Power Detection and Control For Mobile Handset Applications

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Part 1. Power Amplifier Biasing for Power Control

The power control requirements of the GSM/EDGE system pose significant challenges in the power amplifier design. Typical system requirements of 35 dB dynamic range and +/- 2 dB accuracy are often clearly understood and documented, but the interaction of control bandwidth, RX band noise, transient response, switching spectrum and performance into VSWR (Voltage Standing Wave Ratio) is often not understood until a product is fully prototyped and evaluated. Additionally, customer expectations often far exceed the minimum requirements of the governing standard.

As the handset standards mature and move towards converged architectures, detection and control for multiple modes with multiple modulation formats must be supported within a single power amplifier module. A basic understanding of the fundamental amplifier bias methods and their characteristics along with knowledge of the many detection methods available can greatly improve the opportunity for first-time success in next-generation PA module development.

Saturated-mode operation of a power amplifier typically targets highly efficient performance and often includes requirements for gain/output power control as a function of the bias. At the most basic level, a standard power amplifier consists of a cascade of common-emitter amplifying stages. Saturation of the active device in each stage can be accomplished through limiting the supply voltage or current in the device. With the case of a bipolar amplifier, limiting the collector current is often done through limiting of the base current bias. In figure 1a, the use of a voltage reference through a moderately high series resistance to the base is used to control the bias point. Likewise, a current source can be used to directly control the bias point of the power amplifier stage. The device is always operated at the minimum current level required to support the desired output power, high efficiency is maintained with the base current biasing techniques over a wide dynamic range in power.

Similar to the current control bias which limits the output swing by limiting the output current, voltage control of the supply provided to the amplifier can be used to directly limit the output swing of the amplifier. A power supply regulator is used in this method to limit the voltage and force voltage saturation of the amplifying stages.

Linear-mode operation is often used for systems which employ amplitude or complex modulation techniques. It is critical that the amplifier gain remain constant over a wide range of output power. The bias point of the amplifier must not be impacted by the level of RF present within the gain stage. Unlike the high impedance bias of saturated-mode operation, a low impedance bias of the device is required for the linear amplifier. Base-current variation of the gain stage due to power variation of the amplitude modulation can not result in DC voltage variation of the bias point. Figure 1c shows a conventional “current mirror” bias style for a linear amplifier. The feedback within this circuit yields a very low impedance bias for frequencies within the modulation bandwidth. Compensation of the feedback loop will band-limit the circuit and result in a higher impedance interface at RF frequencies such that the bias circuit does not load the RF gain of the power amplifier stage.

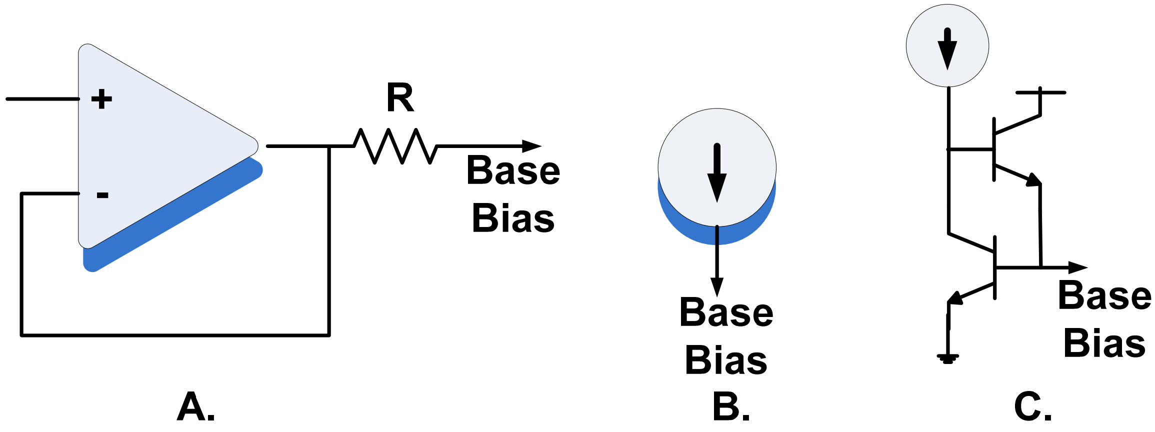

Fig. 1. A. High impedance bias. B. Current source bias. C. Current mirror Biasing

The power control characteristics for each of the previously mentioned bias topologies will now be considered. Current control methods offer the greatest dynamic range for saturated power control. Unfortunately, these methods exhibit significant variation with environmental conditions and require feedback loops to provide accuracy in power control. Figure 2a shows the control characteristic typical of the high impedance base bias method (figure 1a). Notice that the output power exhibits strong sensitivity to temperature and RF input drive. Temperature dependence results from Vbe and beta variation of the bipolar gain stage. Input drive dependence arises from RF rectification within the amplifier shifting the DC bias point.

The graph in figure 2b shows the power control characteristic typical of current source biasing. Again, significant sensitivity to temperature is observed due to beta variation of the RF gain stages. In this bias topology, RF input sensitivity is eliminated since the bias point is not dependant upon DC voltages which can be impacted by rectification.

The use of supply to voltage saturate the amplifier stages offers the most repeatable control characteristic. In this example, the performance is so good that feedback is not required for accurate power control. First order compensation of the control voltage for temperature is sufficient to provide competitive system level performance. Figure 2c shows the typical control characteristic for this method. Note that the dynamic range of this method tends to be less than that of the current mode control.

The control characteristic for the “current mirror” bias technique exhibits a response much different than that of the saturated control methods. With this topology, for a given bias current, the gain of the amplifier remains constant over a wide range of input power levels. As the bias current for the amplifier is adjusted, the transconductance of the bipolar stages is adjusted and the associated gain is shifted. Given that transconductance is a function of temperature, temperature variation of is observed. The dynamic range with this bias method is very limited. Figure 2d shows the typical gain characteristic as a function of bias current for the linear-mode biasing topology. The primary method for power control with a linear amplifier is with input power control rather than with gain control of the amplifier.

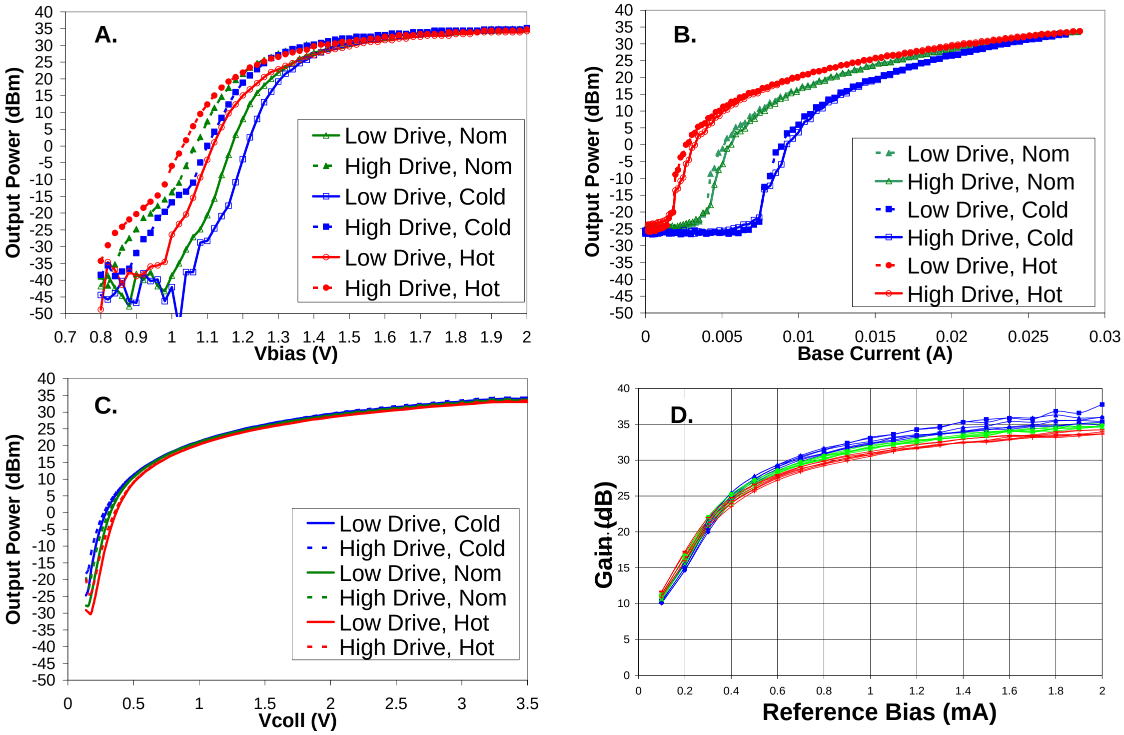

Fig. 2. Bias control characteristics over temperature. A. High Impedance Bias B. Current Source Bias C. Collector Voltage D. Current Mirror Bias

In addition to the dynamic range and environmental sensitivities, the amplifier efficiency and noise characteristics are greatly impacted by the bias control topology. Figure 3 shows the relative power added efficiency (PAE) for a PA using the previously described bias techniques. Notice that the current control topology exhibits the best efficiency over the entire dynamic range. As mentioned earlier, this bias method operates the amplifier at the minimum current required to support the output power. The supply voltage control solution tends to offer the lowest efficiency performance although the peak efficiency is comparable. This topology requires significant overhead in the design to ensure adequate saturation of the gain stages over the entire dynamic range. Note that this control method does not exhibit the “flattening” of efficiency near peak power like the other methods.

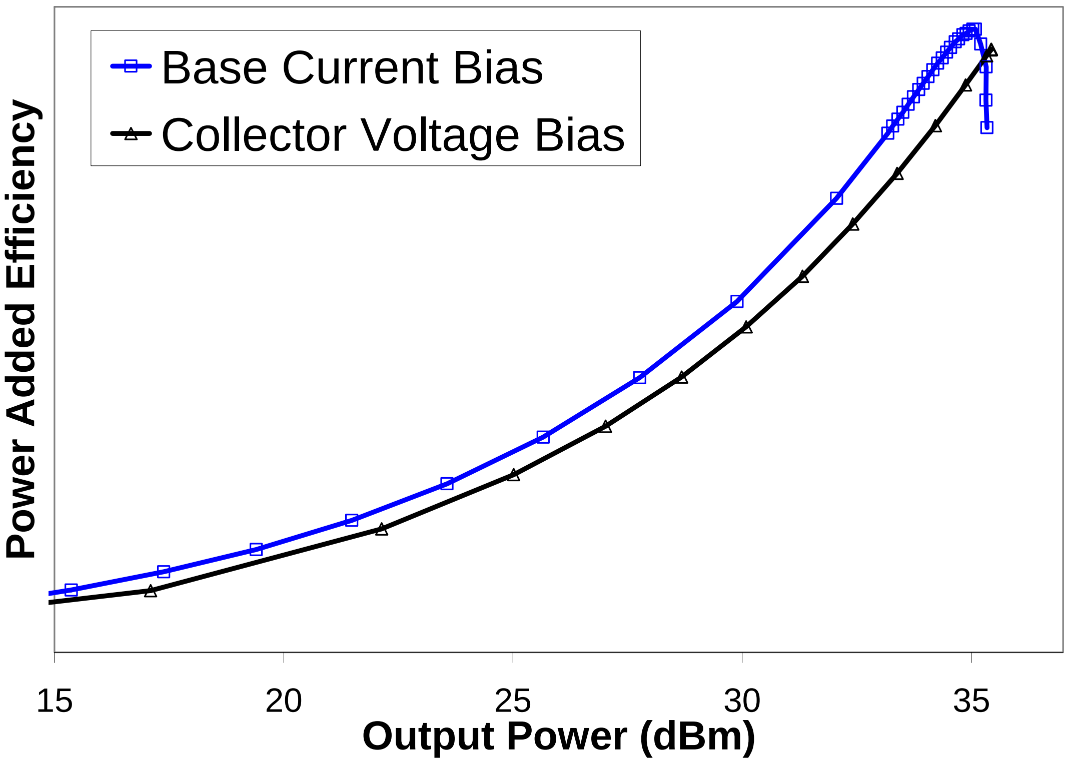

Fig. 3. Efficiency comparison of front-end-modules using base current and collector current bias control methods.

Noise within the power amplifier is one of the most complex considerations for biasing topology. The designer must consider not only the noise figure of the amplifier, but also the conversion gain of bias noise to the carrier, the small signal gain to input noise and spurious of the amplifier as well as the conversion gain for input noise and spurious of the amplifier. Although the current bias technique offers the best dynamic range and PAE, it tends to be the worst for noise. Often, none of the gain stages are operating in compression, resulting in high small signal gain. Also, the device is highly non-linear, resulting in high conversion gain. The high conversion gain and small signal gain places a very challenging requirement on the noise levels injected by the bias. This bias noise is often mixed onto the carrier in the first stages of the amplifier and amplified by the subsequent RF gain stages. Detailed attention to the design of the bias buffering, in addition to careful consideration of bias filtering is required to successfully develop a closed-loop control around this bias architecture.

The Voltage saturation control technique tends to offer the best noise performance and is simplest to design. This method of control keeps the amplifier stages in deep compression at all times, thus reducing the small signal gain of the RF chain. Noise injection for this topology primarily occurs through AM modulation of the carrier. Noise injected on the early stages of the amplifier will be stripped off due to the saturated operation of the subsequent stages. Typically, the bias noise present on the supply of the final stage amplifier will define the bias noise contribution. There is no RF gain following this injection point, resulting in bias circuit noise requirements that are 15 – 20 dB less demanding than the current control topology.