AN1223
APPLICATION NOTE

RF POWER TRANSISTORS: COMPARATIVE STUDY OF LDMOS VERSUS BIPOLAR TECHNOLOGY

Serge Juhel

1. ABSTRACT

RF power transistors consist of two type of devices: Bipolar Junction (BJT) and Field Effect (FET). Due to differences in technology, the bipolar junction transistor will yield superior performance for certain applications while the field effect transistor will be better employed for others. This application note will discuss and compare their parameters and performances.

2. LDMOS ADVANTAGES.

LDMOS (and MOSFETs in general) enjoy superior characteristics on the following points:

1. Thermal stability
2. Frequency stability
3. Higher gain
4. Increased ruggedness
5. Lower noise
6. Lower feedback capacitance
7. Simpler bias circuitry
8. Constant input impedance
9. Better IMD performances
10. Lower Thermal Resistance
11. Better AGC Capability

2.1. Thermal stability.

LDMOS, unlike bipolars, have a negative temperature coefficient and therefore are protected against thermal runaway. This is illustrated as follows: as the device draws more current, its temperature rises. A rise in temperature causes an increase in the gate threshold voltage (VGth) which turns the device off resulting in a drop in current.

Bipolars, on the other hand, have a positive temperature coefficient and are prone to thermal runaway. The main reason for this is the increase of h_{FE} with the increase of temperature. As the device draws more current its temperature rises, hence h_{FE} rises and even more current is drawn resulting in a further temperature hike. This goes on until the device fails. Hence, bipolars need elaborate temperature compensation to prevent such occurrence. MOSFETs, however, are protected against thermal runaway and no compensation is required.

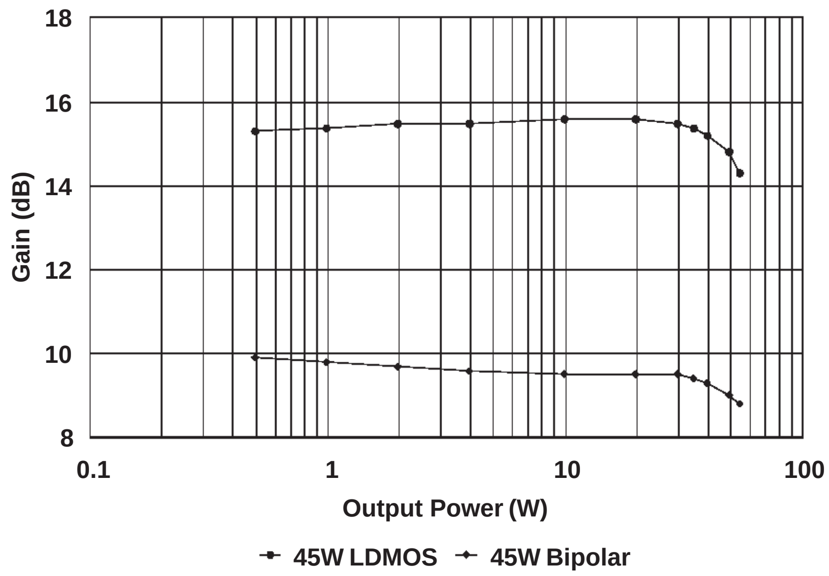
2.2. Frequency stability.

Lack of diode junctions and a higher ratio of feedback capacitance versus input impedance make LDMOS more stable than bipolars. Moreover, bipolars suffer an instability mode known as half f_0 due to varactor effect in base-emitter junction and a lower ratio of feedback capacitance versus input impedance.

2.3. Higher gain.

Two factors contribute to LDMOS superior gain characteristics compared to an equivalent bipolar (see Figure 1). First, wire-bonded connections, which normally connect the source and the external circuitry (because of the vertical bipolar structure - collector on the bottom), are no longer required thus greatly reducing the negative feedback due to the wires self-capacitance and inductance. This leads to higher gain at high frequencies. Second, in a bipolar thermal stability is achieved at the detriment of gain. In an attempt to lessen the likelihood of bipolar thermal runaway, ballast resistors are placed in the emitters of the device. This helps to prevent current hogging. Current hogging occurs when one of the many emitters within the transistor die draws more current than the others. As a single emitter draws more current its temperature hikes and h_{FE} increases, leading to a thermal runaway situation. Placing resistors in the emitters of a device helps to share the current more equally, therefore decreasing the likelihood of thermal runaway. However, gain pays the price for this increased thermal stability. Consequently, in a bipolar the gain is lesser than that in an LDMOS. The fact that an LDMOS has a higher gain means that less amplifying stages are needed, which in turn, means higher reliability and lower costs.

Figure 1: Gain vs. Output Power



2.4. Increased Ruggedness.

In an LDMOS, the source and channel are shorted, hence there is no more breakdown voltage (BVCEO). Consequently, device ruggedness is significantly improved. MOSFETs are indeed more rugged than their bipolar counter part. Ruggedness is an important factor for applications such as commercial radios where the output devices are generally not protected by an isolator (circulator) and often experience large load mismatches.

2.5. Lower noise.

Another drawback of ballast emitter resistors in bipolars is increased noise since current flowing through these resistors will generate noise. MOSFETs are unaffected since they are not fitted with ballast resistors. For most amplifiers this is unimportant but for applications, such as transceivers, which have a transmitter biased for linear operation and a receiver located nearby, noise is a critical factor.

2.6. Lower feedback capacitance.

Many broadband amplifiers use negative feedback to achieve good gain flatness across a wide frequency range. These applications request low feedback capacitance (the one between the output lead and the input lead of a device). MOSFET feedback capacitance (LDMOS) is typically 5 times lower than the feedback capacitance of a comparable bipolar.

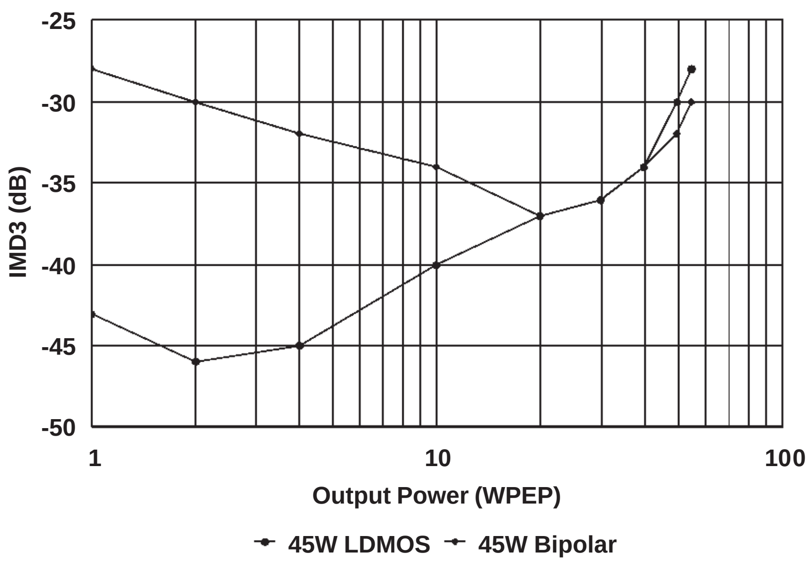
2.7. Simpler bias circuitry.

MOSFETs are voltage controlled devices, therefore no current is drawn from the bias circuitry. Furthermore, MOSFETs have a negative temperature coefficient, hence no temperature compensating component in the bias circuitry is required. Consequently, the bias circuit remains very simple and biasing can be done with a plain voltage divider.

2.8. Constant input impedance.

MOSFETs input impedance varies only slightly with gate voltage fluctuation. This makes it very suitable for amplitude modulation applications where a constant load on the driver stage is necessary in order to prevent parasitic amplitude modulation. Also, MOSFETs constant gate impedance permits identical input matching network for any class of operation (class A, AB, B or class C).

Figure 2: Third Order Intermodulation Distortion vs. Output Power



2.9. Better IMD performances.

As stated above, MOSFETs constant input impedance, as a function of input power level, allows better Intermodulation Distortion (IMD) performances at low power levels (see Figure 2). Bipolars input impedance varies with input power level, hence the transistor becomes unmatched from its matching network and so generates a higher level of IMD.

2.10. Lower thermal resistance.

Since the LDMOS have a lower power density (LDMOS' dice are larger than bipolars'), dissipated heat occurs through a larger area. Moreover, LDMOS do not require an electrical isolator (BeO). Consequently, LDMOS thermal resistance is considerably better than a comparable bipolar.

2.11. Better AGC Capability.

The relationship between the drain current (Id) and the gate voltage (Vg) makes LDMOS (MOSFET) ideal for Automatic Gain Control (AGC) applications. This relationship is linear almost from turn-on to saturation. This means that LDMOS gain can be controlled throughout a wider range of power levels. Typically LDMOS have 30 dB AGC range or better, while AGC range of a comparable bipolar is around 15 dB.

3. LDMOS MAINS DRAWBACKS.

1. Lower power density
2. Damage due to electrostatic discharge

3.1. Lower power density.

For a comparable power level more die area is required by an LDMOS than a bipolar. This results in less dice per wafer and therefore higher MOSFET (LDMOS) cost. A larger area will also restrict maximum available power for a given package.

3.2. Damage due to electrostatic discharge.

Electrostatic discharge, which can reach up to several hundreds of volts, can deteriorate the gate to source channel of the LDMOS so anti-static protection handling is mandatory.

4. CONCLUSION

LDMOS products are best suited for applications such as CDMA, W-CDMA, TETRA, Digital Terrestrial TV etc., requiring wide frequency range, high linearity and good ruggedness performances. But above all, LDMOS are flawless for high linearity requisite. They can be used in class AB (by reducing the output power until the wanted linearity is achieved), where a comparable bipolar could only attain the same linearity in class A, occasioning a high current consumption.

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