RF power detector design with temperature compensation for power amplifiers bias control

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Abstract: This paper presents the radio frequency power detector design for the bias control of the power amplifiers using a DC to DC converter. Non-diode type power detector has large bandwidth which is important for fast tracking of the non-constant envelope RF signal such as in WCDMA (wideband CDMA) system. The measured result shows the output voltage of power detector from 0.77 V at low output power to 1.806 V at 27.5 dBm output. The variation of the detector output voltage is less than 60 mV because of the temperature compensated current sources when the ambient temperature is varied from −30°C to 85°C.

Keywords: DC to DC converter, RF power detector, temperature compensated current sources, WCDMA power amplifier

Classification: Wireless circuits and devices

References


1 Introduction

For highly efficient power amplifiers at backed off output power in mobile applications, typically two different methods are widely used in current technology; one is the parallel power amplifier structure which has two different sizes of power transistors to switch off between high and low power mode.
operation [1] and the other is to control the bias and supply voltage of the power amplifiers for better efficiency at low output power [2]. A DC to DC converter with an integrated power detector is a control circuitry to dynamically change the supply voltage along with the output power [2]. Since a DC to DC converter requires proper voltage control to set the bias voltage of the power amplifiers from the battery, an integrated power detector which can generate a specific voltage level according to the input power is essential. Conventional envelope detectors or peak detectors with a diode and a RC network are commonly used for detecting the radio frequency power in DC to DC converter applications. Lower corner frequency, however, by large RC value limits the bandwidth of digitally modulated signal and in a certain time during communication when the amplitude of radio frequency signal is small or close to zero, the diode detector cannot follow the signal envelope which results in inaccurate generation of the DC voltage from the detector. Also, large value of resistors and capacitors makes it difficult to be integrated in a single chip which is important for reducing the overall size of a power amplifier module.

This paper presents the amplifier based radio frequency power detector with higher corner frequency of the RC filter and also shows the design of temperature compensated current sources to minimize the performance variations of the power detector over the temperature change.

2 Power detector designs

Fig. 1 shows the block diagram and the detailed schematic of the amplifier based power detector which has an input attenuator and a differential amplifier [3]. It consists of two different amplifiers with opposite output characteristics; an inverting amplifier by the common emitter (top one) and a non-inverting amplifier by the common collector (bottom one) amplifier. The input attenuator is required since the tapped RF signal is large enough to damage each transistor which should be small to minimize the current consumption by the power detector. At very low input power level to the detector, only Q1 is on (Q2 is off), so that the Q3 draws the current from VBIAS. The voltage drop across R7 is transferred to the output of the power detector through the buffer (Q5), which is the minimum voltage, VMIN. Since those two amplifiers have opposite transfer characteristics, as the input signal becomes large enough to turn Q2 on, VOUT2 rises from 0 V (or any small voltage across the current source, ICS1) to higher voltage for Q4 to be turned on. On the other hand, Q1 draws more current as the input signal becomes stronger, which drops VOUT1. So, the current through R7 is reduced to increase the output voltage of a differential amplifier. Finally, Q3 should be turned off at higher input to the power detector and the output voltage is equal to VBIAS − VBE5 (≈ VMAX).

There are RC filters at each output of amplifiers (VOUT1 and VOUT2) where 1 KΩ and 6 pF are used in this design to have roughly 26.5 MHz corner frequency. Since the modulation bandwidth of WCDMA signal is 3.84 MHz,
Fig. 1. Block diagram and detailed schematic of the RF power detector. Differential amplifier is used to maintain the minimum required voltage for the power amplifier’s linearity.

the DC output voltage from the detector fairly follows the envelope of the RF input signal.

In this design, modified Gilbert cell with a shared emitter resistor (R9) is used with two current sources at each emitter because of the low voltage headroom across the current source in a conventional differential amplifier. The reason for requiring differential circuitry in a power detector depends on the transfer characteristics of DC to DC converter which is generally linear between control voltage and the output voltage. If the power detector’s output applied to the DC to DC converter is less than 0.7 V at low power level in this case, the output voltage from the converter to the supply of a PA is so low that the linearity response like ACPR (adjacent channel power ratio) cannot meet the specifications. So, when the output power level is low (below 16 dBm) the output voltage of the power detector should be constant larger than the required minimum voltage (0.7 V). Beyond this switching point, output voltage from the power detector starts increasing from 0.7 V to raise the supply voltage of the power amplifier.

Fig. 2 shows a schematic diagram of temperature compensated current sources used in the power detector. It consists of cascode current mirrors with larger devices by 8 and resistors at the emitter. Since the temperature coefficient of VBE of GaAs HBT in the amplifiers of the power detector is negative, VT reference with positive temperature coefficient in the current source makes the overall current variation of the power detector neutral over the temperature change. Cascode current mirrors are used to have larger output impedance for the current source.
3 Measurements

A WCDMA power amplifier with an on-chip power detector is fabricated using 2 µm GaAs HBT technology and integrated with Si DC to DC converter on a 4-layer laminate (6 × 6 mm²). Overall chip size of this WCDMA PA including the power detector and ESD (electrostatic discharge) protection circuits is 1406 × 1160 µm² and 430 × 380 µm² is used for the integrated power detector.

The measured detector voltage and corresponding output voltage from the DC to DC converter are plotted in Fig. 3 according to the output power level while the ambient temperature is changed from −30°C to 85°C. The deviation of the output voltage from the power detector is less than 60 mV compared to the nominal value at room temperature due to the temperature compensated current sources in the power detector. At low output power, the detector voltage is almost constant at 0.77 V and starts to increase at the switching point from low power operation to high power mode operation. Maintaining the minimum voltage level to the DC to DC converter is critical for the linearity of WCDMA power amplifier since it is strongly affected

![Fig. 2. Schematic diagram of temperature compensated current sources for the integrated power detector.](image)

![Fig. 3. Measured output voltage of the power detector and corresponding DC to DC converter voltage.](image)
by the bias and supply voltage. In this measurement, the output voltage from the DC to DC converter is varied from 1.375 V to 3.29 V depending on the output power level when 3.4 V battery is used. About 0.11 V of voltage drop happens across the big inductor between the output of the DC to DC converter and VCC of the power amplifier.

Fig. 4 show the measured power added efficiency (PAE) and adjacent channel power ratio (ACPR) of the WCDMA power amplifier at 5 MHz offset from 1950 MHz with 3 GPP RF signal input. The output voltage from the DC to DC converter is connected to the supply voltage of the power amplifier. The measured PAE shows very stable over the temperature variation which is important in actual application to the wireless system. The ACPR plot in Fig. 4 shows some variation of the linearity over the temperature which is more sensitive to the change of the supply voltage of the power amplifier. In case of the conventional power detector design without temperature compensation technique, the output voltage variation of the DC to DC converter over the temperature is so wide that the ACPR would be dramatically worse, especially at low ambient temperature. Therefore, the minimum variation of the detector voltage is desirable in terms of the linearity issue in the linear power amplifier. This WCDMA power amplifier shows 39.7% of PAE and −38 dBc of ACPR at 27.5 dBm output power and room temperature.

4 Conclusions

In this paper, amplifier based RF power detector is presented to have higher bandwidth of RC filter and to avoid inaccurate generation of the DC voltage from the detected RF power. To get low temperature variation of the output voltage from the power detector, temperature compensated current sources are used and the measured data shows that less than 60 mV of output voltage variation from the power detector is achieved when the ambient temperature
varies from $-30^\circ\text{C}$ to $85^\circ\text{C}$. The measured PAE (power added efficiency) of the WCDMA PA using this scheme with DC to DC converter in a single module is very stable, also. The linearity of the power amplifier is sensitive to the temperature change, so that it is necessary for temperature compensation to be included in the power amplifier bias designs.

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