RF MICRO·DEVICES

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New High Efficiency HBT Analog Cellular Power Amplifier

Abstract

RF Micro Devices introduces a new power amplifier for Analog Cellular applications based on revolutionary HBT (Heterojunction Bipolar Transistor) technology. This power amplifier operates from a single 4.8V power supply without the need for a negative voltage. The power output from 824MHz to 849MHz is 1.2W with 420mA current – a total efficiency of 60%! On-board gain control is included, as is power down. The part is packaged in an industry standard 16-lead SOIC with a fused center lead. Pricing is competitive at less than $5 in volume.

Introduction

With the introduction of digital cellular systems in North America and Europe, analog phone manufacturers are becoming more competitive. Differentiating factors such as talk time, stand-by time, size, and especially cost are driving new analog phone development. In this type of environment, the components used in these phones must offer unprecedented performance/cost advantages. 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 4-cell applications operating between 4.0V and 4.8V this function can now be performed using HBT (Heterojunction Bipolar Transistor) technology from RF Micro Devices. The RF2131 AMPS/ETACS Power Amplifier can amplify a +6dBm input signal to +30.8dBm output, drawing only 420mA from a single positive supply. Additionally, an on-board analog gain control provides greater than 30dB of power control from 2V to 3.6V control voltage. When the control is reduced to 0V, the part is shut off, drawing less than 10mA.

Key Advantages of HBT Power Amplifier Technology

The RF2131 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, 25dB gain AMPS/ETACS 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 RF2131 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.
- 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 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. HBT Power Amplifiers from RFMD provide 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 while drawing less than 1mA from a controller. 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. 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 is controlled over 30dB with a 2V to 3.6V control range. This pin offers less than 1mA current consumption, even under full drive. With very deep Class AB bias on the final stage, the current decreases rapidly with lower power, making the RF2131 very efficient even at reduced powers.
- Low Noise-Power Output. A key parameter related to the power amplifier 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 like AMPS 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 RF2131 operates with better than -90dBm/30kHz in the receive band as shown in Figure 1.

HBT Technology

The RF2131 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 photolithography is required for this process; thus, mask alignment and optical resolution is not an issue. Also, this means wafers can be prepared and stockpiled, 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 0.5mm to 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, as a

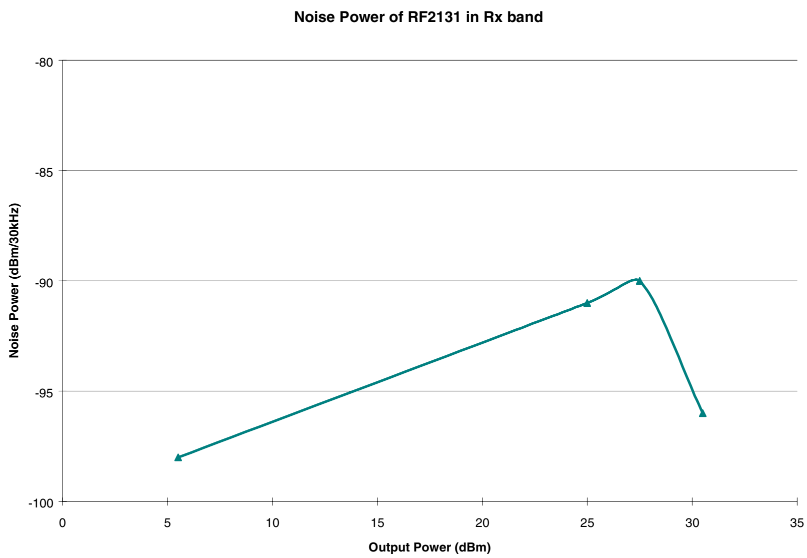

Figure 1. Noise Power of RF2131 in Rx Band

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 currently defined to be 107 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 RF2131.

RF2131 Theory of Operation and Application Information

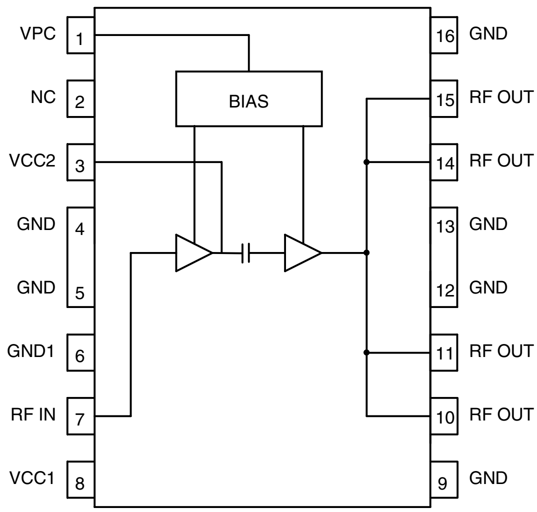

Figure 2. Block Diagram and Pinout for RF2131.

The block diagram for the RF2131 is shown in Figure 2. The part is a two-stage device with 25dB gain at full power. Therefore, for +31dBm output power, the drive 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 4 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, around 40mA. As the RF drive is increased, the final stage self-biases, causing the bias point to shift up and, at full power, draws about 360mA.

The optimum load for the output stage is ~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. For AMPS, the match is slightly different than for ETACS; however, in any case the optimum load for 1.2W is the same at the device.

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 divider with high value resistors on the input pin to V_{PC} and ground. For nominal operation, however, no external adjustment is necessary as internal resistors set the bias point optimally.

V_{CC2} 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 bypass capacitor sets the inductance seen by the part, so placement of the bypass cap can affect the frequency of the gain peak. For ETACS, the capacitor placement is slightly different than for AMPS. This supply should be bypassed individually before being combined with V_{CC} for the output stage to prevent feedback and oscillations.

The RFout pins provide the output power. Pins 10 and 11 should be combined externally with Pins 14 and 15 with a symmetric combiner. Care should be taken to ensure that the output paths are symmetric up to the point of combining. This prevents "odd-mode" cancellation from occurring wherein one side tries to get out-of-phase with the other, which affects efficiency and stability. Bias for the final stage is fed to this output line, and the feed must be capable of supporting the 400mA of current required.

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 and power is 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 RF2131 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 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 RF2131 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 RF2131 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.

RF2131 Performance

The RF2131 performance is summarized in Table 1 below. A full data sheet is available from RF Micro Devices.

A common problem associated with high-efficiency cellular power amplifiers is stability, especially into a duplexer. Since duplexers can be designed with different out-of-band characteristics, a robust cellular power amplifier must operate without oscillation into inductive-coupled as well as capacitive-coupled filters. The RF2131 has been tested into various types of duplexers without oscillating.

The minimum output power is achieved with the power control set between 0V up to ~2V, then the power increases approximately linearly as V_{PC} increases from 2V to 3.6V. The characteristic has been designed to function with a low sensitivity of output power to control voltage. If the sensitivity of the gain control is too high, the ALC loop in the phone may oscillate.

Conclusion

The RF2131 HBT Analog 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 60% and power levels of 1.2W are achievable from a single 16-lead SOIC surface mount package from 4.0V to 4.8V. 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 RF2131 in volume is less than $5.

Parameter	Typical Performance	Conditions
Frequency Range	800-950 MHz	Externally tuned for individual bands
Maximum CW Output Power	1.25-W	With specified load at 4.8V
Total CW Efficiency	60%	At Max Output
Gain at Max Power	25 dB	
Noise Power Output	-90 dBm/30kHz, max	in Receive Band, any power setting
Gain Control Range	30 dB, min	
Vpc Current	1 mA, max	
"OFF" Current	10 uA, max	Vpc < 0.2V
Voltage Range	4.0 to 4.8V	
Stability	Unconditional	
Temperature Range	-30 to +85?C	Operating

Table 1: RF2131 Typical Performance