B shows a corresponding time signal with the envelope $A(t)$, the RF carrier (RF), the duty cycle (DC) and the predistorted phase modulation (PM).

Fig. 6 shows an output spectrum for the case of a sole phase modulation in the PWM modulation mode. This spectrum clearly resembles a typical phase modulation spectrum.

Fig. 8 shows an output spectrum in case of a combined amplitude and phase modulation in the PWM modulation mode.

Finally, Figs. 9A and 9B relate to the case of a linear modulation mode for amplitude modulation only. In Fig. 9A, the absence of any harmonics indicates an amplitude modulation with sinusoidal carrier signal as can be gathered from Fig. 9B where the envelope $A(t)$, the RF signal (RF) and pre-distorted phase modulation (PM) of the PLL circuits are shown.

It is to be noted that the present invention is not intended to be restricted to the preferred embodiment described above, but can be implemented in any modulation apparatus where at least first and second oscillator circuits are controlled by respective components of a baseband signal to obtain respective phase-modulated output signals. Also, the combination of the phase-modulated output signals is not intended to be restricted to a logical OR-combination and a linear adding operation. Rather, any suitable combination of the two phase-modulated signals can be employed to achieve a desired modulation mode.
In summary, a multi-mode modulation apparatus and a method of modulating a carrier signal by a baseband signal in at least two modulation modes have been described. The phase of the carrier signal is modulated in response to a first control signal derived from the baseband signal to obtain a first phase-modulated signal, and the phase of the carrier signal is additionally modulated in response to a second control signal derived from the baseband signal to obtain a second phase-modulated signal, wherein combination of the first and second phase-modulated signals is controlled to select one of the at least two modulation modes. Thereby, information of different components (e.g. phase and envelope) of the baseband signal can be phase-modulated and combined in a suitable manner, so that over-sampling and highly linear triangular or saw-tooth signals are not required. Moreover, the controlled combination provides a flexible multi-mode modulation scheme.

Finally but yet importantly, it is noted that the term "comprises" or "comprising" when used in the specification including the claims is intended to specify the presence of stated features, means, steps or components, but does not exclude the presence or addition of one or more other features, means, steps, components or group thereof. Further, the word "a" or "an" preceding an element in a claim does not exclude the presence of a plurality of such elements. Moreover, any reference sign does not limit the scope of the claims.
CLAIMS:

1. A multi-mode modulation apparatus for modulating a carrier signal by a baseband signal to obtain a modulated output signal, said apparatus comprising:
   - first controlled oscillator means (26) for modulating the phase of said carrier signal in response to first control signal derived from said baseband signal;
   - second controlled oscillator means (36) for modulating the phase of said carrier signal in response to a second control signal derived from said baseband signal;
   - combining means (60, 62, 70; 60, 63, 64, 70, 72) for combining first and second phase-modulated output signals of said first and second controlled oscillator means to generate said modulated output signal; and
   - control means (80) for controlling a combination function of said combining means to select one of at least two modulation modes of said multi-mode modulation apparatus.

2. An apparatus according to claim 1, wherein said combining means comprise at least one logical gate (62; 63, 64) for logically combining respective binary square-wave signals generated from said first and second phase-modulated output signals to obtain said modulated output signal in accordance with a pulse-width modulation as a first one of said at least two modulation modes.

3. An apparatus according to claim 2, wherein said at least one logical gate comprises a NOR-gate (63) and an AND-gate (64) for logically combining said respective binary square-wave signals to obtain push-pull signals for a balanced power amplifier (90).

4. An apparatus according to any one of the preceding claims, wherein said combining means comprise adding means (70) for adding said first and second phase-modulated output signals to obtain said modulated output signal in accordance with a linear modulation as a second one of said at least two modulation modes.
5. An apparatus according to claim 4, wherein said combining means comprising inverter means (72) for inverting said modulated output signal to obtain push-pull signals for a balanced power amplifier (90).

6. An apparatus according to any one of the preceding claims, wherein said control means comprise switching means (80) for switching between respective output signals of said combining means (62, 70).

7. An apparatus according to any one of the preceding claims, further comprising predistortion means (110) for applying a predetermined predistortion to at least one of a phase-related component and an amplitude-related component of said baseband signal in response to said selective modulation mode, wherein said first control signal is generated by adding said phase-related and amplitude-related components in a summing means (27) and said second control signal is generated by subtracting said phase-related and amplitude-related components in a subtracting means (37, 40).

8. An apparatus according to claim 7, wherein said predistortion means (110) are adapted to selectively either remove \( \sin(x)/x \) distortion or generate an amplitude-modulated carrier, in response to said selective modulation mode.

9. An apparatus according to any one of the preceding claims, wherein said first and second controlled oscillator means (26, 36) are phase-locked by respective phase-locked loop circuits (22, 24, 28, 25, 32, 34, 38, 35) which are connected to a reference oscillator (50).

10. A transmitter device comprising a multi-mode modulation apparatus according to any one of claims 1 to 9.

11. A method of modulating a carrier signal by a baseband signal in at least two modulation modes, said method comprising the steps of:
   - modulating the phase of said carrier signal in response to a first control signal derived from said baseband signal to obtain a first phase-modulated signal;
   - modulating the phase of said carrier signal in response to a second control signal derived from said baseband signal to obtain a second phase-modulated signal; and
controlling combination of said first and second phase-modulated signals to select one of said at least two modulation modes.
FIG. 1
FIG. 2

FIG. 3
FIG. 7

FIG. 8