High Efficiency HBT Low Voltage Programmable Gain Power Amp

Abstract

RF Micro Devices introduces a new power amplifier with digital gain control for low voltage applications. The power amplifier operates up to 1GHz and delivers 0.5W at 3.6V with an efficiency near 60%. The digital gain control provides 4 gain settings in 8dB steps. This device uses HBT (Heterojunction Bipolar Transistor) technology and a low cost plastic package. This power amplifier is suited for low cost applications, such as the final output stage for a 900MHz ISM band handset or as a driver for 400MHz mobile phones. The device operates from a single 3.6V power supply without the need for a negative voltage. The power output from 900MHz to 930MHz is 0.45W with 220mA of current – a total efficiency of 57%! In addition to the on-board gain control, the device draws less than 10µA of supply current when in the power down mode without the need for a supply side switch. The part is packaged in an industry standard 16-lead SOIC with a fused center lead. Pricing is competitive at less than $3 in volume.

Introduction

Cordless phone manufacturers are under intense pressure to reduce the cost of their handsets, while improving performance. Phone designs that operate with a low voltage and offer a high degree of integration will succeed in this market. Spread spectrum handsets operating in the Industrial-Scientific Medical (ISM) band offer a clear advantage over their VHF predecessors. The users of spread spectrum handsets are less likely to experience line interference compared with the 45MHz handsets. Electronic noise from appliances, computers and other electronic devices, along with typically poor range is characteristic of the old 45MHz cordless phones. If adequate power is delivered to the antenna, these problems do not exist in the 900MHz spread spectrum phones. As much as 1-W of transmitted power is allowed by the Federal Communications Commission in this band. However, battery life and talk time are reduced as the output power is increased. Cordless phone manufacturers have generally kept their output power levels around 250-mW in order to get the best tradeoff of talk time versus handset range. Cordless phones also implement a gain control function to maximize talk time.

Ideally suited for this 900MHz application is the RF2155, the newest member of a family of HBT high efficiency power amplifiers offered by RF Micro Devices. This integrated PA is also well suited for lower frequency applications, such as a driver amplifier for 400MHz mobile phones. The RF2155 offers digital gain control, high-efficiency, 0.45W output power, operation from a single 3 V supply, and low cost. This Low Voltage Programmable Gain PA amplifies a 0 dBm input signal to 26.5dBm of output power, drawing less than 220mA of current from a single 3.6 V supply. The IC implements a 2-bit digital gain control that gives 4 gain settings in approximately 8dB increments. When the power down pin is reduced to 0V, the PA draws less than 10mA of supply current, without the need for a costly supply side switch. The RF2155 is packaged in a standard 16-lead SOIC with fused center leads. In addition to the high-efficiency, the HBT technology doesn't require a negative supply that is typically needed for a MESFET PA. This integrated power amplifier greatly reduces the component count, overall size, performance variations that are typical of discrete power amplifiers, and most importantly, it reduces the overall cost.

Another application for this IC is as a driver for 400MHz mobile phones.

RFMD Harnesses HBT Technology

The RF2155 is one of a family of power amplifiers from RF Micro Devices based upon HBT technology for both linear and constant-envelope applications. Specifically, the RF2155 is similar to the RF2115 1.0W Programmable gain PA which is currently shipped in high volumes for 6V cellular phone applications. The HBT 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) heterostructures, HBT offers power and efficiency performance that is the highest of any commercially available integrated solution. By coupling this technology with proven power amplifier designs, low cost packaging, and cost-effective test, RF Micro Devices offers this performance at prices that can't be matched in the industry.

HBTs, being bipolar devices, have many advantages. They operate from a single positive voltage supply without adding components – extremely important in a small battery operated system such as a cordless phone. Also, 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 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.

Photolithography only begins after the layer growth is completed. Since all the critical geometries are already defined, the minimum feature size is 2µm. This is much more manufacturable than the 0.25µm to 1.0µm 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, as a space equipment manufacturer, the HBT press has been qualified for Class S space applications. RF Micro Devices and TRW have both thoroughly tested the HBT process and products to determine the ruggedness and failure rates. Based on these measured failure rates, Figure 1 shows the predicted MTBF for the RF2155 as a function of ambient temperature. At an ambient temperature of 85°C, the MTBF is greater than 10^7 hours. This data assumes a maximum junction temperature of 135°C under the full output power condition.

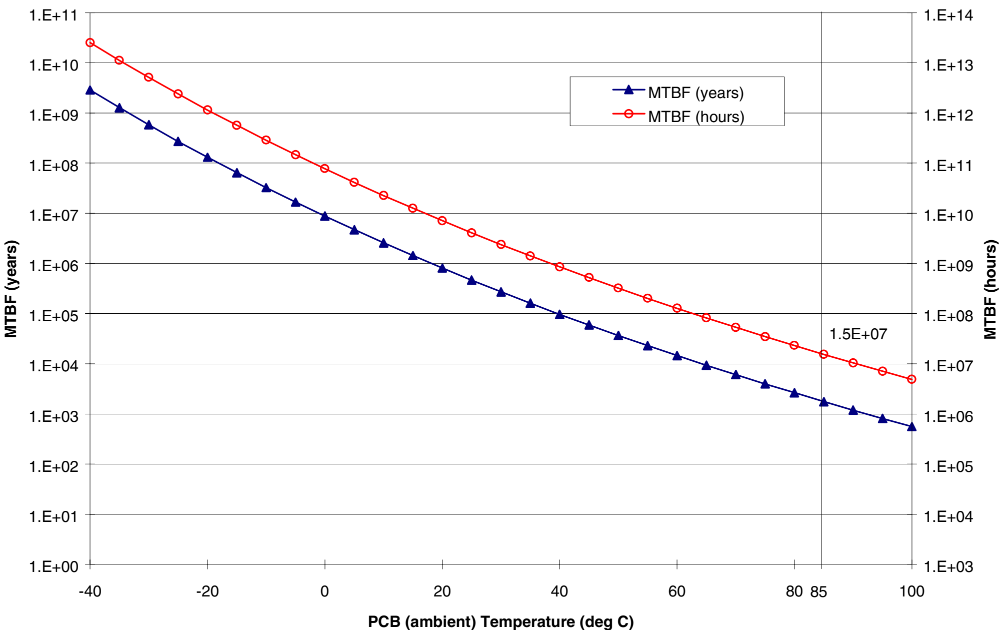

Figure 1. RF2155 MTFB as a Function of Temperature

RF2155 Theory of Operation and Application Information

The block diagram for the RF2155 is shown in Figure 2. The IC is a two-stage programmable gain power amplifier with over 30 dB of small-signal gain that operates between 3V and 5.5V. With an input drive level of 0dBm, the PA delivers up to 27dBm with an efficiency near 60% for a 3.6V supply. A power down feature is implemented with a single pin interface (pin 8), when this pin is grounded, the PA draws less than 10µA. When the voltage on the power down pin (VPD) is increased to a nominal value of 3.0V, the PA is turned on. This pin draws about 3mA of current when set to 3V. Pin 3 is connected to the battery voltage and is used to supply base current to the RF transistors.

The output stage ground is achieved through the large pins on both sides of the SOIC. Ground for the first stage is returned through a separate ground pin (pin 6) to isolate it from the output ground. These pins should be connected directly with vias to the PCB ground plane. The output is brought to two pins: pin 11, which is used for the output signal and pin 14, which is used to feed in the final stage bias.

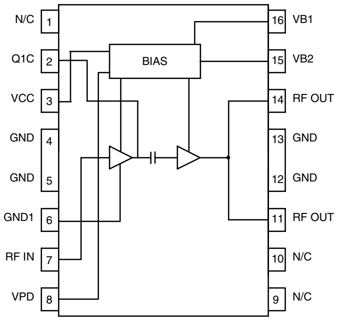

Figure 2. Block Diagram and Pinout for RF2155

The amplifier operates in Class AB mode. When both gain control bits (pins 15 and 16) are logic high (full gain), the IC draws about 70mA of quiescent current. When an RF signal is applied to the input, the output stage self-biases, and draws about 190mA of DC current. Digital control bits, VB1 and VB2 switch degeneration resistors into the common-emitter amplifier, thus reducing the gain of the power amplifier. In addition, when the high order bit, VB1, is set to logic low, the quiescent bias current of the entire PA reduces to about 15mA. This ensures that the current consumption in the lowest gain settings is minimized. For instance, with both gain bits set low, the PA delivers about +3dBm of power and consumes less than 25mA of DC current.The gain control bits operate with a minimum logic high level of 2.5V and a maximum low level of 0.8V. The current draw of the control bits are less than 300µA each for a 2.8V level. A truth table showing out-put power versus bit settings for the 4 available gain settings is shown below:

VB1	VB2	Pout (dBm) (Pin = 0dBm)
1	1	+26.5
1	0	+18.5 ± 3
0	1	+10.5 ± 4
0	0	+1.5 ± 4

Pin 2 is the supply voltage for the first stage. The inductance between this pin and the bypass capacitor sets the frequency of the small-signal gain peak. A short microstrip line between the pin and bypass capacitor conveniently realizes this inductance. Moving this capacitor away from the device shifts the gain peak to a lower frequency.

The input is DC coupled and requires a blocking capacitor. A series inductor can be added to the input to improve the VSWR. Under all 4 gain settings, the input VSWR is better than 2.5:1 with an 8.2nH series inductor on the input.

The RF2155 is designed to operate at a nominal voltage of 3.6V, however the PA will operate with degraded power down to 3.0V. The high HBT breakdown voltages ensure damage free operation up to a maximum supply voltage of 5.5V.

RF2155 Performance

The RF2155 performance is summarized in the following table.A full data sheet is available from RF Micro Devices.

Parameter	Typical Performance	Conditions
Frequency Range	430-950 MHz	Externally tuned for individual bands
Output Power Levels and Supply Currents:		With a 9 ohm load impedance.
Bit1=2.7V; Bit2=2.7V	26.8 dBm / 225 mA	
Bit1=2.7V; Bit2=0V	21.2 dBm / 123 mA	
Bit1=0V; Bit2=2.7V	14.2 dBm / 58 mA	
Bit1=0V; Bit2=0V	4.7 dBm / 23 mA	
Output Power Variation over Temperature; -20 C to +85 C	+/- 0.2 dB	Bit1=2.7V; Bit2=2.7V
Total CW Efficiency	57 %	at Max Output Level
Gain at Max Power	26.5 dB	Bit1=2.7V; Bit2=2.7V
Vpc Current	4 mA, max	
"OFF" Current	10µA, max	Vpc < 0.2V
Voltage Range	3.0 to 5.5V	
Stability	Unconditional	
Temperature Range	-30 to +85°C	Operating

The performance of the RF2155 has been characterized at the 900MHz ISM band on a low-cost, 30mil FR-4 printed circuit board. The application schematic and layout drawing for the PA are included in Figures 3 and 4, respectively. Notice the output match is achieved with a microstrip transmission line and a single shunt capacitor. Bias to the output stage is fed through a microstrip transmission line, this line is less than ¼ wavelength and thus also provides part of the output impedance match and harmonic termination. To reduce PCB area, the microstrip transmission line from pin 11 to the matching capacitor C10 can be realized by a shorter and narrower line. For instance, the inductance of this line is approximately 4 nH and can be realized with a 20mil wide by 310mil long transmission line or by a lumped inductor. The width of the output transmission line between the PA and capacitor C10 was chosen for this evaluation board to give a 50Ω impedance, making it simple to tune the output match. This width preserves the 50Ω load impedance up to the point where the output capacitor is placed on the transmission line. By using lumped inductors on the output pins, the area for the entire PA and external components is less than 0.4 square inches. Notice that the two capacitors, C9 and C14, are 1μF tantalum bypass capacitors and can be reduced to a single capacitor in a typical phone application.

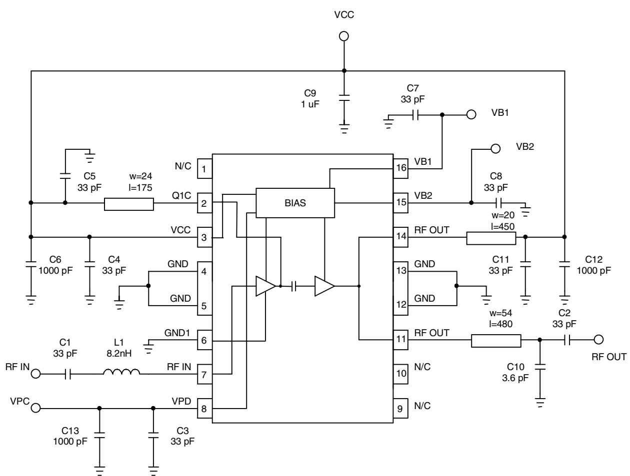

Figure 3. RF2155 Application Schematic; Board Material: FR-4, h=30 mils

Measurement Results

Measured data from the evaluation board described above is presented next. Figure 5 shows the output power and total supply current as input power is varied for the RF2155 operating at 3.6V.

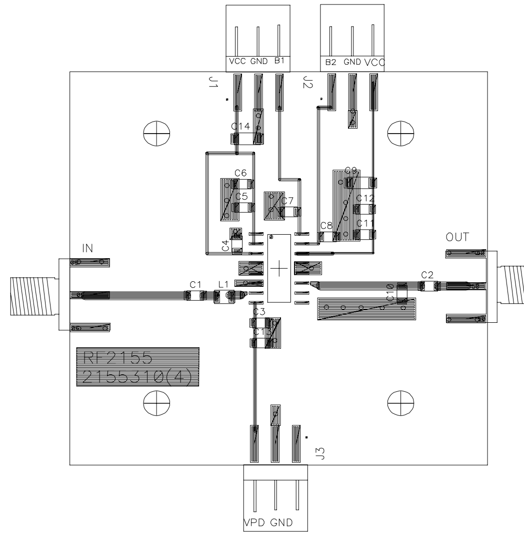

Figure 4. RF2155 Printed Circuit Board; Board Material: FR-4, h=30 mils.

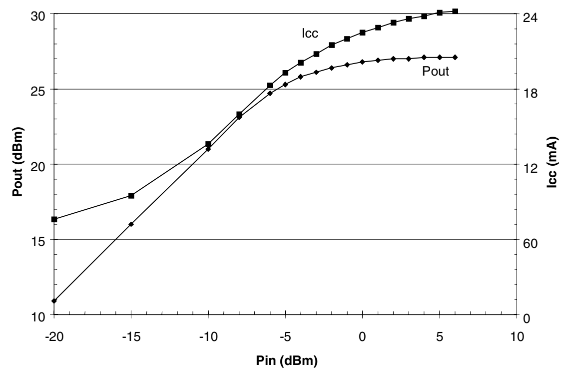

Figure 5. Pout and Icc versus Pin

This data is with the programmable gain bits set to full gain and the power down voltage at 3.0V. Here the saturated power is about 0.5W with an efficiency of 58% for an input level of 0dBm. The 1dB output compression point for the PA is about 25.5dBm. The output power reaches 1.0W when the supply voltage is increased to 5.5 V as shown in Figure 6Notice that the total efficiency of the PA is greater than 56% over the entire supply range of 3.0V to 5.5V. The efficiency peaks above 58% at the typical voltage for a 2-cell nickel cadmium or nickel metal hydride battery.

An important feature of this power amplifier is the programmable gain. Programmable gain provides increased talk time, since it allows the power delivered to the antenna to be reduced when the handset is close to the base station. The digital control implemented in the RF2155 simply requires 2 digital control bits to provide the 4 gain settings. The output power for the RF2155 under the 4 gain settings across the 900MHz ISM band is shown in Figure 7.The variation

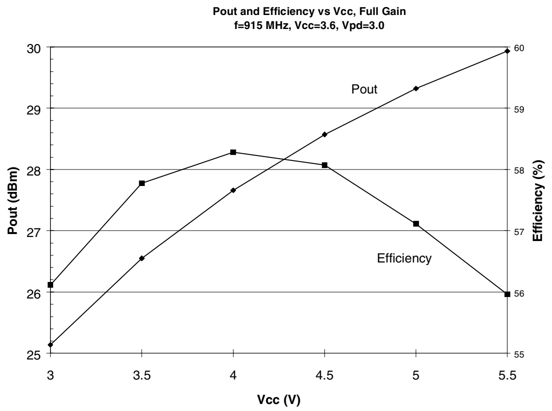

Figure 6. Pout and Efficiency versus Vcc

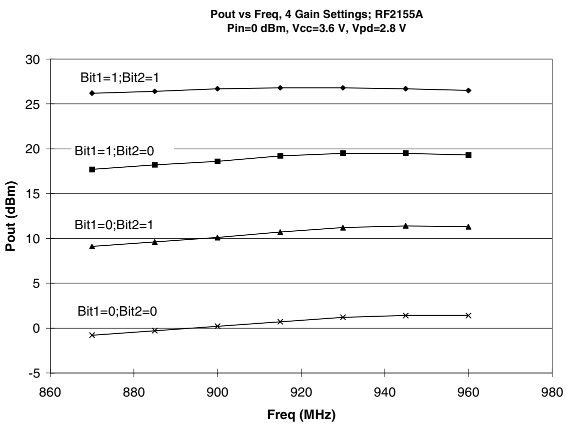

Figure 7: RF2155 Output power in the ISM 900 band, 4 gain settings

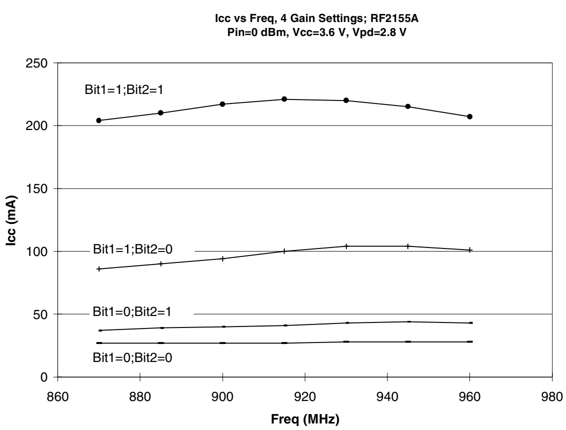

Figure 8: Total current of the RF2155 in the ISM 900 band for the 4 gain settings

in output power across the ISM band is about 0.1dB in the full gain setting. In the lowest gain setting the output power variation across this band is about 1.5dB.

Class AB bias not only gives a better efficiency at a saturated output level, but it also enhances the efficiency at lower output levels. To further improve efficiency at the lower gain settings, the high-order bit, VB1, is used to reduce the quiescent bias current below 20 mA when the bit is set low. Current for the 4 gain settings is shown in Figure 8 There is about a 10 fold reduction in supply current across the gain control range. With +5 dBm output power, the PA draws less than 25 mA.

Conclusion

The RF2155 HBT Programmable Gain Power Amplifier is introduced by RF Micro Devices. With a 0 dBm input level, this IC amplifier delivers up to 0.5W and has an efficiency near 60% while operating from a single supply from 3.0 to 5.5V. Additionally, the PA offers a convenient 2-bit digital gain control function, giving 4 levels of power control, in 8dB steps. This IC draws less than 25mA when in the lowest gain setting, thus significantly increasing talk time. The RF2155 has applications in any analog communications systems that require a high-efficiency, low-voltage, and low-cost PA. Specifically this IC was designed for 900MHz cordless phones and 400MHz industrial radios, where the digital gain control PA will increase battery life, simplify the transmitter design, reduce overall component count, and reduce cost. Using discrete matching components, the size required for this PA is less than 0.4 square inches. The price of the RF2155 in volume is less than $3.

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