Capabilities of Low-cost High Voltage RF Power MOSFETs at HF and VHF

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ABSTRACT

Plastic power MOSFET transistors have found increasing acceptance in all fields of power electronic applications including new high power applications in the frequency range of 1 to 30 MHz. RF power sources for AM broadcasting, medical, industrial and semiconductor processing demand from hundreds to many kilo-Watts of power. In this paper, we compare the standard offerings of several vendors with a new line of inexpensive plastic packaged RF MOSFETs. MOSFET design, package layout, measurement circuits and performance characteristics will be presented.

INTRODUCTION

The RF industry has experienced tremendous growth over the past decade primarily in the area of UHF wireless communication. The growth has overshadowed a somewhat less spectacular but still impressive growth in uses for the spectrum below 100MHz. Applications in this area include medical diagnostic tools such as MRI (Magnetic Resonance Imaging), plasma generation for semiconductor processing equipment, and laser drivers, among others. New devices have appeared to address the expanding UHF markets but lower frequency applications have been required to make do with older devices or those which have been optimized for the higher operating frequencies. This has resulted in extra cost to the lower frequency systems.

Some equipment manufacturers have tried to mitigate the higher transistor cost by stretching the performance of lower cost plastic devices designed for the switchmode power supply market. The power MOSFET has served this market reasonably well up to about 13 MHz, but with limitations. There are system advantages in using these devices. By operating on a 100V or even 300V supply, the output impedance is raised making the matching to 50Ω much easier than the more common 28V or 50V system. Power supply costs are generally lower because copper volume is less at the lower current required for equal power.

Disadvantages with the use of these standard switchmode devices lie in both the package construction and die layout. The TO-247 package's metal back heat spreader, used for heat sinking the device, is electrically tied to the drain of the MOSFET. This requires either using an insulator between the package and the heat sink or grounding the drain directly to the heat sink and changing the circuit topology. Either method adds to the assembly cost of the PA and incorporates the potential for failures due to incorrect installation not to mention the poor and variable thermal transfer characteristics of the insulator. The package construction results in a significant amount of source inductance, limiting the frequency response of these devices.

Switchmode devices are ideally suited for class C, D or E. The switchmode parentage makes these devices difficult to operate in a linear mode, especially at voltages over 100V. For best switching, the desired transfer characteristic is a low ON threshold voltage (V_{th}), and very high dc gain. This, plus a negative temperature coefficient of V_{th} makes for difficult class A or AB applications. Lower gain, ballasted devices are needed. It is an area for future improvement.

In some cases the die geometry, designed for switchmode applications, caused excessive gate propagation delay when operated at high frequency due to the gate's finite metalization conductivity. This reduces both the gain and effective power dissipation of the device.

We have introduced a new series of MOSFETs to address some of the shortcomings of our standard power MOSFETs when operating at RF. These new devices are configured as complimentary pairs with the metal back heat spreader connected to the source. They operate at high voltage, up to 300V V_{dd}, which offers significant system advantages for the generation of high power at

frequencies up to 100 MHz, while maintaining the cost advantage of the TO-247 package. These devices represent a significant challenge to the 50V ceramic/gold paradigm.

Device Comparison

Since the use of plastic packaged switchmode MOSFETs in HF amplifier service has been increasing, we undertook to determine what parameters to use when selecting devices for HF amplifier service. Devices from different manufacturers were selected for evaluation. All devices were equivalent 500V "size 4" die (approximately 40,000 sq. mils) in TO-247 plastic packages. Before the rf tests were performed, several static measurements were made on the devices.

The capacitance vs. drain voltage curves were obtained using a programmable voltage supply, and a HP-4275A operating under Lab-view. The results are shown in figures 1, 2 and 3. The curves for two of the devices are well behaved, the third show the effects of a proprietary fabrication process called j-fet doping which reduces the
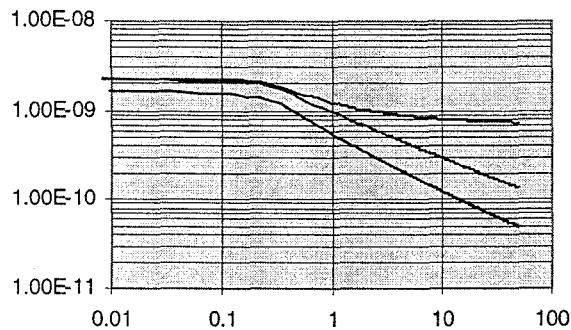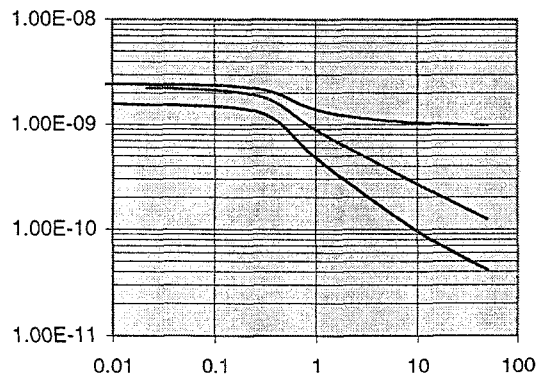

Figure 1   Device A: Ciss, Coss, Crss vs. Vds

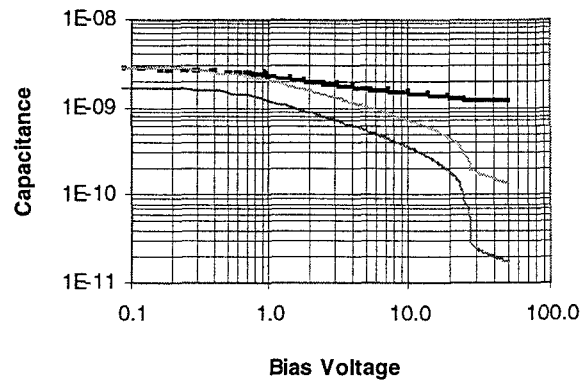**Figure 2   Device B: Ciss, Coss, Crss vs. Vds**

Figure 3   Device C: Ciss, Coss, Crss vs. Vds

Crss above the parasitic j-fet threshold of about 12 Volts. This is a mixed blessing. It provides a very low feedback capacitance when operating CW steady state. Under linear operating conditions it can produce undesirable phase modulation which can degrade the two-tone performance.

The other parameter measured was the equivalent series resistance, ESR, of the gate capacitor. This is one of the factors which determines the cutoff frequency of the device. The results were:

Device	Gate Capacitance ESR, Ω
A	1.341
B	0.060
C	0.691

The gate ESR is determined by the conductivity of the gate metalization. The gate can be viewed as a long distributed R-C network. As the gate metalization resistance increases, so does the attenuation at the far end. As frequency increases, the far end of the gate structure receives less of the drive signal in the proper phase. In the case of the A devices, the gain falls off rapidly -- as does the achievable Pd because the entire device area is not "illuminated". Device B, with the lowest ESR, had the best frequency response.

Measuring And Evaluation Fixture

"Switchmode" transistors have been used in several commercial applications of at RF in recent years[1]. These generally occur in single frequency rather than broadband applications in the lower ISM (Industrial-Scientific-Medical) bands and for MRI (Magnetic Resonance Imaging). Since the drain is common to the heat sink tab

of the TO-247 package, many of these use an inverted common source configuration in the amplifier. This is illustrated in Figure 4.
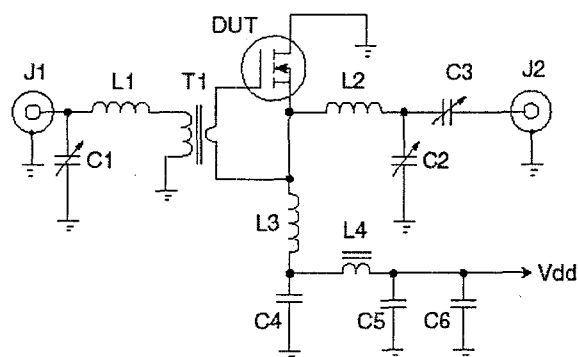

Figure 4 - "Common Drain" Test Fixture

This configuration allows the drain of the device to be connected directly to the grounded heat sink while preserving all of the normal attributes of the common source circuit. The only accommodation is the need for a negative voltage on the source.

Figure 4 is electrically identical to the more familiar common source configuration shown in Figure 5 but it has one major drawback. As the operating frequency is increased, the characteristics of T1, the primary to secondary capacitance in particular, bear heavily on the performance and it is more difficult to achieve equal performance between the two circuits. This is especially true when the circuit is made push-pull.

The three sets of devices were evaluated using a circuit like Figure 4. The values of C1 through C3, L1 and L2 were optimized for each different frequency. C4 through C6 are 10nF monolithic chip bypass capacitors and L3 is a high reactance feed choke. Since the device's output capacitance forms part of the output circuit, a slight adjustment in the tuning was needed between device types at each frequency. Similarly, the input circuit tuning was tailored for each device. Output power, efficiency, and operating voltage were kept constant. The variable was gain.

The devices were operated without forward bias, in saturated class C, and tuned for at least 70% efficiency and best gain[2].
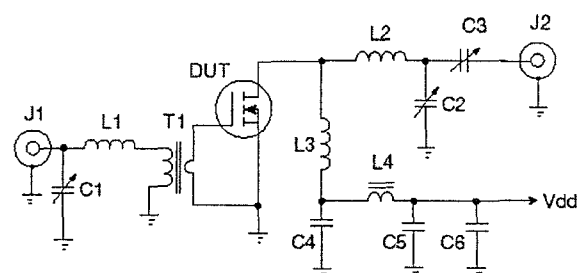

Figure 5 - Common Source Test Fixture

RF Performance

The gain response for each of the three devices are shown in figure 6. The frequency range used covers the common ISM bands of 13.56, 27.12 and 40.68 MHz. Additional measurements were also made on one device
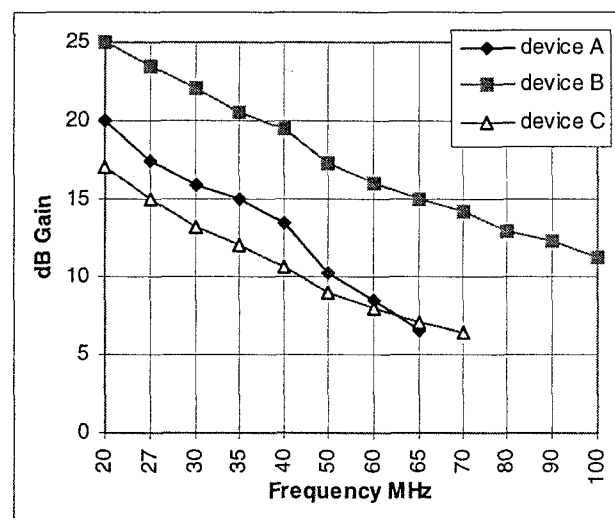

Figure 6 Device Frequency Response

up to 100 MHz. Each device was run class C and tuned for best gain at 75% efficiency. The drain voltage for each was 125V and the output power was 200W at 50% duty cycle. Device B is a clear winner in frequency response performance.

This test is a effective exhibition of the performance improvement gained after the changes were made to the die geometry to optimize the RF performance. Device A and C are typical commercial switchmode MOSFETs of the types used for RF applications below 30 MHz. Device B is a common drain version of the APT449A.

Device Improvements

Advanced Power Technology has recognized both the limitations and potential of the plastic packaged MOSFETs operating at HF. In order to serve this application better, we made changes to standard devices. The first change was made to the package.

In most applications the device is operated in the common source configuration. A standard TO-247 packaged MOSFET requires either the use of an insulator or changing the circuit topology as mentioned before, to isolate the drain from the heat sink. The insulator is a common source of failure and increases the parasitic output capacity. The reversed "common drain" circuit places more stress on the characteristics of the input transformer and eventually falls seriously behind in performance compared to the standard common source circuit. The solution was to incorporate the drain isolation inside the package by mounting the die on a BeO insulator. This approach, long standing in communications transistors, makes these RF MOSFETs easier to apply.

Another package improvement was made to facilitate the use of push-pull circuits. A mirror image symmetric part was introduced which allows the designer to produce a perfectly symmetrical PWB layout. This is of prime concern when the low drive impedance is considered. A small amount of differential circuit trace length in the gate can upset the drive balance which then gives rise to lower efficiency and increased harmonics.

With the packaging in hand, the other improvement was to the die geometry itself. Most power MOSFET manufacturers use a polysilicon gate conductor. APT uses a proprietary self-aligning metal gate. The original meandering gate metal geometry was replaced with a shortened, more dense structure which incorporates multiple high conductivity stripes for both the source and gate metalization. In addition to dramatically lowering the ESR on the gate, this permits using multiple source and gate wire bonds to the package terminals which lowers the net stray inductance. The typical stray inductance, source plus gate, was reduced by approximately 50% to under 10 nH.

The output capacitance and stray inductance can be incorporated into the circuit topology and neutralized at the operating frequency. The main limitation these impose is on operating bandwidth. There is no way to neutralize the effects of high gate ESR. This is the primary limiting factor in frequency response of the die itself and can only be improved through better die geometry. Source inductance, another determinant of gain, could be reduced through the use of more elegant packaging but at a significant cost penalty.

Improved Device Performance

The different versions of these improved devices have been designed into several amplifiers to demonstrate their capabilities. These include a 300V 1 kW 27.12 MHz amplifier using four devices in a parallel push-pull configuration[3], a 125V 50 MHz 250W push-pull amplifier[4], and another push-pull amplifier at 81.36 MHz[5]. These improved devices are two die sizes, one similar to the devices tested for this article and the other twice as large – 80,000 square mils. Each die size is available in two voltage ratings of 450 and 900V. Future offerings in this family will have 250V BVdss ratings.

Conclusion

Three different power MOSFETs in TO-247 packages, of equal die size, power dissipation and BV rating, were evaluated for their suitability for RF amplifier service. Static parameters were measured and RF power gain measured at several frequencies. Device B, an improved RF performance device, had clearly superior performance in RF gain.

[1] United States Patent 5,420,537 "High Power Solid State R.F. Amplifier" Weedon et al. May 30, 1995

[2] Kraus, Bostian and Raab, *Solid State Radio Engineering,* John Wiley & Sons, New York, 1980.

[3] Frey, *Low Cost 1000 Watt 300V RF Power Amplifier for 27.12 MHz,* APT Application Note APT9701.

[4] Frey, *A 50 MHz, 250W Amplifier using Push-Pull ARF448A/B,* APT Application Note APT9702.

[5] Frey, *Push-Pull ARF449A/B Amplifier for 81.36 MHz* APT Application Note APT9801.