SYSTEMS AND METHODS FOR VECTOR POWER AMPLIFICATION

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The advancement of wireless communication technology in the quest for better performance at lower cost has resulted in increasingly stringent demands on the ICs which constitute the building blocks of wireless systems. The RF power amplifier, an important component of any wireless transmitter, is often the villain of the piece, since it is a limiting factor in achieving better performance and reliability, and lowering cost. Thus, RF power amplifier design is a topic of immense interest and import in wireless communications. Another trend that has emerged in recent wireless communication standards is the use of modulation schemes with significant amplitude modulation, to achieve higher spectral efficiency. This has the effect of increasing the power amplifier linearity requirement, which conflicts with the desire for higher efficiency, an important criterion in mobile handsets, since it directly affects talk time. Thus, architectural techniques to enhance the efficiency of linear power amplifiers have become very important in modern RF power amplifier design.

The main claims of this patent can be summarized as follows:

(1) A plurality of substantially constant envelope signals are individually amplified, then combined to form a desired time-varying complex envelope signal.
(2) A time-varying complex envelope signal is decomposed into a plurality of substantially constant envelope signals. The constituent signals are amplified, and then recombined to construct an amplified version of the original time-varying envelope signal.
(3) The invention can be practiced with modulated carrier signals and with baseband information and clock signals.
(4) The invention can be implemented with analog and/or digital controls.

The background idea about the method of vector summing of two constant amplitude phase-modulated signals to generate the non-constant envelope signal is well known as linear amplification with non-linear components (LINC) which was first developed during the 1930's for the development of outphasing modulation. The basic principle of the LINC approach is of separating the bandpass input signal that may have either or both amplitude and phase (frequency) variation into two component signals that are constant amplitude with variations in phase only. These two constant amplitude and angle-modulated signals can be amplified separately by different amplifiers. The two amplifiers operate with constant envelope input signals, hence very power-efficient, and their outputs are summed to produce the desired signal. The desired envelope and phase variation at the output is obtained by varying the relative phases between two signals. The amplified component signals are passively combined to produce an amplified replica of the input signal.

The primary issues related to outphasing PA operation include:

(1) The combining approach results in a degradation of the output signal power due to insertion loss and limited bandwidth, and a decrease in power efficiency, especially, for signals with high peak-to-average ratios.
(2) The typical large size of the combining elements prevent integration in monolithic form.
(3) Phase imbalance is the most serious limitation of the LINC technique. One must be able to demonstrate an effective phase-imbalance compensation approach for viability.

The inventors insist that their approach satisfies the complex signal amplification requirement for wireless communication standards that the traditional LINC cannot achieve. However, the justification is not compelling as detailed below.:

The inventor cites three variations of the so-called vector power amplifier architecture. (1) Cartesian 4-Branch Vector Power Amplifier (2) Cartesian-Polar-Cartesian-Polar 2-Branch Vector Power Amplifier (3) Direct Cartesian 2-Branch Vector Power Amplifier. The primary common feature is to generate I and Q components separately by using the modulation processes in some analog or digital implementation. If we analyze approach (1) in detail (as an example and representative of the overall approach) we find at least one major impediment: how do we satisfy the complex signal amplification requirements without using a lossy and bulky power combing structure.

Basically, the modulated I- and Q-signal are generated from the set of 4 substantially constant envelope constituent signals (I_L, I_U, Q_L, Q_U) mixed with the carrier signal from the frequency synthesizer. Here I_L, I_U are constant envelope signals with reverse-phase along the I-axis. Their summation results in I-phasor are aligned to the I-axis. In the same way, the Q-phasor is generated and aligned to the Q-axis from two (2) constant envelope signals Q_L, Q_U. Here all four (4) constituent signals (I_L, I_U, Q_L, Q_U) have constant amplitude so that four (4) saturated PAs can amplify each signal efficiently. The resultant I(t) and Q(t) signal can be combined into time a varying envelope signal after power combination.

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

In the conventional outphasing PA scheme, the desired envelope and phase variation at the output is obtained "**by varying the relative phases between two signals**" that are inserted into the power combiner. However, in the approach presented in the patent, a Vector PA (VPA) scheme, the phase difference between two signals, I(t) and Q(t), does not vary. The phase difference between I(t) and Q(t) is 90 degree at all times, but the amplitude is varied to obtain the desired envelope and phase at the output as shown in Fig. 5.

In Fig. 5, we have three combiners, 572, 574, and 576. The 572 and 574 receives the two constant envelope signals with opposite phase along the x- and y-axis, respectively. The combiner 576 receives two non-constant envelope signals with the phase aligned to the x- and y-axis, respectively. Therefore, the first two combiners have different functions and operation from the third one. The power combining scheme for the first two combiners, 572 and 574, can be either a resistive power combiner or a reactive power combiner. When the resistive power combiner is used for 572 and 574, then it has the benefit that the linearity of the outphasing system is enhanced because one can avoid the complication of signal-dependent loading of the amplifier. However, power combining under these conditions is unavoidably lossy. So the overall efficiency is equivalent to the efficiency versus power relationship for the Class-A amplifier, which exhibits a strong reduction in efficiency as the power decreases from the peak value. The Chirex-outphasing combiner, made of $\lambda/4$ transmission-line sections with shunt reactances, is a lossless combining structure that offers higher combining structures, but at the cost of degraded linearity. For the power combiner 576, the resistive power combiner scheme is preferred because the input signal amplitude to the combiner is somewhat linear with a fixed phase difference. This means that an actual implementation of Figure 5 (which is fundamental to the invention) will be unavoidably inefficient from an overall power combining perspective.

The inventors ignore this issue, which is critical to the overall efficiency performance. I do not see any evidence that the overall efficiency can equal the constituent constant-envelope amplifiers as the inventor has claimed. Considering the overall system, the power efficiency of the system will be close (at best) to the conventionally linear operated power amplifier.

The basic flaw of the invention is propagated through the disclosure. For example, the architectures that employ the digital components, as shown in Fig. 7 in the patent, the power is "hard wired" without having any other power combining structure. Since the power amplifiers in this scheme are in a saturation mode, the PA can be expressed as a voltage source, meanwhile the linear amplifier is operated as a current source. Therefore the output power cannot combined by simply connecting the nodes together. It is unclear how one can claim that this approach satisfies the complex signal amplification requirement without introducing a power combining scheme (which most likely will introduce loss, area, cost, etc..) and thus affect performance and practical implementation.

In summary, the patent does present some interesting ideas in "theory". However, in practical implementation one can categorize the work as a LINC implementation or a somewhat obvious extension of the LINC architecture.