A 30 W Cartesian Feedback Transmitter with 40 % Efficiency Incorporating an Inverted Doherty Amplifier

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Abstract- We present a 30 W Cartesian feedback transmitter with an efficiency of 40 % and an adjacent channel leakage power ratio (ACLR) of -51 dBc for 859 MHz band π/4-DQPSK applications. The high efficiency of the system was achieved by a significant efficiency improvement for the final amplifier stage using a load modulation technique. The implemented Cartesian feedback transmitter, using a Doherty power amplifier, exhibited a 3rd order inter-modulation distortion (IMD3) improvement of 27 dB for a two-tone signal at an output power level of 45 dBm. It also had ACLR improvement of 16.2 dB for the π/4-DQPSK signal at an output power level of 45 dBm. The system performed with an efficiency as high as 40 % which was an improved value by about 7 % points as a consequence of the high efficiency characteristics of the inverted Doherty amplifier.

Keywords – Cartesian feedback transmitter, linear transmitter, inverted Doherty amplifier, high-power amplifier

I. INTRODUCTION

For transmitters of modern wireless communication systems, high output power, efficiency, and linearity are strongly required for better communication performance. Highly linear power amplifiers generally have low efficiency and the highly efficient power amplifiers are not linear enough. Therefore, linearization of the transmitter system is essential [1]-[6].

There are many kinds of direct linearization techniques for nonlinear power amplifiers such as feed-forward and adaptive pre-distortion methods [1], [2]. There are also linear transmitters such as those using linear amplification with nonlinear components (LINC), a polar modulation transmitter, and a Cartesian feedback transmitter, etc [3], [4].

The Cartesian feedback technique for linear transmitters has many advantages: a relatively compact circuit configuration, high linearity, insensitivity for various conditions due to the feedback, non-parametric linearization, and relatively high efficiency [5], [6].

In our work, we developed a high-power Cartesian feedback transmitter for the 859 MHz band. A compact inverted Doherty amplifier was adopted for the final amplifier stage to achieve a higher efficiency. We discuss, in this paper, the basic structure, operation, and some important considerations for the Cartesian feedback transmitter. We also discuss implementation and experimental results for the overall system including the design and measured results of the inverted Doherty amplifier.

II. THE CARTESIAN FEEDBACK SYSTEM

A. Configuration and Operation

Fig. 1 shows a simplified system diagram and the operational block diagram of the Cartesian feedback transmitter. The feedback system operates: Analog baseband I/Q signals were applied to the subtractors which also had inputs for the feedback I/Q signals. After subtraction, i.e. the feedback process, the residual I/Q signals were up-converted to the RF band using a quadrature modulator. The up-converted RF signal was amplified by the multi-stage nonlinear power amplifiers with sufficient gain. Without a feedback process, it became a general open-loop structure of the direct up-conversion transmitter.
The RF signal was coupled and attenuated to an appropriate level after amplification. Then, the signal was down-converted to be analog baseband I/Q signals by a quadrature demodulator. The down-converted I/Q signals were fed back to the subtractors after a proper filtering process using the loop filters which completed the closed-loop of the Cartesian feedback transmitter.

The linearization process of the Cartesian feedback system can be analyzed using a simple operational diagram as shown in Fig. 1(b). The distortion terms, generated by the system, were: One was the forward path distortion \(D_{\text{fp}}\) including the power amplifier’s nonlinearity and another was the feedback path distortion \(D_{\text{pb}}\) including the demodulator’s nonlinearity.

The transfer function of the overall feedback system can be derived as:

\[
Y = \frac{X}{B + \frac{D_{\text{fp}}}{AB} - \frac{D_{\text{pb}}}{B}},
\]

where \(A\) (\(Ge \; G_{\text{la}}\)) and \(B\) are gains for the forward and feedback paths, respectively. The transfer function of (1) indicates that the distortion, generated in the forward path, can be suppressed by the loop gain \(AB\) However, the distortion, generated from the feedback path, cannot be suppressed. Therefore, a highly linear demodulator is required.

B. Important Considerations for the Feedback System

There were some important considerations for the Cartesian feedback transmitters. Using ADS simulation, we checked the effects of the phase and gain mismatches and DC offsets on the system performance. In the simulation setup, the phase of the LO signal was changed using a phase shifter block. The gain mismatch between the I and Q paths was realized by individually adjusting the gains of the loop filter pair. The DC offset was generated and changed by the subtractor.

Fig. 2 shows the simulated results for the effects of the gain mismatch (a), phase mismatch (b), and the LO up-conversion quantity due to the DC offset (c). The output power and IMD3 significantly varied according to the gain mismatch from -3 and 3dB of the Q path with a fixed gain of the I path. The output power and IMD3 were changed from 46 to 43 dBm and -46 to -57 dBc, respectively. Therefore, the gain mismatch between the I and Q paths should be tightly controlled and minimized to maintain the output performance.

For the phase mismatch from -60° to +60° between the I and Q paths, the resulting performance variations were not severe. Therefore, the phases for both the I and Q paths could be more coarsely controlled than the amplitudes.

The DC offset can be generated by the demodulator and operational amplifiers for the feedback path. The DC offset can be up-converted to the RF band with the same frequency as the LO signal, which can saturate the power amplifiers. An LO signal power of more than 20 dBm can be up-converted from a DC offset voltage of 100 mV by the modulator. Hence, a compensation circuit is necessary to minimize the DC offset.

III. THE INVERTED DOHERTY AMPLIFIER

Fig. 2. The effect of the gain mismatch (a), the effects of the phase mismatch (b), and the LO leakage according to the DC offset (c).

Fig. 3 shows a schematic diagram of the inverted Doherty amplifier. If the peaking amplifier was perfectly turned off, the matching network and offset line of the carrier amplifier modulated the load impedance twice while the conventional Doherty amplifier accomplished that using a \(\lambda/4\) transmission
line. The carrier amplifier for this case had a λ/4 line to suppress leakage current. For a high power level, both amplifiers were turned on and delivered the same output power to the load.

The inverted Doherty amplifier was built using Freescale's MRF9030 (30 W-PEP LDMOSFET) for the final stage of the amplifiers. The measurement results for the IMD3 and power-added efficiency (PAE) for two-tone excitation with a tone spacing of 25 KHz at the center frequency of 859 MHz are shown in Fig. 4. At an output power of 45 dBm, the Doherty and class-AB amplifiers respectively exhibited PAEs of about 50% and 43.7% while the IMD3s for both amplifiers were about -24 dBc.

The measurement results of the ACLR and PAE using the π/4-DQPSK signal with a bandwidth of 25 KHz at the center frequency of 859 MHz are given in Fig. 5. At an output power of 45 dBm, the Doherty and class-AB amplifiers respectively had 48% and 41% while the measured ACLRs were almost identical for both amplifiers. Table I summarizes the representative performances of both amplifiers.

IV. EXPERIMENTAL RESULTS FOR THE SYSTEM
The Cartesian feedback system employing the inverted Doherty amplifier as the main amplifier was assembled in a 210x297 mm² case using the implemented RF and baseband building blocks as shown in Fig. 6. The baseband signals were generated and applied to the system for the RF two-tone and $\pi/4$-DQPSK signals.

The gain of the open-loop forward path (subtractor, modulator, and amplifier stages) was 74 dB while the gain of the feedback path (coupler, attenuator, demodulator, and loop-filter) was about -47 dB. For the closed-loop condition, we had a gain of 47 dB and a loop gain of 27 dB.

The measured spectra for the open-loop and closed-loop conditions at an output power of 45 dBm are shown in Fig. 7. For the two-tone signal with a tone spacing of 25 KHz, we obtained an IMD3 improvement of 27 dB. We also achieved an ACLR improvement of 16.2 dB at a 25 KHz offset for the $\pi/4$-DQPSK signal. After closing the loop, an ACLR of as low as -31dBc and an overall system efficiency of more than 40% were achieved at an output power of 45 dBm (about 31.62 W).

Table II summarizes the performances of the system before and after closing the loop.

V. CONCLUSION

In this paper, we discussed a Cartesian feedback transmitter including the inverted Doherty amplifier with high-linearity and efficiency. Compared to its open-loop condition, the implemented Cartesian feedback transmitter exhibited an enhanced IMD3 and ACLR of about 27 dB and 16.2 dB, respectively. The PAE was also improved because of the load impedance modulation from the Doherty amplifier. The subsequent system efficiency even including the digital controller was more than 40% using the $\pi/4$-DQPSK signal at a center frequency of 859 MHz.

REFERENCES