SDR Transmitter Based on LINC Amplifier with Bias Control

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Abstract — **This paper describes a LINC (Linear Amplification using Nonlinear Components) handset transmitter adopting DC bias control. The power amplifier is operated at a saturated output power level and its level is adjusted by DC bias control. Thus the transmitter guarantees high efficiency at all usable output power level. Due to the LINC linearization, it can operate as a linear power amplifier. The new LINC transmitter can be used as a transmitter for software defined radio (SDR), since it can efficiently amplify both the GSM type constant envelope signal and CDMA type non-constant envelope signal, and its control part is very simple and mostly embodied in the digital domain. For verification, a 1.71 GHz LINC prototype transmitter has been implemented and tested. The results, compared with conventional cases, clearly show the suitability of the new LINC transmitter for SDR application.**

I. Introduction

In CDMA type mobile radio transmitters, the efficiency and linearity are key factors. Generally, there is a trade-off between two properties and it is very difficult to satisfy those at the same time. The LINC transmitter is known as an excellent solution with a high efficiency and good linearity[1],[2]. Also, it is based on a saturation amplifier and is ideally suited for the amplification of GSM type constant envelope signal.

For LINC, it is possible to use highly efficient but highly nonlinear RF amplifiers (e.g., class-E, -F, or E/F[9]), because constant envelope signals are created by adding error signal at the input of the power amplifier, and the subtraction process of the error signal at the output combiner creates the wanted linear amplification for CDMA type amplifier. For the constant envelope signal, the error signal will be zero. DC bias of the power amplifier can be easily controlled for the power level and efficiency without considering linearity of the amplifier. Thus, the efficiency can be high even at a low power operation. The most of control for the transmitter including power level, linearity by error addition, etc., is embodied in the digital domain. Therefore, the LINC transmitter is a promising solution for application to multi-standard terminal of SDR (Software Defined Radio)[3]-[5].

This paper proposes a new LINC handset transmitter optimally employing above-mentioned merits for mobile terminal service. The new LINC transmitter has been constructed in prototype to evaluate excellence of LINC technique as a mobile radio transmitter and demonstrated experimentally for an up-link CDMA IS-95 signal having 4.5 dB peak-to-average ratio at 0.1 % CCDF (Complementary Cumulative probability Density Function) at 1.71 GHz DCS band.

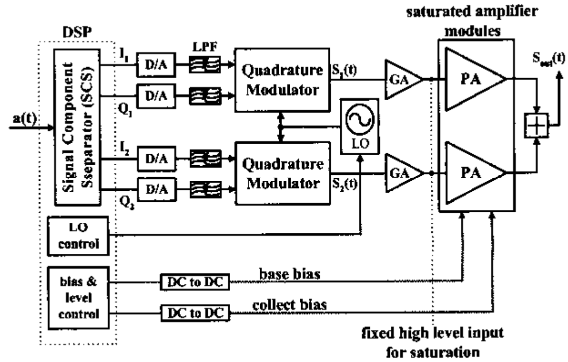

Fig. 1. Proposed LINC transmitter architecture for mobile terminal service.

II. Architecture of Proposed LINC Transmitter

Fig. 1 shows the architecture of the new LINC handset transmitter proposed in this work. The signal component separator(SCS) block in the digital part converts a non-constant signal a(t) to constant envelope phase modulated signals, $S_1(t)$ and $S_2(t)$[6]. $S_1(t)$ and $S_2(t)$ components are efficiently amplified by saturation RF amplifiers. The outputs are combined by a Wilkinson combiner and the original amplitude and phase modulated signal is restored. The gain and phase imbalances between the two amplifier branches are compensated by SCS block[7],[8]. In other words, $S_1(t)$, $S_2(t)$ are adjusted to compensate the imbalances. The LO control block provides data, clock and LE(Load Enable) signals to lock PLL(phase-locked

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loop) at the RF carrier frequency. RF modulation method is direct upconversion using quadrature modulator. The bias and level control block in the digital part controls DC to DC converters to regulate the base and collect DC biases. This block plays an important role in the proposed LINC architecture. $S_1(t)$, $S_2(t)$ signals are amplified by gain amplifiers(GA) to high levels to compulsorily saturate the main amplifiers. In a fixed DC bias condition, output power of the main amplifier maintains a constant level. The output power level of the overall transmitter is determined by the bias and level control block, that is, by tuning DC biases. The simple level control method without using any variable gain amplifier(VGA) can be utilized, since the LINC transmitter has a good linearity independent of the DC biases. Moreover, a handset transmitter changes the output power level at a low speed and a slowly adjustable DC to DC converter is good enough for this application. The new LINC transmitter adopting the level control method guarantees high efficiency for all usable output power level. Since a handset transmitter usually operates at a low power level, the high efficiency at a very low power level is a very significant merit for a power transmitter.

The LINC system can nimbly jump from one radio standard to another (say from CDMA to GSM), since the two constant envelope sources for LINC operation are provided in the digital domain and the most control parts are also embodied in the digital domain. Therefore, the proposed handset transmitter can be a very good architecture for multi-standard terminal transmitter for SDR application.

III. Implementation and Experimental Results

A LINC prototype transmitter has been constructed to evaluate the expected performances of LINC technique as a mobile radio transmitter. The LINC transmitter is built on the basis of the architecture described in section II. Namely, power amplifier is compulsorily saturated at a limited power level and output power level is adjusted by DC bias control. In this system, a personal computer (PC), which is installed a DSP board, 4 channel DAC's and digital outputs, is used to convert a modulated signal to the two constant envelope signals, to compensate the gain and phase imbalances and to control DC to DC converter and the rest of peripherals. The installed DAC has 14-bit resolution and 40 MHz maximal update rate. The RF chain consists of a two-stage 30 dB gain amplifier and a SKYWORKS CX77304-17 final stage. The final stage power amplifier module (PAM) working in 1.71 GHz DCS band has 31.5 dBm PEP of saturation power, 30 dB of linear gain and 40 % CW efficiency at PEP. The used modulated signal is an up-link CDMA IS-95A signal having 1.2288 MHz of the chip rate and 4.5 dB peak-to-average ratio at 0.1 % CCDF. The carrier frequency is 1.71 GHz DCS band.

The experiments are conducted to demonstrate that the proposed LINC transmitter is superior to a conventional LINC transmitter or a conventional direct upconversion transmitter, and also is suited for SDR application. The conventional LINC transmitter adopts level control by adjusting the input power level instead of DC bias tuning. And the conventional direct upconversion transmitter is a modified version to use CDMA IS-95A source itself for $S_1(t)$ and $S_2(t)$ signals in fig. 1 and has no bias control.

Pout = 16 dBm			Pout = 30 dBm		
V_B (V)	V_C (V)	Efficiency (%)	V_B (V)	V_C (V)	Efficiency (%)
1.93	0.67	12.883	2.20	2.86	21.939
1.90	0.67	13.024	2.10	2.90	23.472
1.80	0.69	13.957	1.99	2.99	24.632
1.70	0.71	14.992	**1.96**	**3.03**	**24.751**
1.60	0.75	15.994	1.93	3.07	24.746
1.50	0.80	17.087	1.90	3.14	24.680
1.40	0.89	17.909	1.87	3.19	24.691
1.30	**1.04**	**17.922**	1.84	3.26	24.486
1.25	1.23	16.523	1.81	3.35	24.136
1.24	1.39	15.140	1.78	3.43	23.898
1.23	1.52	14.176	1.75	3.55	23.389
1.22	1.86	11.999	1.72	3.73	22.620

Table 1. Efficiencies of the proposed LINC transmitter for various DC-bias conditions at two average power levels (16 and 30 dBm).

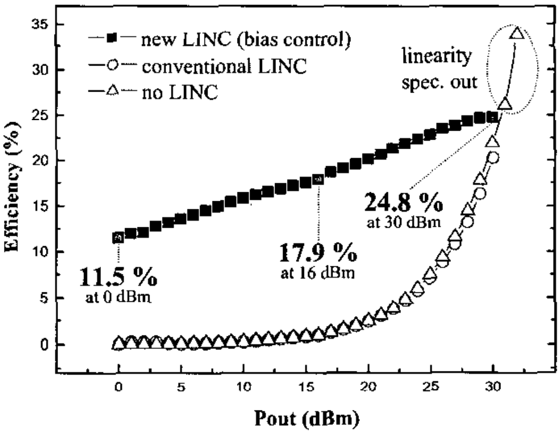

Fig. 2. Efficiencies of three cases (proposed LINC transmitter, conventional LINC transmitter without bias control and conventional direct conversion transmitter) for various average output power levels.

The experimental results are presented in table 1, fig. 2, fig. 3 and fig.. 4. Table 1 shows efficiencies of the proposed LINC transmitter for various DC-bias conditions at two average power levels (16 and 30 dBm). Maximum efficiencies are 17.92 % at 16 dBm and 24.75 % at 30 dBm. There is an optimal bias point with the maximum efficiency for a given power level. Therefore, the base and collect biases must be adjusted for the output power level and efficiency at the same time. Fig. 2 compares efficiencies of three cases (proposed LINC transmitter, conventional LINC transmitter without bias control and conventional direct upconversion transmitter) for various average output power levels. The figure clearly shows the efficiency improvement realized by using the new DC bias control method for LINC transmitter. The efficiencies of the new LINC transmitter are 24.75 %, 17.92 % and 11.5 % respectively at 30 dBm, 16 dBm and 0 dBm of the average output powers, while those of conventional ones are 21.9 %, 0.97 % and 0.03 %, respectively. The efficiency slope of the new LINC transmitter is remarkably slow compared with the two conventional cases. Thus, the new LINC transmitter is very suitable for mobile handset service, since handset transmitter usually operates at a low power level (about 0 dBm). Fig. 3 shows ACPR's at 885 KHz offset of the new LINC transmitter and conventional direct conversion transmitter for various average output power levels. Because the linearity of LINC transmitter does not change through output power level, ACPR of the new LINC transmitter is fixed at -52.8 dBc. On the other hand, the linearity of the conventional transmitter becomes poor at a high output power level.

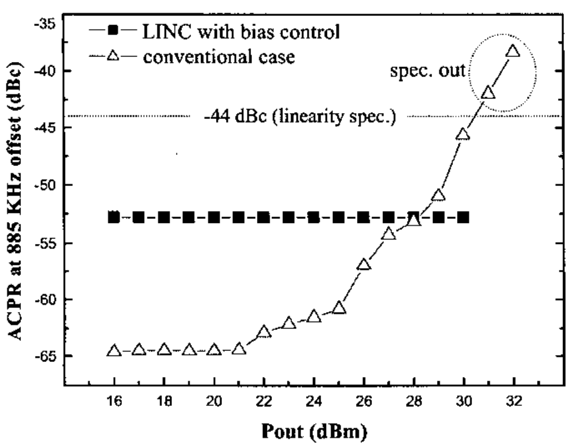

Fig. 3. ACPR's at 885 KHz offset of new LINC transmitter and conventional direct upconversion transmitter for various average output power levels.

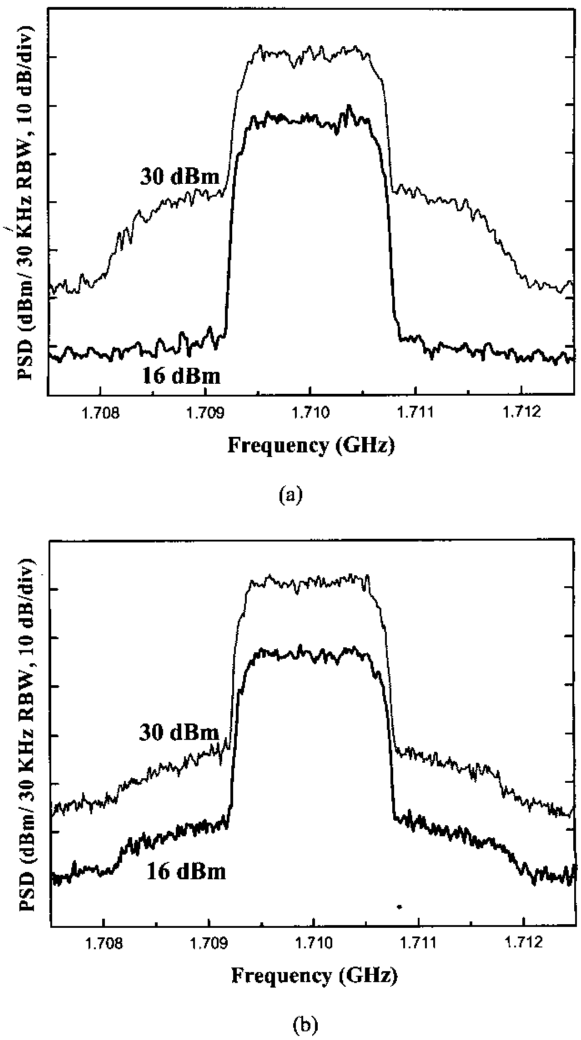

Fig. 4. the PSD's at 16 and 30 dBm of the average output power level (a) for conventional direct upconversion transmitter and (b) for new LINC handset transmitter.

Fig. 4 shows the PSD's(Power Spectral Density) of two cases, visualizing the spectra for the conventional transmitter (see fig. 4(a)) and the new LINC transmitter (see fig. 4(b)) at 16 and 30 dBm of the average output power level. A large nonlinear distortion at a high power is shown in only the conventional case (fig. 4(a)). If being adopted an efficient amplifier (e.g., class-E, -F, or E/F[9]) having about 80 % or more CW efficiency, the average efficiency of the new LINC transmitter is expected to be more than about 55 % at maximal average output power (30 dBm). This efficiency can be maintained for wide power level. In the conventional direct conversion case, the high efficient amplifier can be not employed due to the poor linearity. So far, we have discussed for the linear amplification of a non-constant envelope signals such as CDMA. But, by adjusting the input signal, the constant envelope signal such as GSM can be efficiently amplified by the saturation amplifier. Therefore, the transmitter can be highly efficient for both GSM and CDMA type signals, which is a big advantage for SDR application.

IV. Conclusions

We have proposed a new LINC transmitter for SDR application, optimally employing the potential merits. The new LINC technique adopts DC bias control for adjusting output power level. This system is highly efficient for both GSM and CDMA type signal amplifications, since the DC biases are adjusted to have maximum efficiency for a given RF power. And, the LINC technique is an efficient linear amplifier for the CDMA signal. For experimental verification, a practical prototype LINC transmitter has been constructed and tested using CDMA IS-95A signal. The efficiency of the new LINC transmitter is 24.75 % at maximal average output power (30 dBm) and 17.9 % and 11.5 % respectively at 16 dBm and 0 dBm. ACPR is -52.8 dBc at 885 KHz offset for overall power level. The efficiency maintained high even at a very low power. If being adopted highly efficient power amplifier having about 80 % or more CW efficiency, the average efficiency of the new LINC system is expected to be more than about 55 % at maximum average output power (30 dBm). However, in the conventional case, the highly efficient saturation amplifier can be not employed due to the poor linearity. Thus, the experimental results confirm that the new LINC transmitter provides good performance in the linearity and efficiency. This transmitter is a hopeful solution for the SDR for multi-standard terminal, since it has excellent performance and can be easily embodied in digital domain for various controls.

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