New High Power, High Efficiency HBT GSM Power Amplifier

Abstract

RF Micro Devices introduces a new power amplifier for GSM applications based on revolutionary HBT (Heterojunction Bipolar Transistor) technology. This power amplifier operates from a single 4.8V or 6V power supply without the need for a negative voltage. The power output at 4.8V is 35dBm, and at 6V the PA provides 36dBm! The overall efficiency is as high as 62 percent. On-board power control is included, as is power down. The part is packaged in an industry standard 16-lead SOIC with 4 fused, wide leads.

Introduction

With the maturation of digital cellular systems in Europe, Japan, and North America, next generation handsets must offer advantages to the consumer. These generally take the form of lower cost, smaller size, and longer battery life.

One component which has traditionally been either expensive, large, power-hungry, or any combination of these has been the RF power amplifier. This critical component governs much of the battery life, size, ease of implementation, and manufacturability of the phone. For 5-cell applications between 5.3V and 6.0V, this function can now be performed using HBT (Heterojunction Bipolar Transistor) technology from RF Micro Devices. The new RF2123 GSM power amplifier provides all of these advantages to the handset designer, amplifying a +6dBm input signal to over +35dBm output, at up to 60 percent efficiency. Moreover, no negative voltage is required, either internal or externally generated. Additionally, an on-board analog gain control provides greater than 60dB of power control from 1V to 4V control voltage. When the control is reduced to <0.5V, the part is shut off, drawing less than 1mA.

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, and on-board power control. These advantages are discussed below:

- Talk time. The current consumption of the transmitter is dominated by the power amplifier. For battery operated applications, the power-added (or total) efficiency is extremely important. Sixty percent total efficiency for a two-stage, 30dB gain GSM power amplifier IC is ideal for maximizing talk time – a key performance advantage at the competitive system level.
- Small Package Size. As cellular phone sizes shrink, the available real estate for RF components shrinks as well. Traditional power amplifier designs become difficult to implement in the required area; thus the SOIC packaged, integrated amplifier approach is extremely beneficial. The RF2123 takes the place of a large discrete implementation, or a MESFET IC implementation with additional components such as a negative voltage generator and a supply-side switch. The unique "Quad BatWing" package pioneered by RF Micro Devices allows superior heat-sinking and electrical grounding. This allows over 4-W of output power to be transmitted in GSM mode with no special heat slug or non-standard packaging.
- 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 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 leakage current, and additional external components minimize the benefit.
- HBT provides an elegant solution to the high-efficiency 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 RF2123 HBT Power Amplifier provides a single pin for power down. This function powers down the part with less than 0.5V on the control pin, and provides full power with 4V on the control. In power-down mode, less than 1mA of total current is consumed, allowing very long stand-by times for the phone.

- To utilize a GaAs MESFET power amplifier, the system designer must insert a switch into the bias supply line to the part for shutdown. The gate cannot be used to switch the MESFET on and off due to the high gate-source capacitance. On-board charge pumps must consume milliamps of current during power-down. This supply-side switch must be capable of supporting very high currents, and tends to be very ex-pensive 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 is controlled over 60dB with a 1V to 4V control range. A typical power control characteristic is shown in Figure 1.
- High Reliability. At RF Micro Devices, we have logged over 1.5 million device hours under RF stress accelerated lifetest since 1993. Junction temperatures of 250°C are used to accelerate the test. In addition, TRW has been running accelerated DC lifetest, which correlate with RF stress results. The reliability is much improved over the initial HBT technologies available 8-10 years ago. Today, over 40 million hours MTBF at 125°C junction temperatures is achieved.

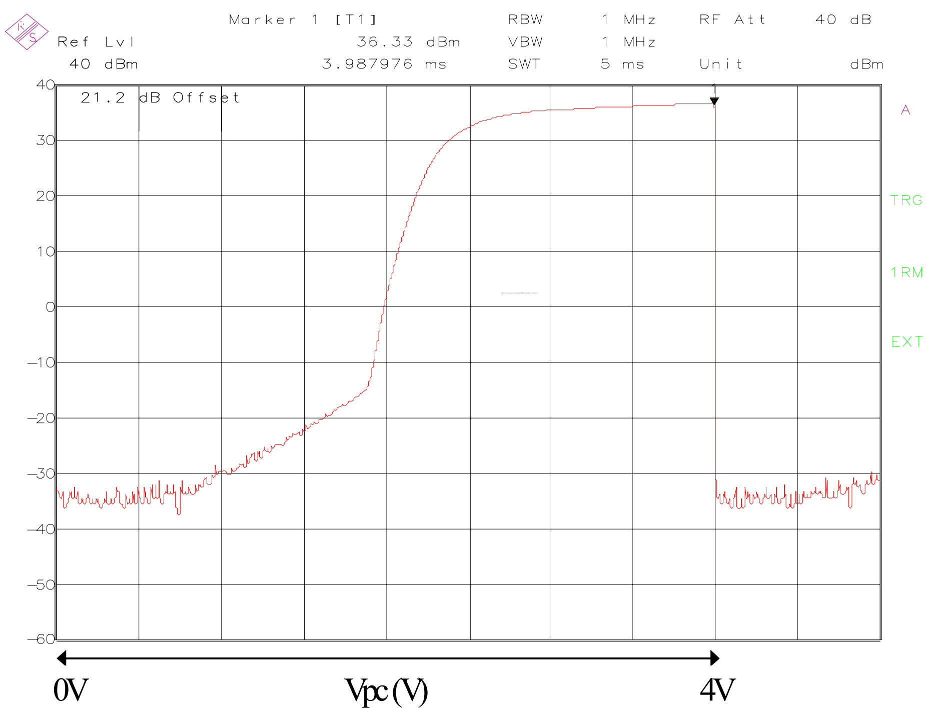

Figure 1. Output power vs. Vpc from 0 to 4V. Note that the power control range is >60dB with the maximum output power at 36.3dBm.

HBT Technology

The RF2123 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, 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 an 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 photo-

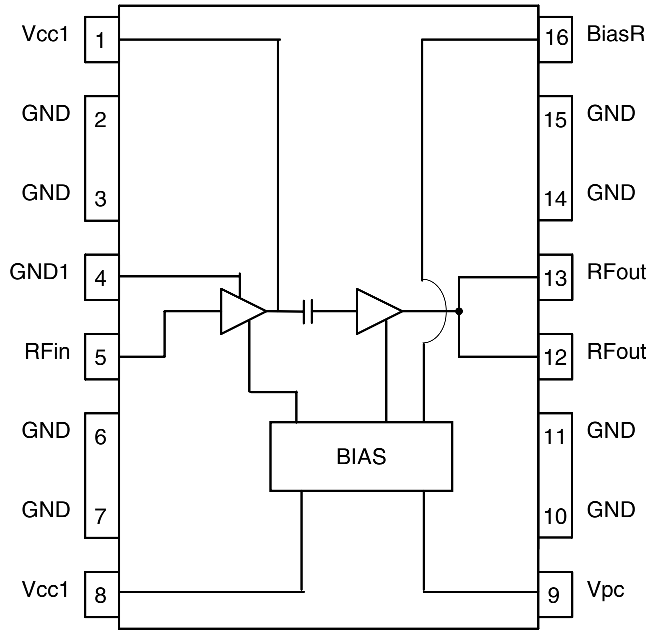

Figure 2. Block Diagram and Pinout for RF2123.

lithography 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 2mm. This is much more manufacturable than the 0.5-1.0mm gate geometries typically required by GaAs MESFETs.

We feel 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 TRW, as a space equipment manufacturer, has qualified the HBT process 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 currently defined to be 4x107 hours at a junction temperature of 125°C. Additional information is available on the reliability of HBTs, and may be obtained with the application information package on the RF2123.

In order to meet the continuing demand for GaAs HBT, RF Micro Devices has licensed the proprietary TRW HBT process for commercial wireless applications and is building a high-volume wafer fab in Greensboro, NC, to provide the industry with these power amplifiers and other high-performance ICs. This wafer fab will be the largest GaAs HBT wafer fab in the world, and will continue to enforce our dominant position as the leading supplier of GaAs HBT circuits.

RF2123 Theory of Operation and Application Information

The block diagram for the RF2123 is shown in Figure 2. The part is a two-stage device with 30dB gain at full power. The drive level required to fully saturate the output is +6dBm. 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 two output pins, and combined off-chip to form the output line.

The amplifier operates in Class AB bias mode. The final stage is "deep AB", meaning the quiescent current is extremely low. As the RF drive is increased, the final stage self-biases, causing the bias point to shift up and, at full power, draws about 1A. The optimum load for the output stage is ~3.5W. 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 two shunt capacitors 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.

Vcc1 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 transmission line. A tuning capacitor external to Pin 1 sets the frequency of the gain peak. A resistor in parallel with the bias choke for the first stage helps to stabilize and dequeue the circuit.

The RFout pins provide the output power. Pins 12 and 13 should be combined externally. Bias for the final stage is fed to this output line, and the feed must be capable of supporting the 1-1.5A of current required.

The HBT breakdown voltage is >20V, so nominally at 6V 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 to 9.5V. 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 RF2123 includes overvoltage protection diodes at the output, which begin clipping the waveform peaks at ~15V. 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 RF2123 includes reference diodes in the bias circuit 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.

While the part is safe under CW operation, maximum power and reliability will be achieved under pulsed conditions. The data shown in the following table were taken with a 12.5% duty cycle and a 600ms pulse.

RF2123 Performance

The RF2123 performance is summarized in Table 1 below. A full data sheet is available from RF Micro Devices.

Parameter	Typical Performance	Conditions
Frequency Range	890-915 MHz	
Maximum CW Output Power	4-W	With specified load at 6V
Total CW Efficiency	55%	at Max Output
Gain at Max Power	30 dB	
Gain Control Range	45 dB, min	
Vpc Current	1 mA, max	
“OFF” Current	10 uA, max	Vpc < 0.2V
Voltage Range	5.3 to 6V	
Stability	Spurious <-60dBm	Output VSWR < 8:1
Temperature Range	-30 to +85 C	Operating

Table 1. RF2123 Performance Summary

Conclusion

The RF2123 HBT GSM Cellular Power Amplifier has been introduced by RF Micro Devices. This amplifier provides the best overall performance of any integrated PA on the commercial market. Operating from a single positive supply, efficiencies of 55% and power levels of 4-W are achievable from a single 16-lead SOIC surface mount package at 6V. 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.