Characteristics of E-pHEMT vs HBTs for PA Applications

AVAGO TECHNOLOGIES

White Paper

Introduction

Many different semiconductor technologies are currently being used for power amplifiers (PAs) that include a mix of Silicon and GaAs devices – Silicon Bipolar, Silicon MOSFET, GaAs MESFET, GaAs HBT and GaAs pHEMT. Avago uses enhancement-mode pHEMT (E-pHEMT) process for its PA design while most competitors have developed GaAs HBT technology. This paper shows why E-pHEMT technology can provide superior electrical and reliability performance for power amplifier design in wireless communications.

I. Electrical Performance

Low battery leakage current consumption

Historically, leakage current has not been a strength of E-mode FET devices. However, Avago's PAs using E-pHEMT technology have a very low drain-source current (Idss) consumption of less than 10 µA at room temperature. This performance has been achieved due to a combination of using a buried gate, correct crystal orientation, reducing the second recess depth and optimizing the InGaAs channel with a selective etch process.

No need for drain switch or negative voltage supply

One of the drawbacks to the conventional depletion-mode pHEMTs, despite the high performance, is the conduction of current at zero gate bias, or when the drain current, Id, reaches a saturated level (Idss) at a gate-source voltage (Vgs) of 0 VDC. However, E-pHEMT devices from Avago are true enhancement mode devices and conduct only a small amount of leakage current at zero gate bias, so that Id ≈ 0 at Vgs = 0 VDC. Therefore, it can operate without negative voltage supply or drain switch.

Low quiescent current consumption (Idq) in CDMA Applications

Quiescent current is controlled through a regulated voltage line, with a variable control voltage level of 1.0 ~ 2.7 V Vcntl. Avago CDMA PAs have lower quiescent current consumption using the E-pHEMT process. To maximize talk time, a low-power mode option was incorporated into the PA modules to improve the quiescent current (Idq) below 30 mA at 1.2 V Vcntl and 70 mA at 2.5 V Vcntl compared to 100 mA Iq using the GaAs HBT process.

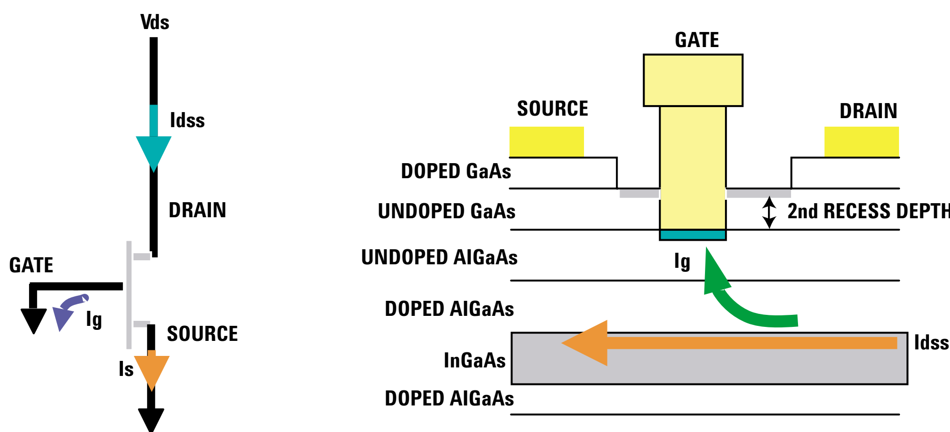

Figure 1. The drain-source current (Idss) of an E-pHEMT process

High power added efficiency (PAE) for longer talk time

Power added efficiency (PAE) is a good criterion for how much talk time you get per battery charge. Specifically, PAE is defined as:

$$\text{PAE} = \frac{\text{P}\frac{RF}{OUT}\Big|_W - \text{P}\frac{RF}{N}\Big|_W}{\text{P}^{D}\Big|_W}$$

There are a couple of key reasons why Avago's E-pHEMT PAs have excellent PAE when operated in both linear modes (CDMA) and in saturated modes (GSM). First of all, the low RDSon gives high drain efficiency while high gain reduces the input drive requirement. Secondly, high ft and fmax allow for very fast switching to reduce power dissipation in the device. When operated in linear mode, PAE is typically 8.5% at medium Pout (16 dBm) and over 40% at maximum Pout (28.5 dBm) in comparison to 7% and 32% of GaAs HBT PAs at the same conditions. As a saturated amplifier, E-pHEMT has demonstrated industry leading PAE levels. Efficiency performance of 60% in EGSM band and 57% in the DCS/PCS bands is realizable in production.

Low Voltage Operation

Power amplifiers typically require a bias buffer to properly set the bias point. For PAs based on bipolar technologies, this results in having two PN junctions, ~1.2 V, in series as part of the circuit. The sum of these drops limits the amount of available bias network headroom, especially as the battery voltage drops below 3 V. E-pHEMT devices have very low turn-on voltages and therefore do not have the same limitation in bias headroom. This allows for superior Pout and efficiency performance at bias levels less than 3 V in comparison to HBT devices.

II. Reliability Performance

No thermal runaway

In general, bipolar devices cannot perfectly match the entire active geometry to design PA. This can allow for small areas to become "hotter" than other local areas. This imbalance in thermal regions can cause thermal runaway. Thus, the GaAs HBT devices need to add ballast resistors to equalize this imbalance. These ballast resistors result in lower gain and output power.

The inherent increase in RDSon of hotter areas in E-pHEMT devices provides intrinsic ballasting. E-pHEMT devices do not require ballast resistors to eliminate thermal runaway and thus do not sacrifice Pout or PAE performance.

No Secondary Breakdown Mechanism

There is a secondary breakdown mechanism in HBT devices. The imbalance and hotspotting due to localized breakdown effects can cause excessive heat that can fuse the electrodes of HBT devices. Therefore, HBT devices require the addition of a clamp on the collector to limit peak output voltage such as zener diodes. This extra circuitry can add some loss and generate spurious when clipped. This secondary breakdown does not exist in E-pHEMT due to the intrinsic ballasting effect of increasing RDSon versus temperature.

Survivability Under High Mismatch

PAs are often subjected to large variations in output impedance, such as 10:1, and must survive. The removal of the antenna, presence of large ground planes and operation in a charger can create large voltage variations at the output of the PA. Any device will exhibit a breakdown when subjected to a large enough potential difference between the output and input (Drain-to-Gate for FETs and Collector-to-Base for BJTs). In a bipolar device, the increased potential difference causes the base to get very thin, resulting in extremely high beta values. Consequently, any injection of current in the high potential state causes a "punch-through" breakdown to the emitter.

Conversely, with the same high potential difference in a FET, the source is shut off completely and there is no breakdown path from the drain to the source. The level for the breakdown in a FET is determined by the potential from the drain to the gate, BVGD. The BVGD of a FET device is much higher than the potential difference that causes a collector to emitter "punch through" in a bipolar device. The higher breakdown level in the FET results in more robust performance.

Comparison between E-pHEMT technology and GaAs HBT

Table 1. Summary of E-pHEMT vs. GaAs HBT technologies

	E-pHEMT	GaAs HBT	Primary Performance Impact
Effiiency	High	Good	E-pHEMT - 60%, GaAs HBT - 50% (GSM)
High Gm upon turn-on	Yes	No	Class-B and high effiency operation(low power PAE)
Gain dependence on bias current	Constant	Proportional to Ic	Large variation of gain vs. Icc for HBTsConstant gain vs. Idd for E-pHEMT
Gm vs. Bias	Linear	Non-linear	Linearity for digital modulation
Low supply voltage PAE	Excellent	Fair	Headroom constraint for design using next generation battery technology
Thermal runaway	No	Yes	Ballasting and thermal design, performance tradeoff and limitation
Survivability Under High Mismatch	Limited by BV_{GD}	Degraded by high beta	E-pHEMT very robust vs. mismatch load

For product information and a complete list of distributors, please go to our web site: **www.avagotech.com**

Avago, Avago Technologies, and the A logo are trademarks of Avago Technologies, Limited in the United States and other countries.
Data subject to change. Copyright © 2007 Avago Technologies Limited. All rights reserved.
5988-8574EN - May 25, 2007