Power Detection and Control
For Mobile Handset Applications

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Part 2. Power Detection Methods

Power control architectures for mobile handsets can be categorized into two main groups, Direct and Indirect detection. Indirect power detection takes advantage of relationships between DC characteristics and RF output power without the need to directly evaluate the RF output waveform. Using these relationships, simple circuitry and simple process technologies can offer a potentially lower cost and smaller size solution. These indirect detection techniques suffer in performance due to limited visibility to antenna loading conditions. Direct power detection monitors aspects of the RF waveform. This technique often requires an RF coupler, high frequency circuitry and RF process technology driving cost and increased complexity of dynamic range/isolation tradeoffs.

Many indirect detection techniques have been used for a variety of power amplifier products in the market. Fundamentally they can be categorized in three different ways. Power can be estimated through DC current, DC voltage, or the DC power through the product of DC current and voltage.

The diagram in figure 1a shows an example of current sense control using a resistor placed in series with the power supply to monitor current in the final stage of the RF amplifier. Variations of the current sense architecture can also include a “sense amplifier” which produces an output current proportionate to the current in the RF stage eliminating the need to monitor the potentially high currents of the PA final. With current sense, the output power is directly proportionate to the DC current and is related through the effective load impedance presented to the amplifier. This technique is best suited to saturated-mode operation of the power amplifier, but can be adapted to linear modes of operation. An amplifier operating in linear-mode tends to have a high quiescent current which does not directly contribute to output power. This quiescent current must be subtracted from the over-all amplifier current to achieve acceptable dynamic range. The most attractive attributes for current sense is extremely high efficiency and precision control of the amplifier current which maintains battery life under all operating conditions. Current sense can be implemented at very low cost.

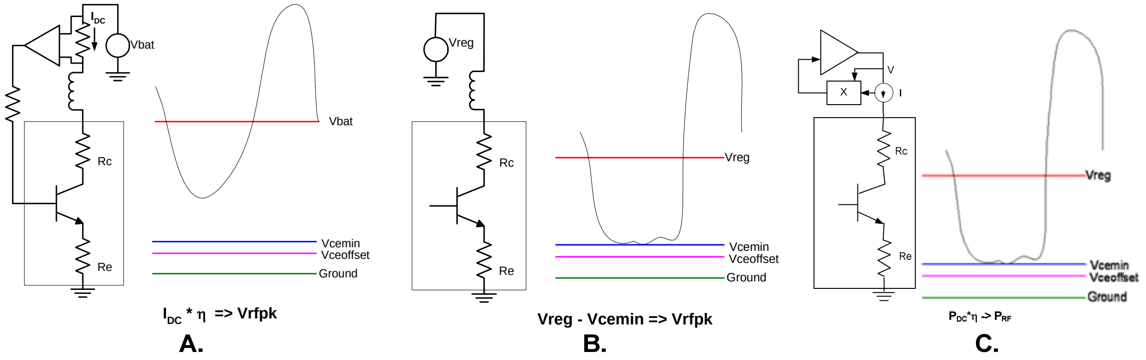


Fig.1. Indirect control methods. A. DC current Sense. B. DC Voltage Control. C. DC power control

The plot in figure 2a shows the typical power control accuracy for the current sense architecture for a saturated-mode amplifier. Given constant load impedance, precision control of output power over temperature, supply and frequency can be accomplished. A low value sense resistor ($< 0.1\Omega$) is used to minimize loss and impact to PAE. The extremely low sense voltage greatly complicates the design of the feedback amplifier such that DC offsets and drift do not significantly impact the control accuracy and dynamic range. Trimming has been required to limit part-to-part variation of the offset to less than 1 mV. Offset drift of < 10uV/C is often required for competitive control accuracy.

Indirect detection using DC voltage assumes voltage saturation in the amplifier output stage. Clearly, this technique is only applicable to saturated-mode operation and is integral with the bias and control topology. As shown in figure 1a, the RF waveform is centered at the DC supply voltage supplied to the RF device. During conduction, the collector waveform is brought to the minimum value identified as Vcemin in the graph. This minimum voltage, relative to the supply voltage defines the amplitude of the RF waveform. Temperature drift of the Vcemin term is specific to the device process and geometry but can be compensated with the Vreg voltage.

The plot in figure 2b shows the typical power control accuracy for the voltage sense architecture. Temperature variation dominates the low power accuracy. As compared to the performance observed in the current sense, one can see that the low power accuracy is degraded. This performance is achieved with much less offset and drift accuracy of the Vreg control relative to the current sense solution. Isolation of the amplifier stages also contributes to degradation of the control accuracy at the low output power levels.

The primary disadvantage of indirect power detection is poor accuracy into non-ideal load conditions. Variation in the load impedance and phase results in variation of delivered power as current or voltage is held constant. Figure 2c shows the typical power variation observed for the voltage detection architecture. This variation can be predicted based upon the known load variation presented directly at the output of the RF device. There is no method to compensate for the variation when only voltage or current sensing is used.

Indirect power detection is used to improve the control accuracy under VSWR conditions. Skyworks has patented a solution for combining the voltage control and current sense architecture to control DC power delivered to the RF device. Given a constant RF efficiency in the amplifier device, the DC power delivered to the amplifier is directly proportional to the RF power delivered to the load. Figure 1c shows a conceptual implementation of the solution based upon the voltage control architecture which defines the DC voltage. The regulator can sense the current while feedback is used to adjust the voltage such that the voltage and current product remains constant.

Design of the amplifier load characteristic is critical to maintain consistent power control into VSWR for the indirect DC power control architecture. Control accuracy at low output power is no better than the voltage sense solution and may be degraded due to additional variation introduced by the multiplier present in the feedback path. Figure 2d shows measured data demonstrating the potential improvement of control accuracy into VSWR for this type of detection architecture.

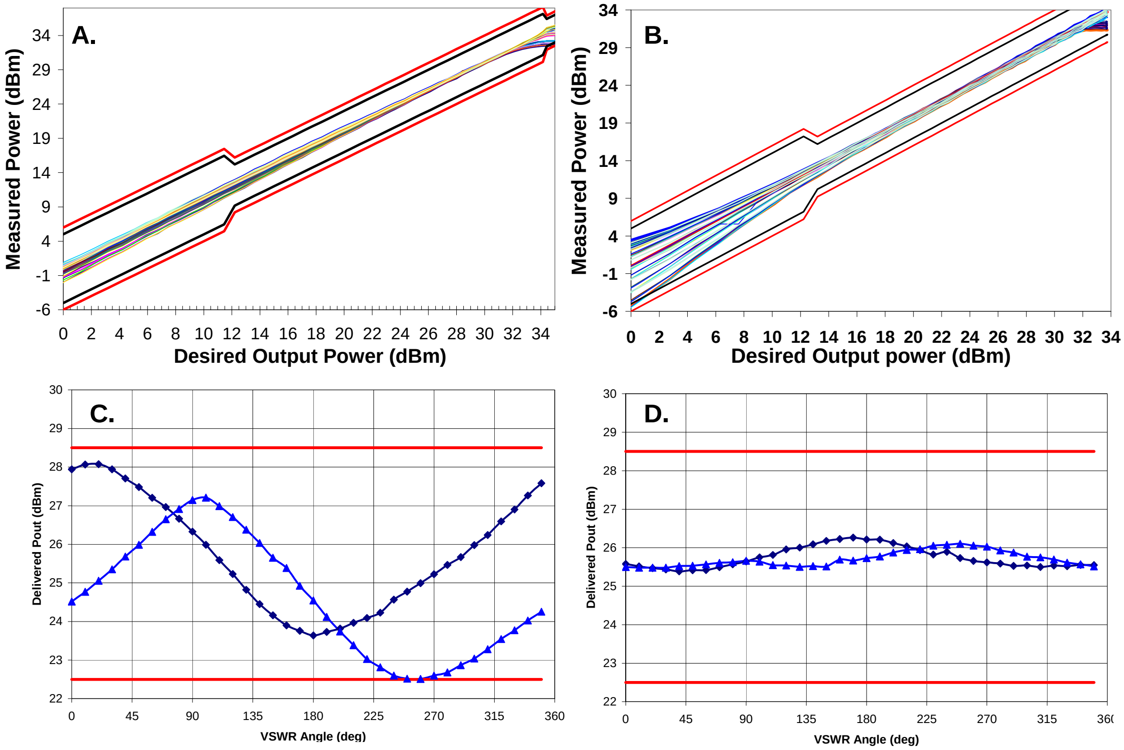


Fig. 2. Indirect control characteristics. A. Current sense dynamic range/accuracy B. Voltage control dynamic range/accuracy C. Current/Voltage control accuracy under varying RF loads D. DC power control under Varying RF load

Most direct detection techniques are fundamentally based upon an RF peak detection circuit. This circuit operates at the RF carrier frequency and provides a DC voltage representative of the RF envelope peak values. Many solutions exist to implement the detector function ranging from biased and unbiased diodes in a wide array of exotic process technologies to bipolar and MOS circuits. Figure 3a shows an example peak detector implemented in silicon with a temperature compensated bipolar NPN acting as an emitter follower driving a holding capacitor. The RF bandwidth of the detector is limited at low frequency by the input coupling and by the active device on the high frequency side. The envelope detection bandwidth or video bandwidth of this circuit is defined by the RC time constant at the output.

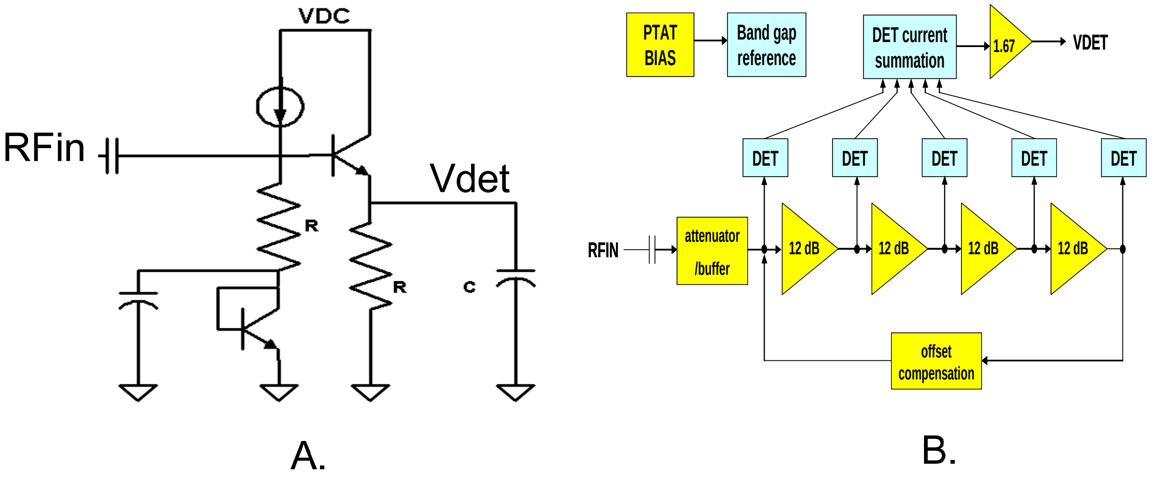
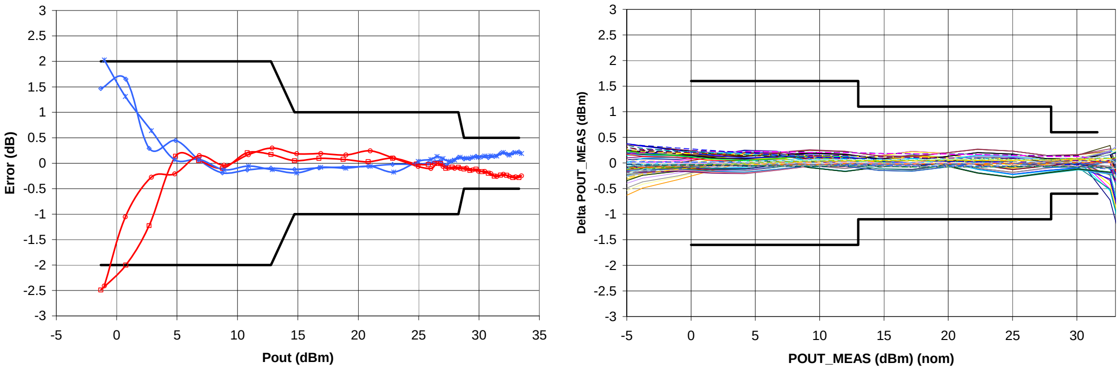


Fig. 3. RF detection circuitry. A. Peak Detector B. Logarithmic detector

A peak detector exhibits an exponentially increasing voltage with increasing input power. At low input powers, peak RF voltages become very small and can no longer be resolved relative to offsets within the detector. With careful attention to offsets and temperature drift, RF peak detectors can provide only 30 – 35 dB of usable dynamic range. Detection accuracy over temperature for a typical peak detector is shown in figure 4a.

The logarithmic detector provides improved detection dynamic range and a linear in dB/V output characteristic. Although several variations exist for logarithmic detection, the demodulating log detector architecture is most popular for handset solutions due to its lower current operation. Figure 3b shows a block diagram for a demodulating log detector consisting of a cascade of several peak detectors separated by RF gain stages. The gain specified in each of the RF stages is carefully selected to use a limited region of the peak detector. Summation of each detector output results in a linearly increasing voltage with increasing input power. The dynamic range of the log detector far exceeds the peak detector due to the significant RF gain within the signal path. Figure 4b shows the detection accuracy of the log detector. Either AC coupling or correction feedback is required to prevent DC offsets within gain sections from saturating the detectors. This DC offset may often be a limiting factor in the dynamic range of the detector. The RF bandwidth of the detector is limited on the low side with the AC coupling or offset correction feedback while the upper range is limited by the amplifier bandwidth. The envelope detection or video bandwidth is limited by the detector and summation section.



A.

B.

Fig. 4. Detector accuracy over temperature. A. Peak detector B. Logarithmic detector