A 3V HBT Power Amplifier for CDMA/AMPS Handsets

Abstract

A high power, high efficiency, low cost power amplifier has been developed utilizing commercial gallium arsenide (GaAs) heterojunction bipolar transistor (HBT) technology. The RF2152 is suitable for 3V applications, especially CDMA/AMPS handsets. Operating in the IS95 bandwidth with a supply voltage of 3.4V, the amplifier can provide 28dBm of output power (meeting IS95 linearity requirements), with 30dB of gain and a power added efficiency (PAE) of 38 percent.

Introduction

The RF2152 is the latest addition to a family of power amplifiers introduced by RF Micro Devices (RFMD) utilizing GaAs HBT technology. This commercially proven technology has several advantages over other technologies, such as MESFET or PHEMT. Since HBT's are bipolar, no negative bias is required, nor is it necessary to include a charge pump to generate this voltage, which adds die count and cost to the product. The HBT can be completely powered down using a control voltage, eliminating the need for a drain supply switch used in MESFET designs. RFMD's HBT process also utilized backside vias, resulting in low ground inductance when used in conjunction with a slug type package. The amplifier is packaged in a 16-pin EDSSOP package, and has been developed with low cost 0402 size components for minimizing application circuit size.

The performance summary of the RF2152 power amplifier is shown below.

Frequency	824MHz to 849MHz
V_{CC}	3.0V to 5.0V
Output Power	31dBm AMPS 28dBm CDMA
Gain	30dB
Linearity	-44dBc @ 885kHz -56dBc @ 1980kHz
PAE	55% AMPS 38% CDMA

The RF2152 can also be tuned for JDMCA/TACS (877MHz to 924MHz) with similar performance.

Package Description

The RF2152 power amplifier is packaged in an EDSSOP-16 package with backside ground. The dimensions for this package are shown in Figure 1.

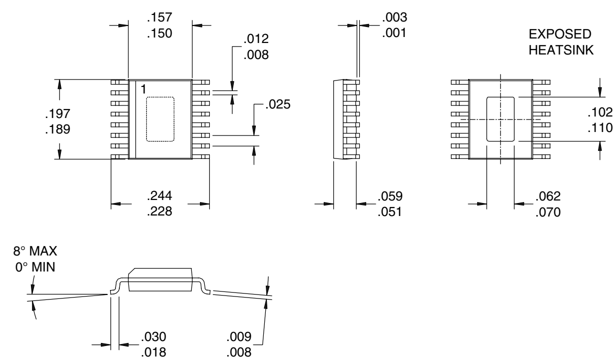

Figure 1. PSSOP-16 Package Outline

Advantages of Using an MMIC Power Amplifier

There are currently two options available for the power amplifier in a CDMA handset. The first is a module that usually consists of a single package containing the power amplifier die, and several components used for matching and bias decoupling. The other option is to use a packaged power amplifier MMIC, and design a matching network externally on the phone PCB. RFMD is currently developing products for both of these options, with the RF2152 being a packaged MMIC amplifier requiring external components.

The advantage of the packaged amplifier becomes obvious when choosing the operating voltage for the handset. In discussions with various vendors, it was found that approximately 50 percent of handset designs for the 3V CDMA market will use a regulated V_{CC}. In this case, there will be a single output impedance that will result in optimum performance from the power amplifier. Modules are typically designed to operate across the entire possible region of operation, typically 3.0V to 4.3V, for a lithium ion battery-powered design. This requires a compromise in load line design, since the module cannot be opened and retuned for the various applications. Of course, for the other 50 percent of the handset designs, this load line (designed for a wide range of V_{CC}'s) can also be implemented on the PCB for MMIC power amplifiers.

The following discussion shows the variation in load lines for two supply voltage conditions. The calculation of the correct load line can be approximated by the equation:

$RL=\{(V_{CC}-VSAT)^2\}/(2*PSAT)$
(Assuming a real load line)

Where
VCC=the supply voltage for the handset.
VSAT=the saturation voltage for the transistor (for this example, 0.4V will be used).
PSAT=the saturated output power of the amplifier, typically 3dB above linear output power for a CDMA power amplifier.

For a 3.0V handset application, with 28dBm output power at the power amplifier:
RL=2.7ohms

However, for a 4.3V handset application, with 28dBm output power at the power amplifier:
RL=6.04ohms

In the case of a handset design using an unregulated supply voltage, a load line must be designed that will allow the part to meet CDMA specifications under all these conditions. So it is obvious a compromise must be made. In the case of a handset design using a regulated V_{CC} design, however, an optimum load line can be used *if the tuning is accessible to the handset designer*. Using an MMIC power amplifier makes this optimization possible.

High Volume Low Cost Commercial HBT Technology

The RF2152 utilizes the TRW/RFMD high volume low cost commercial HBT process. This is a mature process developed by TRW in the late 1980's. Since the early 1990's, TRW and RFMD have worked together to optimize this process for low cost commercial applications. A unique feature of this process is the utilization of molecular beam epitaxy (MBE), which is an accurate and repeatable method for growing the various transistor layers. Previously viewed as an expensive research process, MBE is now being used in low cost commercial processing. This has been accomplished through the development of multi-wafer MBE reactors at TRW. This results in better uniformity and reduced process variation when compared with older MOCVD-type processes.

A major milestone in the success of this process was reached with the recent announcement of the completion of the world's largest HBT fab located at RFMD's headquarters in Greensboro, North Carolina. With the implementation of cross-linked manufacturing, RFMD and TRW will now provide customers with two geographically separated manufacturing locations for high volume production using the same process. The only difference is the transition to four-inch wafers at the RFMD fab. This results in a 70 percent increase in parts per processed wafer.

Manufacturing Advantages of Using HBT Technology

As mentioned earlier, the TRW/RFMD HBT process takes advantage of high volume MBE-based transistor growth. In an HBT transistor, the critical geometries are vertical, and are controlled during this MBE process. This is very different from MESFET technologies, where critical geometries are based on photolithographic processing steps that are dependent on mask alignment and optical resolutions.

Additionally, the turn-on voltage (VBE) of an HBT is controlled by the bandgap of the structure, and is not a function of processing. With MESFET's, the turn-on voltage (VT) is greatly affected by processing, especially surface effects such as traps. This results in large variations in bias current, which are commonly corrected using expensive post processing adjustments such as laser trimming resistors.

the HBT process also allows wafers to be completed and stockpiled, thus eliminating several steps from the critical path of production development.

Finally, the minimum geometries in the HBT process are 2μm, typically two to four times the gate geometries found in MESFET's. This also increases the manufacturability of this process.

Design Advantages of Using HBT Technology

There are many advantages to using HBT technology in power amplifiers, rather than the older MESFET and HEMT-based approaches. One of the biggest is simplicity for the customer's designs. HBT's, unlike MESFET's, do not require any negative voltages for operation, so a charge pump is not required either in the IC package (where it will use current) or in the handset (where it will add cost).

Another advantage is power control. All power amplifiers require some means of power-down control to reduce battery current consumption when not in use. In MESFET-based designs, the conventional means for power-down control is to use an external "drain side switch" to disconnect the battery voltage, and shutting down the charge pump supplying gate bias. This "brute force" approach is required because the alternative would be to design a charge pump to provide additional negative voltage to fully deplete the MESFET, which would consume too much current.

There are two negative results with using a drain side switch. First, the cost of an added component. Second, the voltage drop across the switch, which must be considered when comparing PAE results with HBT power amplifiers.

For example, assuming two amplifiers (one MESFET and one HBT), both operating at 3.0V, 28dBm out, 40 percent PAE, and the drain side switch has a voltage drop of 0.15V. This would require that 3.15V be supplied to the MESFET amplifier to have 3.0V at the drain. This would result in a drop of two PAE percentage points.

Looking at this another way, the affect of a drain side switch on talk time is even more apparent. Assuming the battery was allowed to run down to 3.0V before shutting the phone off, and both PA running at 40 percent efficiency, the following currents are derived:

PA without drain switch (i.e., HBT PA)
28dBm out=0.63W
40 percent PAE

I_{CC}=0.63W/(3.0V*0.4)

I_{CC}=525mA

However, in a PAE with a drain switch, the voltage at the drain will be 2.85V. Assuming the load line was reoptimized to provide 40 percent PAE, the current required will be:

I_{DD}=0.63W/(2.85V*0.4)

I_{DD}=552mA

The result is a five percent increase in current consumption in a FET-based amplifier at low battery voltage.

Theory of Operation and Applications

A functional block diagram of the RF2152 is shown in Figure 2.

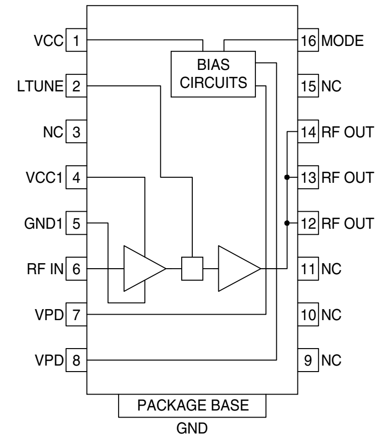

Figure 2. Block Diagram of RF2152

As shown above, the RF2152 is a two-stage power amplifier with internal bias circuits. Interstage tuning is accomplished partially off-chip to account for board ground inductance from various manufacturing technologies. Power down and low power modes are controllable via external pins.

The first stage ground is brought out through a separate pin for isolation from the output stage. The output stage is grounded through the package slug.

The following is a description of the various I/O's.

Pin	Function
1	Supplies VCC to the bias circuits
2	Interstage tuning control
3	No Connect
4	Supplies VCC to the first stage
5	Ground for the first stage
6	RF input
7	Bias fine control
8	Power down control
9	No Connect
10	No Connect
11	No Connect
12	RF Out
13	RF Out
14	Harmonic Trap
15	No Connect
16	VMODE (output bias adjustment

Application Circuit

The application schematics for the most common applications (IS95 CDMA) are shown in Figure 3.

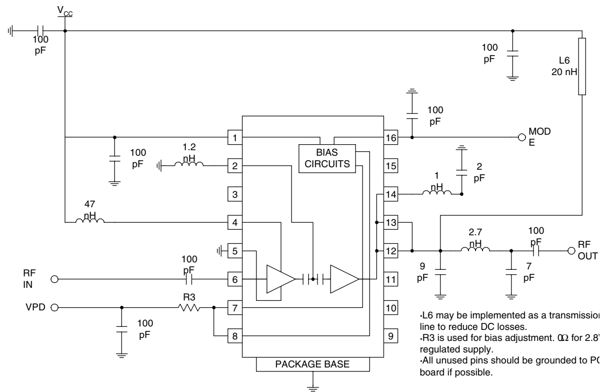

Figure 3. RF2152 Applications Circuit

It should be noted that many of the capacitors shown for bias decoupling have been found necessary to reduce test equipment noise on a test bench, but unnecessary in an actual handset with a battery.

The evaluation board layout, containing the power amplifier and matching components, may be found in the RF2152 data sheet.

Performance over Wide Supply Voltage Variations

To demonstrate the possible utilization of the RF2152, typical parts were tuned for use across a wide supply voltage range of 3.0V to 5.0V. This would demonstrate the typical requirements of a handset using very low cost NiCad batteries with a typical charger voltage of 5.0V. Figures 4 through 18 show the amplifier performance overall bias and temperature conditions, *without retuning the part*.

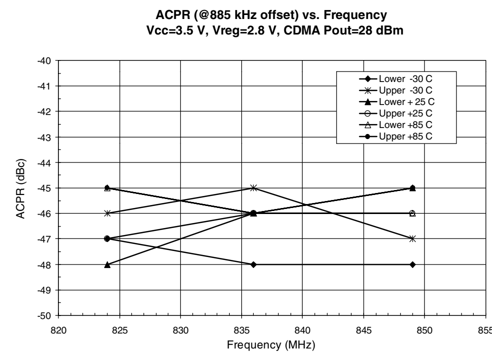

Figure 4. CDMA Mode: Adjacent Channel Linearity

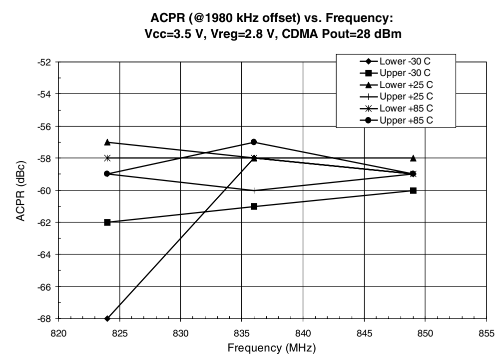

Figure 5. Alternate Channel Linearity

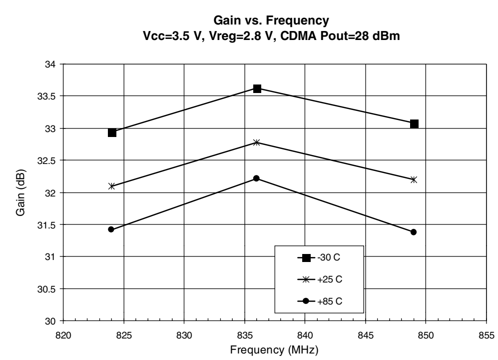

Figure 6. Gain versus Frequency

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TECHNICAL NOTES AND ARTICLES

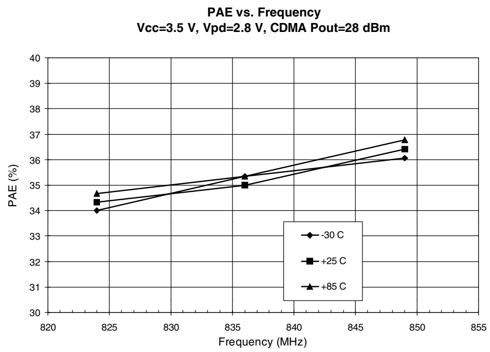

Figure 7. PAE versus Frequency

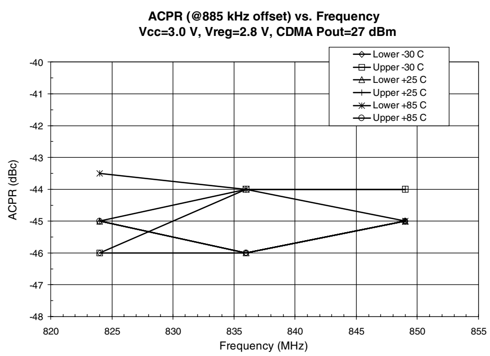

Figure 8. Adjacent Channel Linearity (3.0V)

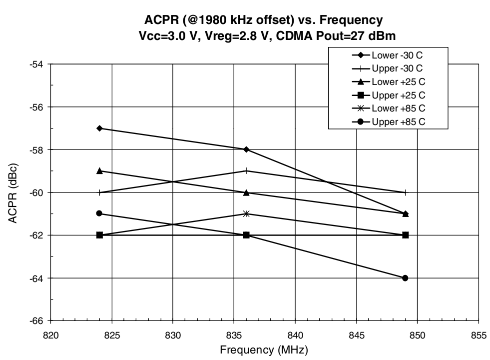

Figure 9. Alternate Channel Linearity (3.0V)

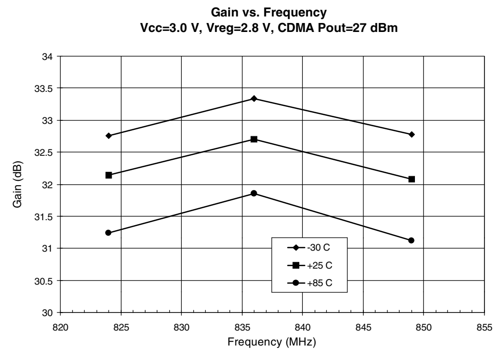

Figure 10. Gain versus Frequency (3.0V)

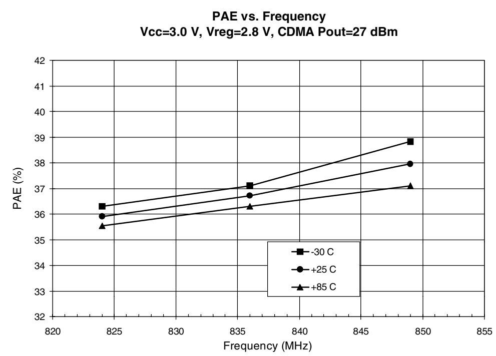

Figure 11. PAE versus Frequency (3.0V)

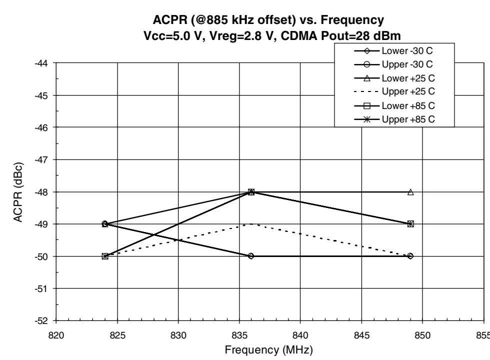

Figure 12. Adjacent Channel Linearity (5.0V)

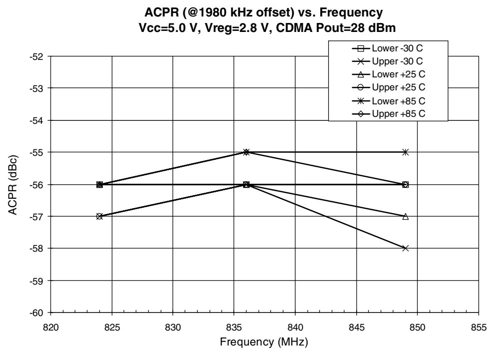

Figure 13. Alternate Channel Linearity (5.0V)

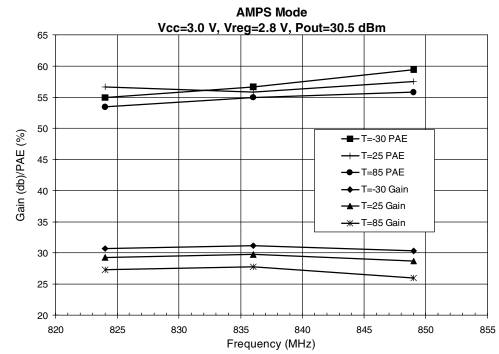

Figure 16. AMPS Mode Performance (3.0V)

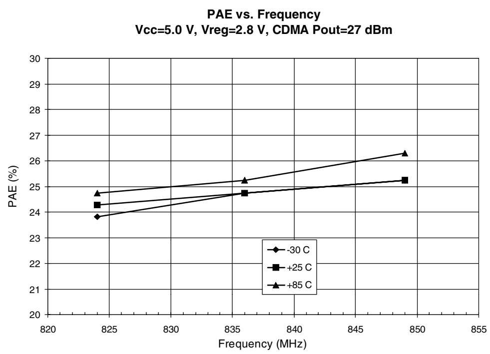

Figure 14. PAE versus Frequency (5.0V)

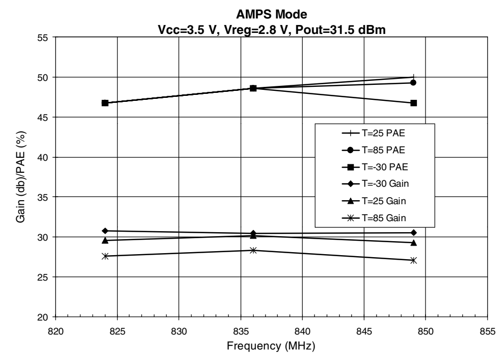

Figure 17. AMPS Mode Performance (3.5V)

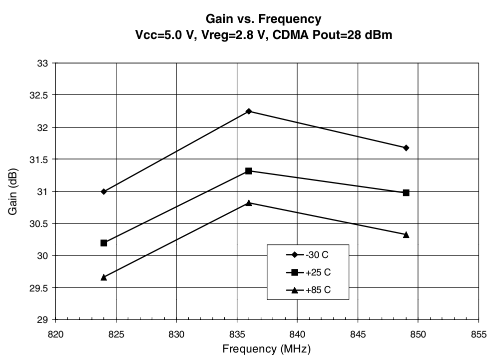

Figure 15. Gain versus Frequency (5.0V)

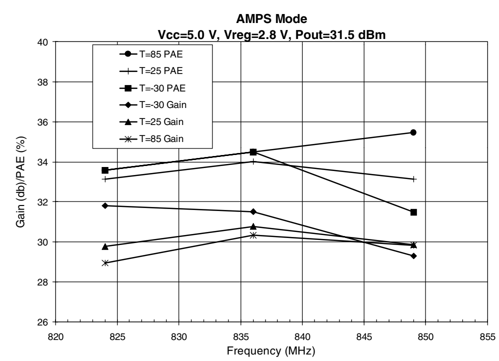

Figure 18. AMPS Mode Performance (5.0V)

Performance with Regulated Supply Voltage

The data below shows the performance of an RF2152 power amplifier tuned for optimal performance at 3.5V.

FREQ	PIN	ICC	ACP1	ACP2	EFF
824	-3.5	469	44/44	58/59	38%
836	-4.4	460	44/44	58/59	39%
849	-4.6	444	44/44	58/59	40%

Low Power Mode

While CDMA power amplifier performance is typically specified at 27dBm to 28dBm output power, the actual average operating output power of a CDMA handset is typically 10dBm to 15dBm. With this in mind, the RF2152 utilizes two external bias control pins to lower the quiescent current approximately 50 percent in low power (less than 15dBm) mode.

Pin 16 (VMODE) directly controls the output bias. Pulling this line TTL low will reduce the bias in the output stage by about 50 percent. Pin 7 is a fine adjustment for both stages. Depending on the output power required in the handset design, this line can be used for further bias reduction in low power mode.

Conclusion

The RF2152 HBT is an integrated power amplifier on the market for IS95 CDMA and dual CDMA/AMPS applications. The amplifier offers the handset designer the opportunity to optimize an amplifier for their particular application with excellent performance. The amplifier is optimized for CDMA performance, with excellent efficiency and low power mode aimed at improving talktime in 3V handsets.