EFFICIENCY

GMRR specializes in the development of highly efficient RF power amplifiers and transmitters. Higher efficiency is advantageous to our clients for several reasons, including:

- Reduced cost of operation;
- More "talk time" (longer operation from battery power);
- Reduced heat dissipation, hence reduced heat-sink and cooling costs;
- Increased reliability due to cooler operation of the transistors; and
- Reduced size and weight.

This note explains the impact of the efficiency of an RF power amplifier.

Basic Relationships

Efficiency is generally defined as the ratio of the RF-output power Po to the dc-input power P_i (power consumption); i.e.,

$$\eta = P_o / P_i \quad .$$

Efficiency thus defined is also called drain efficiency or collector efficiency, depending upon the type of RF-power transistor. The power dissipated (as heat) by the amplifier is the difference between dc-input power and RF-output power; i.e.

$$P_d = P_i - P_o \quad .$$

Efficiency generally varies with the amplifier output in a manner unique to each type of amplifier. Figure 1 shows how efficiency, power consumption (dc input), and power dissipation (heat) vary for a typical class-B linear amplifier and two of GMRR's high-efficiency amplifiers.

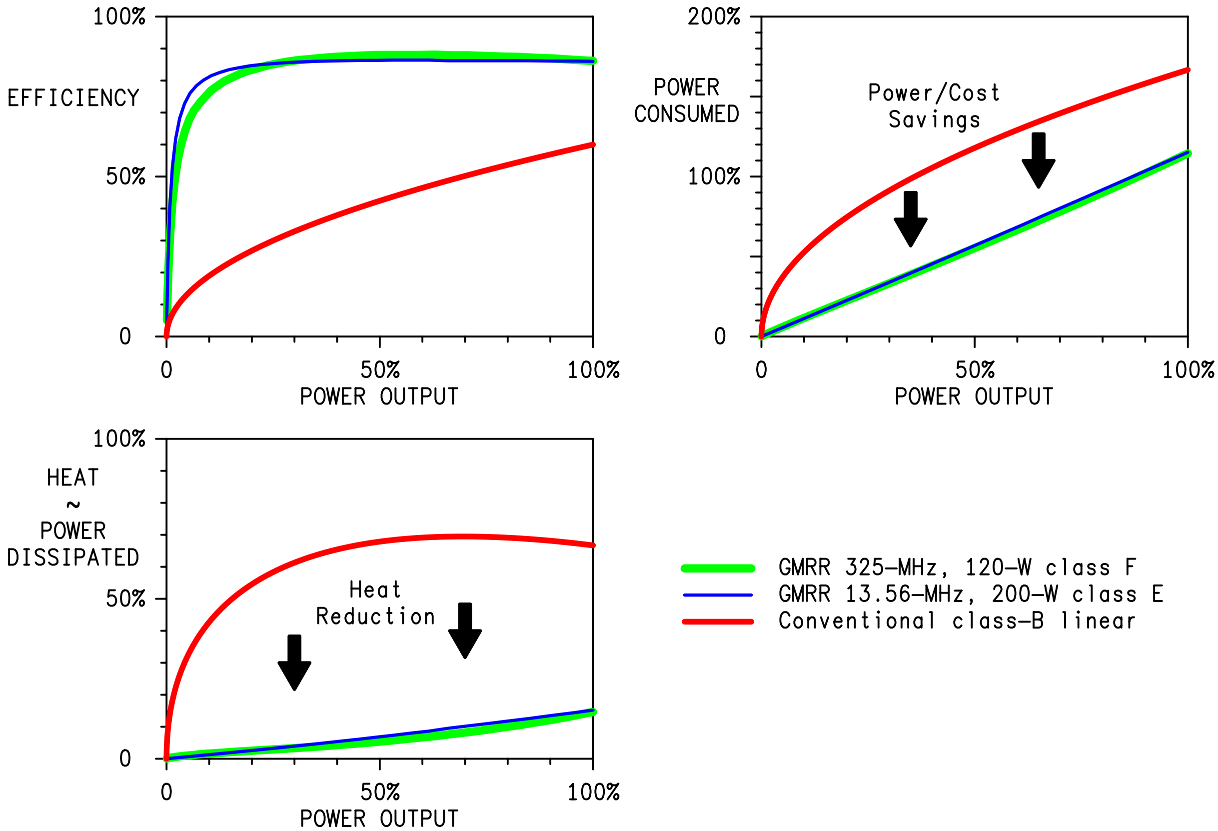

Figure 1. Basic variations in efficiency.

In a class-B amplifier, the dc input current varies in proportion to the RF-output voltage, hence the square root of the RF-output power. For an ideal amplifier (ideal transistors, lossless components), the efficiency at full output is 78.5 percent. In practice, however, on-state resistance in the transistor, capacitance, and other losses reduce the efficiency at peak output to about 60 percent, which is shown in the graph.

The curves for the class-E and class-F amplifiers are actual measured performance. These amplifiers achieve efficiencies of 80 to 86 percent at full output and maintain high efficiency over 10 dB or more of the amplitude range.

The graph on the upper right shows the impact of efficiency upon power consumption. At full power output, the high-efficiency amplifiers consume about 2/3 of the power of the linear amplifier. However, in most applications, the amplifier must operate at power levels below peak, and these are often more likely than peak output. The high-efficiency amplifiers remain efficient at nearly all amplitudes, while the efficiency of an ordinary linear amplifier decreases with the amplitude of its output. Consequently, the power consumption of the high-efficiency amplifiers can be less than half of that of an ordinary linear amplifier. This translates to half of the operating cost in a large fixed transmitter or twice the talk time in a mobile transmitter.

The graph on the lower left shows the impact of efficiency on the power dissipated, hence the heat that must be removed from the amplifier. At full output, the waste heat produced by the high-efficiency amplifiers is only a fraction of that produced by a linear amplifier. Cooler operation leads directly to higher reliability. The reduced heat dissipation can also allow reduction in the size of the heat sink, weight, cooling equipment, and cooling costs (which require about 0.4 W for each watt of heat).

Average Efficiency

Most modern radio signals have time-varying envelopes (amplitude modulation). As a result, their RF PAs operate well below peak power most of the time. In some applications, the output power must be varied to fit a communication range or heating requirement. In other applications, the amplitude varies continuously to produce a desired radio signal.

The probability densities of two typical radio signals are shown in Figure 2. These curves represent the relative likelihood that the signal is at different amplitudes. The "SRRC" signal is typical of a single modulated carrier, while the "Rayleigh" signal is typical of multi-carrier OFDM signals. The efficiency at lower amplitudes is as or more important than that at full output. For example, the efficiency of an ideal class-B amplifier at peak output is 78.5 percent However, when producing a multi-carrier signal with a 10-dB peak-to-average ratio, the average efficiency is only 28 percent.

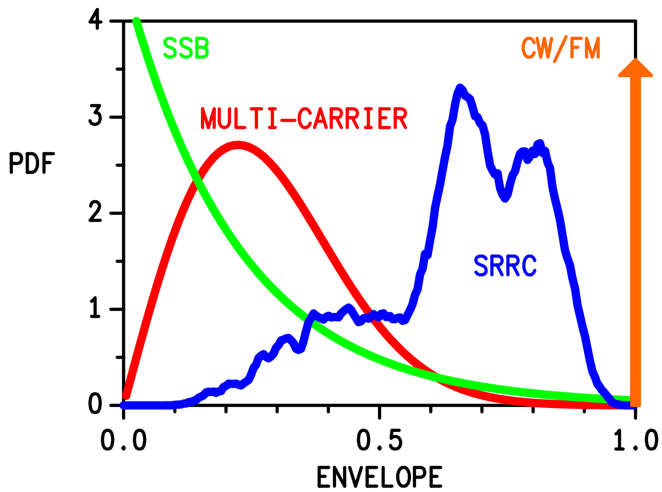

Figure 2. Signal probability densities.

Other Definitions

Power Added Efficiency (PAE) is a widely used measure of efficiency that incorporates RF drive power P_{DR} as well as dc input power. It is defined by

$$\eta_A = (P_o - P_{DR}) / P_i \quad .$$

A weakness of PAE is that it can become meaningless (even negative) when the output is low compared to the drive.

Overall efficiency is defined by

$$\eta_O = P_o / (P_i + P_{DR}) \quad .$$

Overall efficiency is a more realistic measure of performance at all outputs and is readily extended to include other factors such as driver dc input and the power consumed by low-level circuits.