A Linear, High Efficiency, HBT, CDMA Power Amplifier

Abstract

RF Micro Devices introduces a new linear power amplifier for CDMA applications based on their HBT (Heterojunction Bipolar Transistor) technology. This power amplifier operates from a single 4.8V power sup-ply without the need for a negative voltage. The amplifier will provide up to 29dBm average output power under CDMA modulation, with >50% efficiency! Saturated output power for analog operation is 31.5dBm at over 57% efficiency. On-board power down is included, and provides less than 10mA current consumption in the OFF state. The part is packaged in an industry standard 16-lead SOIC with a fused center lead. Pricing is competitive at less than $7 in volume.

Introduction

As CDMA (Code Division Multiple Access) systems begin to see implementation in the US and other countries, many manufacturers are rolling out their CDMA cellular handsets. The final power amplifier for these handsets is critical to the competitive positioning of the product. This power amplifier must:

- operate at full power with the CDMA waveform without generating adjacent channel interference,
- operate in analog AMPS or ETACS mode while in systems which do not support CDMA,
- have very high efficiency to maximize talk time,
- maintain efficiency and linearity at lower power levels.

Traditionally, CDMA power amplifiers have been based on hybrid modules, which are large and expensive. In contrast, the RF2108 is an integrated power amplifier, providing the full performance from a single 16-lead SOIC plastic package. This package may be assembled using standard surface-mount techniques, and enables the designer to maintain a very small footprint for the RF output interface.

Using HBT semiconductor technology from RF Micro Devices, the RF2108 allows full high-efficiency, linear performance from a single positive 4.8V power supply. The part operates from 4.0V to 4.8V, to accommodate battery voltage degradation. Power down is accomplished with 0V on a single control pin, consuming less than 10mA in stand-by mode. During full power operation, the power-added efficiency (or total efficiency) can be as high as 53% while simultaneously meeting CDMA Adjacent and Alternate Channel Interference requirements. When driven with a CW signal (as in FM-modulated AMPS mode), the output power at 4.8V increases to 31.5dBm at 57% efficiency. Depending upon the implementation of the power control ALC loop, an on-board control may be used for AMPS mode to provide >30dB of power control with a fixed input level. More commonly, the input level may be varied as is done in CDMA mode.

Key Advantages of HBT Power Amplifier Technology

The HBT Power Amplifier drives several key features of the phone operation and design. Some are advantages to the end customer, such as talk time and overall phone size. Others are related to the ease of design and manufacturing the phone, such as single voltage supply, on-board power-down, device linearity, and on-board power control. These advantages are discussed below:

- Talk time. The current consumption of the transmitter is nearly always dominated by the power amplifier. For battery operated applications, the power-added (or total) efficiency is extremely important. Linear applications such as CDMA have typically required Class-A biased power amplifiers, which have low efficiencies of approximately 25-35%. The RF2108 provides very high efficiency of >50% while meeting CDMA ACPR requirements. Also important for CDMA systems is the quiescent bias current. Since, in the CDMA system the average power levels are kept low, the current consumption at average +10dBm output is an important figure of merit. Since the RF2108 is biased deep into Class AB, the current consumption at +10dBm output is 40mA. This extends the lifetime of the battery under nominal operating conditions in the phone. Also, in analog mode, the RF2108 provides, without a matching circuit change, up to 31.5dBm with 57% efficiency.
- Small Package Size. CDMA cellular phones are entering a consumer market which is relatively mature. The consumer demands small handsets, which drives the PCB area available for the RF components. Most existing CDMA linear power amplifiers use hybrid modules, which are difficult to implement in the required area; thus, the SOIC packaged, integrated amplifier approach is extremely beneficial. The RF2108 replaces a mod-

ule implementation with a single 16-lead SOIC.

- No Negative Voltage. HBT is a unique technology, allowing performance better than GaAs MESFETs, yet allowing biasing similar to Silicon Bipolar from a single positive voltage. This eliminates one of the primary disadvantages with GaAs MESFETs – the requirement for a negative voltage. For a system de-signer to implement negative voltage with sufficient current to drive a power MESFET gate, some kind of switching regulator or “charge pump” must be used. This can be expensive and cumbersome. If the charge pump is implemented on-chip, excessive low-frequency noise, additional current, and additional external components minimize the benefit.
  HBT provides an elegant solution to the high-efficiency linear power amplifier. With no need for additional components, the part provides an overall smaller, more efficient, and lower cost solution.
- No supply-side switch. The RF2108 HBT Power Amplifier provides a single pin for power down. This function powers down the part with 0V on the control pin, and provides full power with 3.6V on the control. In power-down mode, less than 10mA of total current is consumed, allowing very long stand-by times for the phone.
  To utilize a GaAs MESFET power amplifier, the system designer generally must insert a switch into the bias supply line to the part for shutdown. This switch must be capable of supporting very high currents, and tends to be very expensive as a result. A MOSFET switch will cost on the order of $0.50 to $0.75, which is a substantial portion of the overall power amplifier cost. The loss through the switch also reduces the voltage available on the drain of the MESFET PA, thus requiring more current to achieve the same output power.
- Gain Control. Using the same pin as is used for power down, the gain can be controlled over 30dB with a 2.0V to 3.6V control range. Since linearity is not maintained during this power control, this function is useful in AMPS mode only; for CDMA mode the input power to the PA will be varied. If this function is not required, the pin may be tied strictly to a power down control.
- Low Noise-Power Output. A key parameter related to the power amplifier in AMPS mode is the noise power output in a 30kHz bandwidth. This defines the required rejection in the receive band (869MHz to 894MHz) for the duplexer, since for a full-duplex system the transmitter will tend to “self-jam” the receiver. The noise transmitted by the power amplifier is related to it’s noise figure and gain in the receive band. The RF2108 operates with better than -90dBm/30kHz in the receive band.

HBT Technology

The RF2108 is one of a family of power amplifiers from RF Micro Devices based upon HBT technology for both linear and constant-envelope applications. This technology, provided by TRW and being commercialized by RFMD, is a proven technology originally developed for military and space applications. Based upon a Gallium Arsenide/Aluminum Gallium Arsenide (GaAs/AlGaAs) heterostructure, the power and efficiency performance is the highest of any commercially available integrated solution. Being a bipolar structure, the part can operate from a single positive voltage supply without adding components – extremely important in a battery operated system such as a cellular phone.

The critical geometries in a HBT transistor are vertical structures, not lateral. The emitter, base, and collector are stacked vertically by semiconductor layer growth, using MBE (Molecular Beam Epitaxy). This is a very accurate and repeatable growth process. Since each layer is placed over the entire wafer at once, no photolithography is required for this process; thus, mask alignment and optical resolution is not an issue. Also, this means wafers can be prepared and stock-piled, eliminating this step from the critical path of product manufacturing.

Once the layers are completed, then the lithography begins. Since all the critical geometries are already defined, the minimum feature size is currently 2µm. This is much more manufacturable than the 0.5µm to 1.0µm gate geometries typically required by GaAs MESFETs.

The TRW HBT process is the most reliable commercially available HBT process in the world. As a military subcontractor, TRW has qualified the process for many of their military programs. Additionally, as a space equipment manufacturer, the HBT process has been qualified for Class S space applications. This level of ruggedness is absolutely needed for spacecraft, since it is somewhat difficult to repair a failed component in space, but is also demanded by the commercial marketplace today. RF Micro Devices and TRW have both been diligently testing the HBT process and products to determine the ruggedness and failure rates. The MTBF is found to be $4x10^7$ hours at 125°C junction temperature, and $5x10^5$ hours at 185°C. Over 1.35 million device hours have been tested on packaged power amplifiers under full RF stress conditions at 250°C junction temperature without a failure to-date. Additional information is available on the reliability of HBTs, and may be obtained with the application information package on the RF2108.

RF2108 Theory of Operation and Application Information

The block diagram for the RF2108 is shown in Figure 1. The part is a two-stage device with 28dB linear gain. The drive required for full-power CDMA operation is approximately 0dBm. To fully saturate the output, approximately +4dBm CW is required. Bias control is provided through a single pin interface, and the final stage ground is achieved through the large pins on both sides of the package. First stage ground is brought out through a separate ground pin for isolation from the output. These grounds should be connected directly with vias to the PCB ground plane. The output is brought out through the 4 output pins, with two pins providing bias and harmonic termination, and the other 2 pins feeding the RF output.

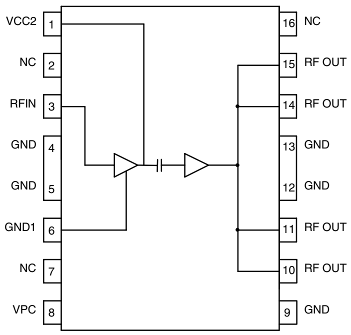

Figure 1. Block Diagram and pinout for RF2108

The amplifier operates in Class AB bias mode. The final stage is “deep AB”, meaning the quiescent current is extremely low, around 40mA. As the RF drive is increased, the final stage self-biases, causing the bias point to shift up and, at 27dBm average output power, draws about 240mA. The bias level changes according to the drive level without distorting the RF signal through a proprietary biasing technique (patent pending). The optimum load for the output stage is approximately 10Ω. This is the load at the output collector, and is created by the series inductance formed by the output bond wires, leads, and microstrip, and a shunt capacitor external to the part. With this match, a 50Ω terminal impedance is achieved. The input is matched to 50Ω with just a blocking capacitor needed.

The input is DC coupled; thus, a blocking cap must be inserted in series. Also, the first stage bias may be adjusted by a resistive pull-up with high value resistors on this pin to Vpc. For nominal operation, however, no external adjustment is necessary as internal resistors set the bias point optimally.

$V_{CC}2$ provides supply voltage to the first stage, as well as provides some control over the operating band. Essentially, the bias is fed to this pin through a short microstrip. A bypass capacitor sets the inductance seen by the part, so placement of the bypass cap can affect the frequency of the gain peak. This supply should be by-passed individually before being combined with Vcc for the output stage to prevent feedback and oscillations.

The RFout pins provide the output power. Bias for the final stage is fed to pins 14 and 15, which also provides the second-harmonic trap. Pins 10 and 11 provide the output line, which is matched as shown in the application schematic for optimum operation at either minimum battery voltage or nominal voltage.

The part will operate over a 4.0V to 4.8V range. If the full power is desired at minimum voltage, then the load can be optimized at that point. At that point, the specified efficiency, linearity and power should be attainable. As the voltage is increased, however, the output power will increase. Thus, in a phone design, the ALC (Automatic Level Control) Loop will back down the power to the desired level. This will occur at a less-than-optimum efficiency, since the load is optimized for 4.0V. This is true of any power amplifier, however, the important point to note is that the RF2108 can be set up to provide the specified power at 4.0V if desired.

The HBT breakdown voltage is >20V, so nominally at 4.8V there should be no issue with overvoltage. Under extreme conditions, however, which can occur in a cellular handset environment, the supply voltage could be as high as 8.5V. These conditions may correspond to operation in a battery charger, especially with the battery removed, which “unloads” the supply circuit. To add to this worst-case scenario, the RF drive may be at full power during transmit, and the output VSWR could be extremely high, corresponding to a broken or removed antenna. Under all of the above conditions, the peak RF voltages could well exceed 2X the supply voltage, forcing the device into breakdown. The RF2108 includes overvoltage protection diodes at the output, which begin clipping the waveform peaks at approximately 13V. This protects the device’s output from breaking down under these worst-case conditions, and provides a rugged, robust component for the system designer.

High current conditions are also potentially dangerous to any RF device. High currents lead to high channel temperatures and may force early failures. The RF2108 includes a proprietary bias circuit (patent pending) to temperature compensate the RF transistors, thus limiting the current through the bias network and protecting the devices from damage. The same mechanism works to compensate the currents due to ambient temperature variations, and the part is remarkably consistent over the full -30°C to +85°C commercial temperature range.

RF2108 Performance

The RF2108 performance is summarized below. A full data sheet is available from RF Micro Devices.

The single-tone power and efficiency vs input power, along with the two-tone IMD products vs output power are shown in figures 2 and 3.

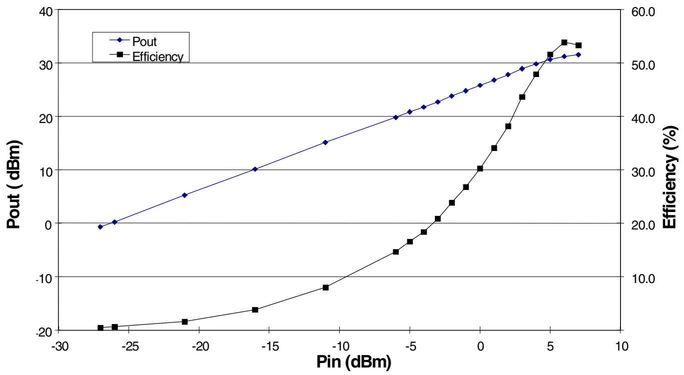

Figure 2. Power output and efficiency vs. input power

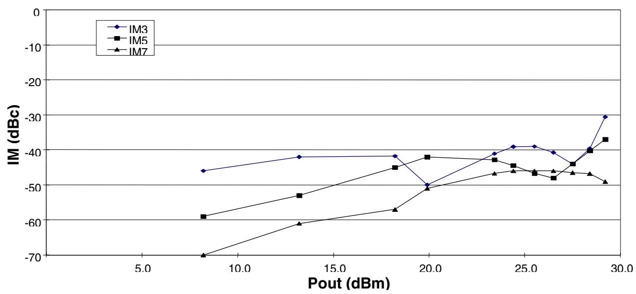

Figure 3. Two-tone IMD vs. output power

Since the CDMA utilizes QPSK signaling, the adjacent channel power (ACP) measurement test for linearity. Figure 4, 5 and 6 show plots with the ACP of the RF2108 at various power levels.

A common problem associated with high-efficiency cellular power amplifiers is stability, especially into a duplexer. Since duplexers can be designed with various out-of-band characteristics, a robust cellular power amplifier must operate without oscillation into ceramic, helical, and SAW duplexers. The RF2108 has been

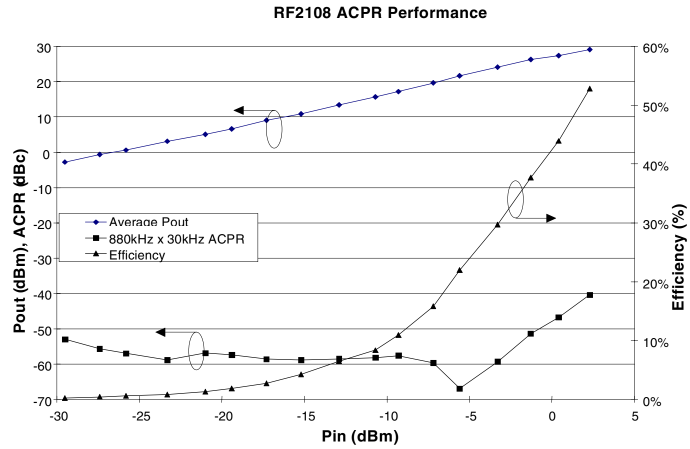

Figure 6. ACPR and efficiency vs. input power

tested into various types of duplexers, without oscillating.

Parameter	Typical Performance	Conditions
Frequency Range	800 to 900MHz	Externally tuned for individual bands
Maximum Linear Output Power	29dBm	While meeting ACP requirements
ACP @ 885kHz Offset	-40dBc	Relative to 1.23MHz center band
ACP @ 1.98MHz Offset	-60dBc	Relative to 1.23MHz center band
Maximum CW Output Power	31.5dBm	With specified load at 4.8V
Total CW Efficiency	57%	At Max Output
Power Gain	28dB	
Noise Power Output	-90dBm/30kHz	In Receive Band, any power setting
Quiescent Current	40mA	
“OFF” Current	10μA, max	V_{PC}<0.2V
Voltage Range	4.0 to 4.8V	
V_{PC} “ON”	3.6V	
Stability	Unconditional	
Temperature Range	-30 to +85°C	Operating

Conclusion

The RF2108 HBT CDMA Cellular Dual-Mode Power Amplifier has been introduced by RF Micro Devices. This amplifier provides the best overall performance of any CDMA PA on the commercial market. Operating from a single positive supply, linear efficiencies of 50% and power levels of 29dBm are achievable from a single 16-lead SOIC surface mount package from 4.0V to 4.8V. In AMPS mode, the part provides 31.5dBm power with 57% efficiency. Power down and power control are integrated on-chip without additional components required. The new power amplifier can be used to simplify cellular phone design and improve operation, as well as significantly reducing overall cost. The price of the RF2108 in volume is less than $7.

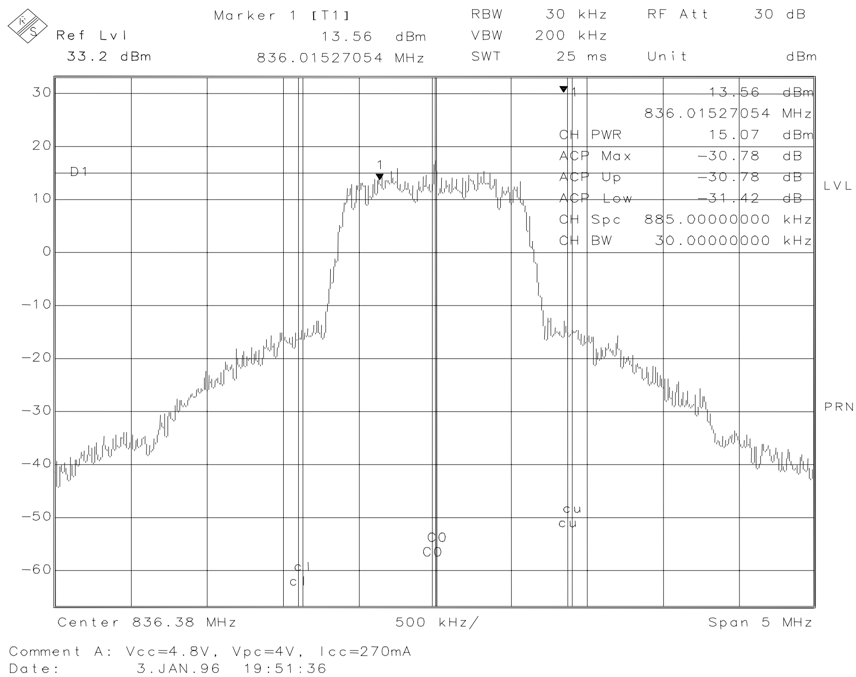

Figure 4. ACP at +27dBm output power and 44% efficiency

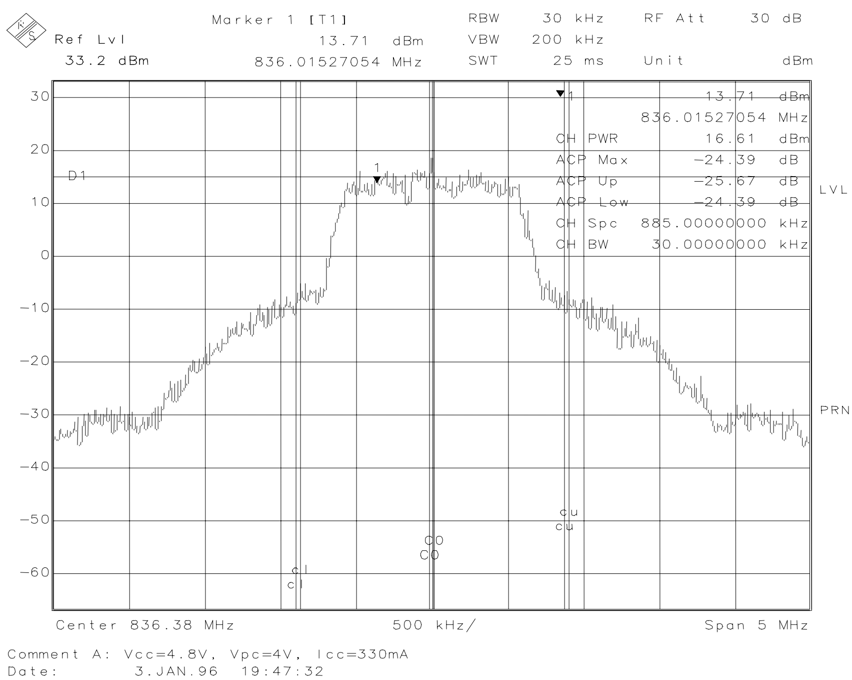

Figure 5. ACP at +29dBm output power and 53% efficiency