Linear RF Power with Silicon JFETs

The Silicon JFET produces unusual linear and high power for UHF applications. This paper describes an 850 MHz pulse amplifier with 75% efficiency and 25 W power.

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The spectrum available for voice and data communications has become particularly crowded. System conversion to digital or multicarrier modulation and new power applications, such as those in the lower ISM frequency bands compound the problem. It has become increasingly important for equipment manufacturers to make sure signal distortion and spurious frequency generation are reduced to the lowest practical levels. As a result, applications in the area of linear RF power amplification have seen a significant increase in performance requirements.

To comply with the new standards and regulations, RF communication equipment frequently must be designed for linearity, with high intercept points (IP) for low order as well as high order intermodulation distortion products (IMD) and performance should remain constant over a wide dynamic range (DR) of amplified signal.

At the same time, tradeoffs are made between system manufacturing costs, which are primarily associated with system complexity, and system operating costs, which are associated with operating electrical power and maintenance expenses.

Common practice to build the most suitable linear amplifier is to select an amplifying device having the best inherent linearity and then, if is linearity is inadequate, use an appropriate signal processing, feedforward or feedback technique to enhance linearity. Clearly, the 'more linear' the active device, the simpler the required linearization efforts[1].

Most state of the art linear RF power amplifiers use bipolar junction transistors (BJTs) or MOS field effect transistors (MOSFETs). These transistors' linear performance can be optimized by adjusting the operating point and the load RF impedance. While both the BJT and the MOSFET technologies have matured, amplifier improvements have been derived mostly through innovative signal manipulation techniques rather than improvements in the amplifying devices' linearity.

This paper describes experimental results in linear RF power amplification achieved with a third type of transistor, the silicon power junction FET (JFET). It has inherently more linear properties than other available RF transistors[2]. Linear applications examples of RF power and receiver amplifiers were selected to illustrate how, by using JFETs significant benefits in performance and cost accrue. Their design into RF amplifiers is further enhanced by packaging them in prematched silicon linear amplifier modules or SLAMs. The JFETs are operable up to 1300 MHz[4] but in this paper we shall describetheir operation at RF.

JFET Characteristics.

The key to the JFETs' linearity is that, unlike BJTs and MOSFETs, they have nonsaturating I-V characteristics, as shown in Figure 1. The bias voltage polarities are identical to those of GaAs FETs. They use negative gate voltage and positive drain voltage.

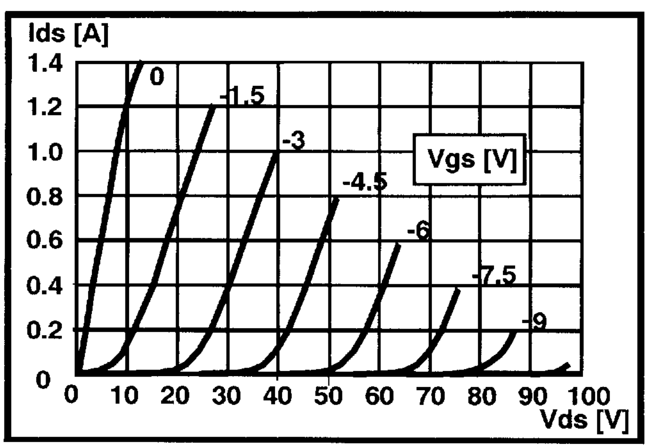

Figure 1. JFET I-V Characteristics.

A result of these characteristics is that the device transconductance remains virtually constant from very low to very high operating currents. In contrast, for the other transistor types, the transconductance exhibits significant compression at both very low as well as very high operating currents.

Another transistor parameter that affects the linear performance is the device's intrinsic capacitance and its variation with drain and gate voltage. Unlike the BJT and the MOSFET, the JFET's capacitance decreases rapidly between zero and low reverse voltage and intermodulation distortion (IMD) products and wide dynamic range.

A unique JFET operating characteristic is its low variation in maximum available RF power as a function of load impedance variations. Under normal operating conditions, the BJT and MOSFET load lines are selected within a narrow region extending from the 'knee' of the saturating I-V characteristics up to the highest supply voltage point. As shown in Figure 2, the maximum load power remains virtually constant over a relatively wide range of load impedance variation.

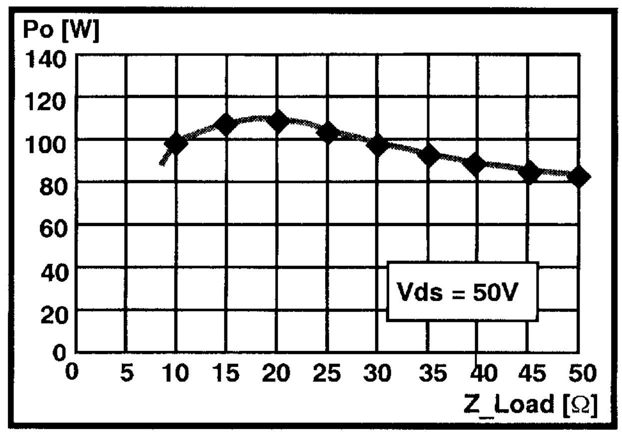

Figure 2. JFET output power as a function of load impedance.

Linear amplifiers operate either class-A or class-AB. Class-A yields the best linearity, but since the operating point is halfway between zero and breakdown, less output power and efficiency than Class-AB. Class AB, on the other hand, takes place at lower bias levels, allowing a larger RF peak voltage swing. It offers higher efficiency but less linearity and dynamic range.

In most multitone applications the signal has an amplitude modulated component and, in addition to the average single tone power, there is a need to measure the signal's *peak envelope power* (PEP). The IMD products are measured with respect to the PEP with the two equalamplitude signals falling within the operating bandwidth of the amplifier.

At rated class AB output PEP, BJTs are typically capable of providing IMD3 products -35 dB to -40 dB below PEP levels. As the output power is lowered, IMD3 performance degrades. For a specified usually varies from 3-8 dB. MOSFETs exhibit IMD3 levels ranging from -30 dB through -35 dB at rated output PEP. Unlike the BJT, when the MOSFET output power is reduced, IMD3 improves, providing approximately 10 dB of usable dynamic range. In selecting either the BJT or MOSFET there is a design tradeoff between the BJT's better high power IMD performance but lesser dynamic range and the MOSFET's lesser IMD performance and wider dynamic range.

However, the JFET offers better IMD3 at rated PEP than the MOSFET anda wider dynamic range that the BJT at up to 500 MHz. Figure 3 compares BJT, MOSFET and JFET IMD3 performance data measured at 215 MHz and a bias voltage of 50 V. All three devices used in this comparison were rated for 50 watt PEP operation.

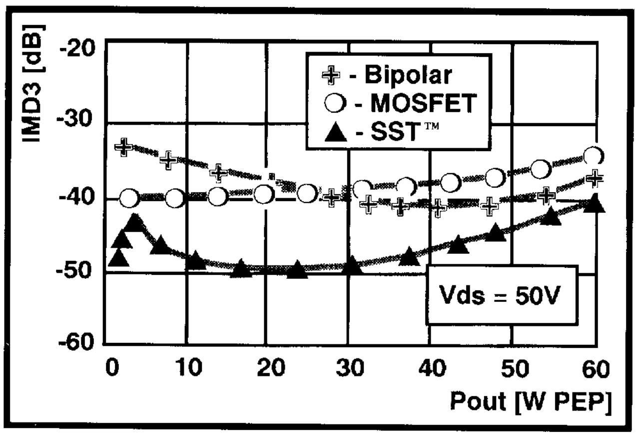

Figure 3. Class AB IMD3 Comparison.

The JFET's IMD3 variation with output power can be modified by changing the transistor quiescent current. Higher currents tend to yield better IMD3 but at an increased quiescent power consumption. This is illustrated in Figure 4, where the IMD3 performance and quiescent power tradeoffs are shown for a 20 JFET tested at 400 MHz. As shown, higher Idq also results in a wider linear power dynamic range.

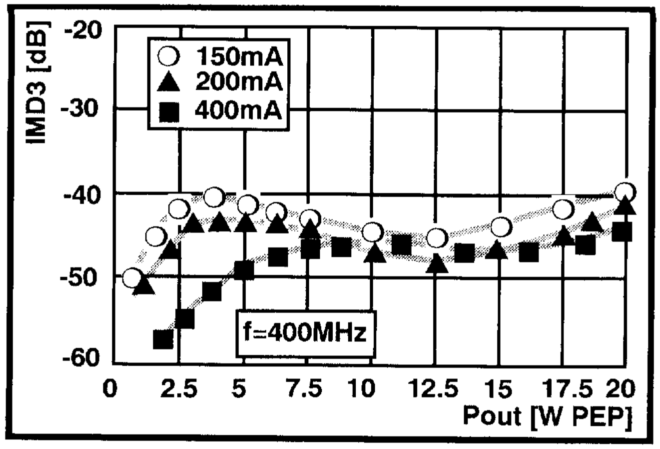

Figure 4. IMD3 Dependence Upon Idq.

While BJTs can be biased at levels sufficient to provide the required IMD3 dynamic range, the actual linear power dynamic range is reduced at the high power, because the IMD5 products rise faster than the third order products. The JFETs exhibit a slower rise of the IMD5 product, and as shown in Figure 5, a wide dynamic range on low, as well as on high IMD products.

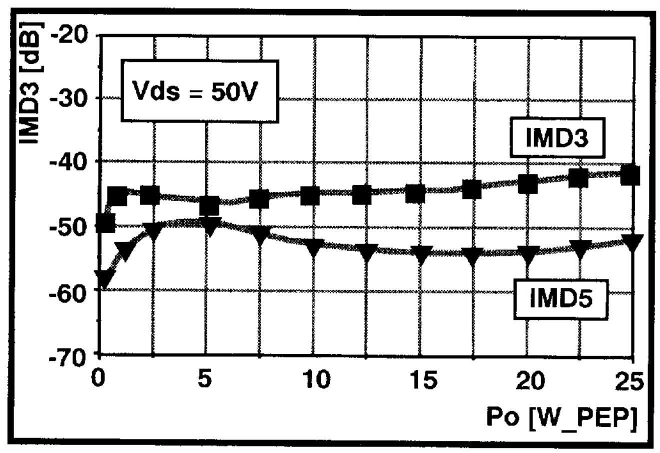

Figure 5. IDM3 and IDM5, f=30 MHz.

Another operating parameter that influences linear performance is the bias voltage. Figure 6 shows the IMD3 of a JFET rated for 40 watts PEP, which was evaluated at Vds levels of 50 V and 60 V. The test frequency is 215 MHz. As shown, IMD3 levels and the dynamic range improve at higher Vds, while the IMD3 at low power is unaffected by the bias change.

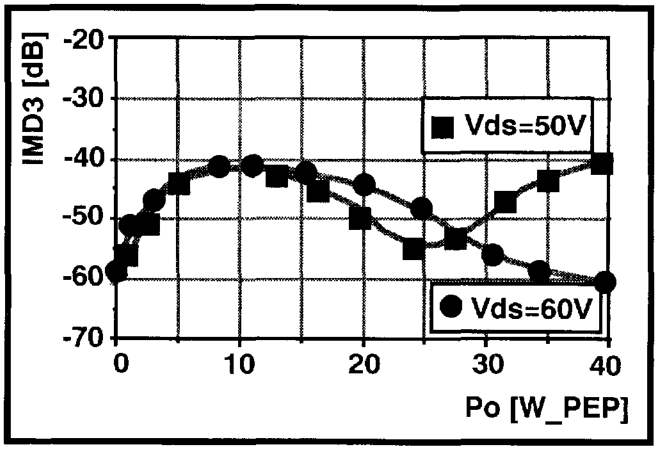

Figure 6. JFET IMD3 versus output power (watts PEP) at 215 MHz for 50 and 60 volt Vds.

The load impedance has a strong effect on linear operation performance and Figure 7 illustrates the trade-off between output power and dynamic range for improved IMD3, lower rated power and reduced dynamic range. As shown in Figure 2, the JFET load impedance required for optimal linear operation can be selected without sacrificing the maximum available output power.

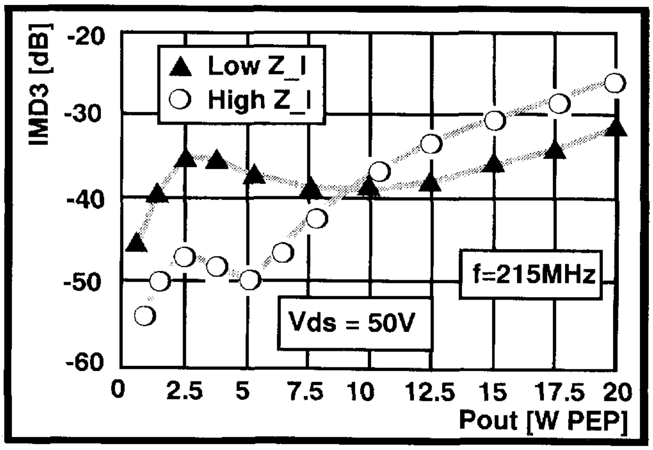

Figure 7. IMD3 versus load impedance.

All of the JFET amplifier examples shown here operate common source. This limits the useful frequency range for present devices to about 500 MHz. JFETs can be used to more than 1 GHz[4] but to obtain sufficiently high power gain the common gate configuration is used at these higher frequencies. Figure 8 shows data for a common gate 850 MHz pulse amplifier. As with common source operation, linearity improves as supply voltage levels increase. Although, as shown, linearity performance is very good, this type of amplifier has limited applications. As it approaches power saturation the JFET operates with a class-B efficiency as high as 75 %.

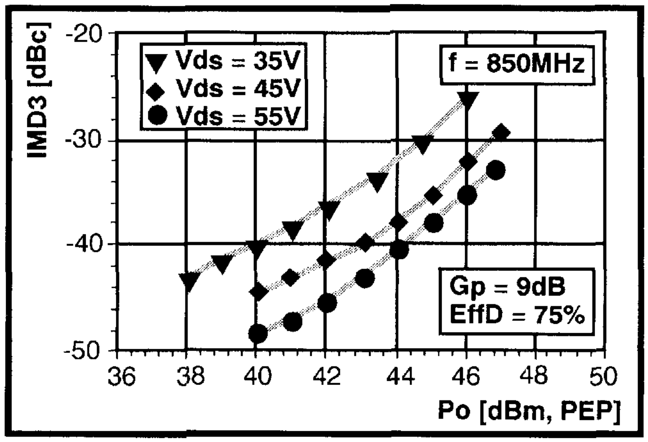

Figure 8. Class A Pulsed RF IMD3.

The JFET provides:

1) Very linear class AB operation	≤ -40 dBc
2) Wide dynamic, range class AB	10 dB
3) High class AB efficiency	≥ 40 %
4) Wide supply voltage range	24 V - 55 V

Acknowledgments

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Editor's Note

The author's firm markets JFETs as described in this article under the trademark SSTs for (Solid State Triodes).