High bandwidth current mode amplifier for envelope modulated RF amplifiers

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A high bandwidth discrete current mode amplifier capable of driving large voltages into low impedances is presented. A differential current mirror output stage ensures stability at high frequencies. Small signal bandwidth is 24 MHz and large signal bandwidth extends into the megahertz region. When amplifying the AC component of a 3 MHz 3rd generation partnership project (3GPP) long term evolution (LTE) envelope signal, an efficiency of 19.1% is achieved at 18.8 V peak-to-peak output across a 15 Ω load.

Introduction: Modern communication systems based on orthogonal frequency division multiplexing (OFDM) like WiMax and long term evolution (LTE) [1] achieve high data rates and high spectral efficiency by exploiting both amplitude and phase modulation. This necessitates the use of linear RF power amplifiers (PAs) to convey the modulation accurately to the receiver without violating the spectrum mask. Historically, linear amplifiers are low efficiency and therefore unsuitable for energy conscious base stations [2]. Simultaneously achieving high linearity and high efficiency requires novel amplifier architectures.

One solution is the envelope tracking (ET) [3] architecture which modulates the power supply of an RF PA with the signal envelope. Greater efficiency can be achieved if the envelope modulator is split into two frequency bands [4, 5]. The low frequency path is a switched mode power supply (SMPS) and the high frequency path is a linear amplifier. At low power applications the linear amplifier is often an off-the-shelf operation amplifier (opamp).

Off-the-shelf opamps are generally designed for low-power applications. High power and high slew rate options do exist [6, 7], but their performance cannot meet all the requirements of a high power high bandwidth ET amplifier.

Assuming a 9 dB peak-to-average power ratio (PAPR) LTE modulated signal, a 30 W RF PA with a 24 V supply voltage and a 10 Ω supply voltage impedance, the linear amplifier must source 1.6 A at the peaks and sink 0.88 A at the nulls. Assuming an envelope modulator bandwidth of 1.5–2.5 times the RF signal bandwidth [4], the linear amplifier must have a slew rate of at least 108 V/μs.

Conventional opamps [6], based on emitter follower output stages, suffer from an effect whereby the bias current increases under high frequency large signal conditions [8]. This Letter describes a current mode amplifier of the translinear amplifier family, based on a differential current mirror output stage [9], which avoids this problem.

Circuit description: The circuit of the current mode amplifier is shown in Fig. 1. The relatively high value output resistors (R16 and R17) maintain stability through local negative feedback around the output devices (Q5 and Q6). Approximately 0.22 V is dropped across R16 and R17 and across the reference resistors (R12 and R13). Classically, current mirrors use thermally coupled identical devices to maintain a high degree of tracking. Non-identical devices can be used in the current mirror branches if a moderate voltage drop is tolerated across these resistors. The moderate voltage drop across R16 and R17 reduces the efficiency, but ensures stability from high frequency run-away.

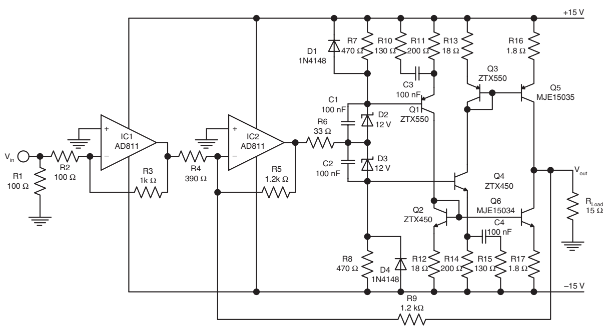

Fig. 1 *Current mode amplifier circuit diagram*

Q5 and Q6 have a gain bandwidth product (GBW) of approximately 80 MHz [10]. At high frequencies their current gain drops significantly, i.e. 16 A/A at 5 MHz. The ability of Q5 and E6 to track the reference path (Q3 and Q2, respectively) will become less effective at high frequencies. A relatively large reference branch current of 12 mA and a low current mirror gain of 10 ensure Q3 and Q2 can drive Q5 and Q6, respectively, at high frequencies.

The gain of the current mirror stages is determined by the two stages of amplification in each current mirror based around Q1 and Q6, and Q4 and Q5, respectively. Since the amplifier operates in a current mode, the output voltage, and therefore the gain of the discrete stages, depend on load resistance R_{Load}. The balanced architecture ensures that the output current, and therefore the output voltage, is the summation of both current mirrors. The amplifier is biased towards class B operation by the two zener diodes (D2 and D3), so each current mirror amplifies one half cycle of the signal. This effectively cancels out the doubling in output current from the balanced architecture. The total stage AC gain is therefore:

$$G_{voltage} = R_{Load} \frac{R12}{R17} \frac{1}{R10//R11} \tag{1}$$

R10//R11 is the parallel value of R10 and R11, which is equal to the parallel value of R14 and R15. The ratio of R12 to R17 is the current gain of the current mirror, and is equal to the ratio of R13 to R16. The overall AC gain of the discrete stages is 5.6 dB, with a 3 dB high pass cutoff of 5.8 kHz.

Biasing the current mirrors into class B with zener diodes reduces the bias current of the current mirrors and increases the efficiency. To bias the current mirror stages into full class B requires that the value of the zener diodes be increased so the current mirrors are pushed into the cutoff region. This will degrade the high frequency performance as the transistors will be operating in a nonlinear region for part of the signal cycle.

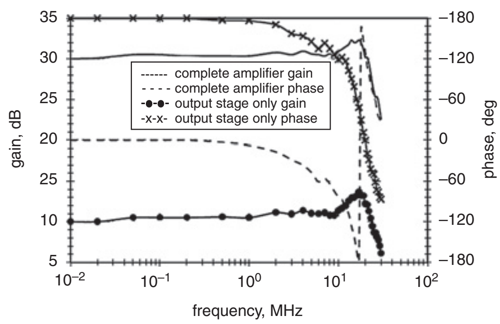

Fig. 2 *Measured small signal response with 15 Ω load impedance*

An AD811 current feedback operation amplifier (IC2) introduces global negative feedback to maintain linearity. Overall stability is maintained by minimising the gain of the individual stages. A further AD811 (IC1) outside of the negative feedback loop serves as a preamplifier.

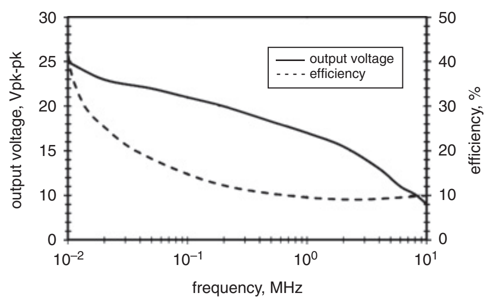

Fig. 3 *Amplifier maximum output voltage swing into 15 Ω load impedance*

Practical results: All the results presented are based on a physical prototype. Under quiescent conditions the current consumption is 194 mA from +/− 15 V supply rails. The closed loop small signal bandwidth is 24 MHz with a small resonant peak at 14 MHz as shown in Fig. 2. The full power bandwidth and corresponding efficiency are shown in Fig. 3 under sinusoidal excitation.

The current mode amplifier can accurately replicate the AC component of a 3 MHz bandwidth LTE envelop signal. An efficiency of

19.1% at 18.8 V peak-to-peak (4.65 V RMS) can be achieved with a tolerable degree of signal clipping. Under LTE excitation the amplifier's input and output signals were sampled with a digital oscilloscope and the input and output signals plotted against each other in Fig. 4. The smearing of points is owing to the amplifier's power bandwidth curve, as suggested in Fig. 3. Output clipping is visible at both the top and bottom of the transfer characteristic. The sparsity of points in the upper right hand quadrant indicates that the peaks contain little information; hence a degree of clipping can be tolerated.

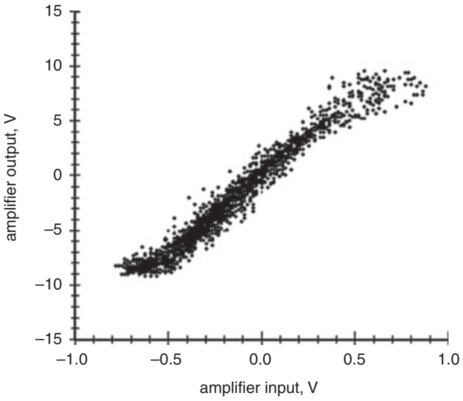

Fig. 4 *Sampled output voltage against input voltage with 3 MHz LTE envelope signal*

Conclusions: An amplifier architecture is presented capable of driving a large amplitude high bandwidth signal into a low impedance load. The use of differential current mirrors ensure the output stage is not victim to high frequency run-away. Low-cost commercially available transistors are used throughout, producing a small signal bandwidth of 24 MHz and an impressive large signal bandwidth. The amplifier can accurately and efficiently amplify the AC component of a 3 MHz LTE envelope signal, making it suitable for medium power envelope modulated RF PAs. The amplifier's performance is largely determined by the output devices. Alternative output devices may provide a different power bandwidth curve.

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