

Transistor Biasing Issues for Linear Amplification of Complex Signals

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Here is tutorial review of biasing issues for transistors, with notes on the methods that are used to control bias in modern wireless linear power amplifiers

Transistors are the workhorse of RF and microwave signal amplification. They are everywhere, as discrete devices and incorporated into integrated circuits. Every transistor

must be provided with an operating voltage, a signal input and bias.

This basic tutorial explores the last of these—bias. Bias techniques have undergone some changes in recent years to accommodate the complexity of modern communications. We will review some fundamentals, then offer an overview of issues that effect the way transistor biasing is managed to maintain linearity in today's wireless systems.

Bias Fundamentals

The purpose of bias is to establish operation on the desired portion of a transistor's input/output transfer function curve (Figure 1). Note that bias is almost always referenced to voltage, even though BJTs are current-controlled devices. In these devices, the bias voltage establishes the base-emitter current that is the input to the device. FETs are voltage-controlled, so bias is a direct

Looking at Figure 1, and remembering that the input signal is summed with the bias voltage, let's look at the operating regions:

Cutoff region "C"—We'll start with this region, since it has the least impact on linear amplifiers. When the chosen bias sets operation in the cutoff region, a large contribution is required from the input signal to create any output at all. When no signal is present, there will be no collector or drain current (other

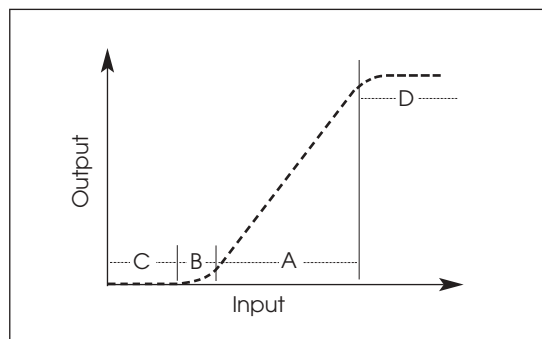


Figure 1 · A highly simplified transistor transfer function curve. Input is base current for a bipolar junction transistor (BJT), gate voltage for a field-effect transistor (FET); Output is collector current for a BJT, drain current for a FET. "A" is the conduction region, "B" is the transition region, "C" is the cutoff region and "D" is the saturation region.

than leakage). This situation is acceptable, even preferred in two circumstances: Class C power amplifiers and digital/switching applications, including switch-mode power amplifiers. This on/off step function is, by definition, nonlinear. Thus, transistors biased at or below cutoff are not suitable for linear applications such as small signal amplifiers or linear power amplifiers, and we require no further discussion for this article.

Saturation region "D"—Each transistor has a maximum collector or drain current it can deliver. When the bias+input signal is high enough to reach this output level, the amplifier ceases to be linear. When dealing with the saturation region, we are mainly concerned with the maximum power available from the device. In modern wireless systems,

the maximum *average* power is of little concern, but *peak* power is important. Some complex signal waveforms have average power as little as seven percent of their peak power.

Rather than deal with peak power as a biasing issue, most wireless amplifier designers select (or design) a transistor type that will support the required peak power. For applications where it is required, there are techniques that offer one to three dB of compensation for the compression of the signal at peak power.

Conduction region “A”—When the bias establishes the operating point of a transistor within the conduction region, the output is a linear function of the input. Class A amplifiers are biased to remain within the conduction region during the plus or minus voltage swing of the input signal. The range of the input swing is determined by how far the bias point is up the curve. The cost of accommodating higher input (and output) voltage swing is higher no-signal output current. In short, class A amplifiers consume a lot of current, even when no input signal is present.

The main issue with the conduction region is power consumption, or efficiency. Yet, this type of operation is normally chosen to obtain linear operation. Since the most advanced modulation methods used today require linear amplification, this is a major area of interest. In today’s wireless systems, the main issue with power amplification is how to maintain full class A performance while mitigating its low efficiency.

Transition region “B”—The transition region is key to any discussion of biasing for linear operation. Semiconductor junctions never operate ideally, going from non-conduction to conduction completely and exactly at the threshold current or voltage. So, there is a region in the transfer curve where the output gradually increases with increasing bias.

In audio and many RF applications, class B amplifiers have been

common for many years. These typically use two devices, operating in push-pull (180 degree phasing). Each device only needs to conduct during half of the cycle of the input signal. Each half-cycle will be amplified linearly in its associated device, with only a small quiescent current during the “off” portion of the cycle.

Although class B amplifiers are much more efficient than class A, other performance issues limit linearity, such as phase accuracy in the 180 degree dividing and combining circuits, obtaining identical performance of the two devices, and the effects of not-quite-complete cutoff during the unused half-cycle. If we can accept these imperfect behaviors, class B push-pull amplifiers are a useful way to get linear amplification with good efficiency.

Next, if we change the bias of a class A amplifier so that the swing of the input signal sometimes reaches into the transition region (class AB), we lower the quiescent current, improving efficiency, but like class B push-pull, it is at the expense of some nonlinearity. Some established applications can tolerate a degree of imperfection in “linear” amplification. For example, single-sideband (SSB) voice transmission can tolerate some distortion and NTSC television signals can use relatively simple compensating circuits to minimize observable effects.

Today’s Linearity Issues

Modern digital wireless signals are sufficiently complex that they require linear amplification with little compromise. In response to these requirements, engineers have developed a number of techniques to obtain an optimal balance between linearity and efficiency. The major techniques are outlined below:

Predistortion—The concept of predistortion is to modify the input signal in manner that is opposite of the effects of the amplifier nonlinearity. The amplifier transfer function can

be measured and a circuit devised with the appropriate compensation. Some types of predistortion also vary the bias in proportion to the input signal.

Although predistortion can be highly effective, it has the limitation that amplifier nonlinearities are not constant. They vary with temperature, component aging and other factors. Some of these can be addressed separately to help make predistortion more effective.

Temperature compensation—To make any linearization technique more reliable, amplifiers must have temperature compensation. The task is getting harder with high peak-to-average ratio of digital signals, since the temperature of the transistor die changes much faster than the temperature of the heat sink! Some transistors are being manufactured with an integral diode or resistive thermal sensor that is used with compensation circuitry that adjusts the bias to maintain the same operating point under varying conditions.

Degradation compensation—All transistors change over their operating lifetime, but the popular LDMOS devices have a significant rate of change over time. Early devices even had to be replaced as they fell out of spec. Current production LDMOS transistors have improved this performance problem, but most amplifier manufacturers have implemented some type of bias adjustment to compensate for the remaining performance degradation over time.

There are other interesting techniques used for compensation of nonlinearities, such as feed-forward linearization and digital predistortion, but as they are not directly related to bias, are not discussed here.

This overview has identified some of the power amplifier linearity issues faced by today’s engineers. In future issues, we will provide timely technical articles on this subject that show how specific problems are being dealt with.