VSWR Testing of RF Power MOSFETs

Overview

No amplifier designed for 50Ω will always see a 50Ω load. Things go wrong, mistakes are made. In some applications the amplifier qualification test requires complete survivability at all phases of total reflection, Γ=1. At the device level, manufacturers are constantly striving to produce ever more rugged devices. This requires an understanding of the failure mechanisms that result from VSWR testing, but it also requires a repeatable method for testing. In this application note, we will review the failure mechanisms and past test methods and propose a new VSWR ruggedness test method. An accompanying video entitled "Microsemi VSWR - Load mismatch ruggedness" is available on the Microsemi YouTube™ channel.

Ruggedness Testing

Vigorous VSWR testing will inevitably produce several failed devices. Generally there are three failure modes depending on the characteristics of the load:

1. Over-voltage failure (either die body or periphery),
2. Over-dissipation failure where the SOA of the part was exceeded,
3. Latch-up.

Sometimes it is difficult to distinguish between over-voltage and latch-up. Device engineers work hard to suppress the causes of latch-up. Over-voltage failures can be addressed by operating the device at a suitable supply voltage for the amplifier's class of operation. Dissipation failures are strictly a function of thermal heat-sinking, since an amplifier's efficiency will naturally diminish at certain phases of the load's reflection coefficient. In an operational setting, the amplifier control system should implement drive or supply voltage foldback at that point to prevent damage to the device. A typical VSWR test setup is shown in Figure 1.

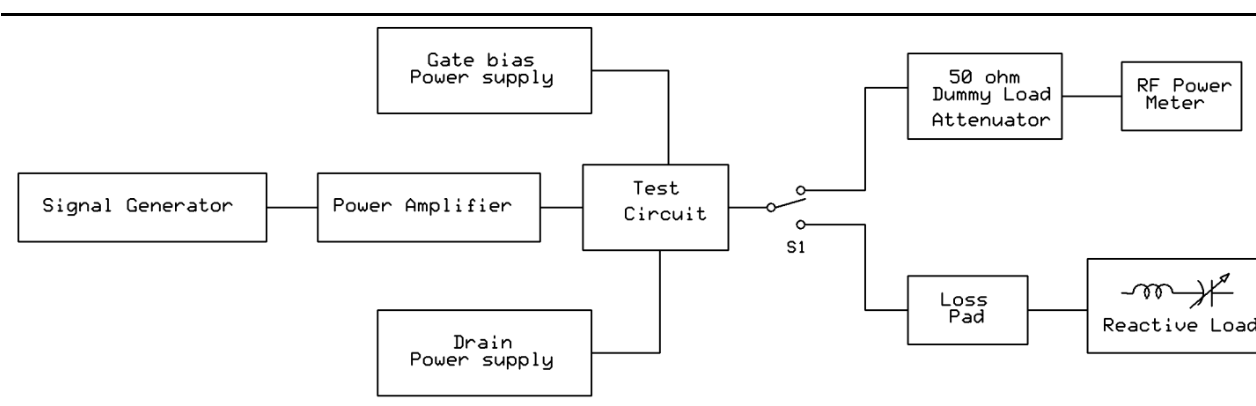

Figure 1 · VSWR Testing System

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Both VDMOS and LDMOS structures have a parasitic bipolar element within the structure which if turned on, will cause it to latch-up and destroy the device. See Figure 2. This is a well known weakness of the DMOS device, and several proprietary methods have been developed to degrade or suppress the bipolar element. The industry standard for demonstrating latch-up ruggedness is the unclamped inductive surge or UIS test. A schematic of the test circuit is shown below in Figure 3.[1]

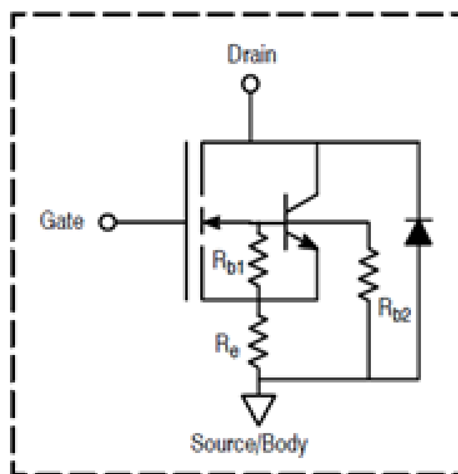

Figure 2 · MOSFET Structure Showing Parasitic Elements

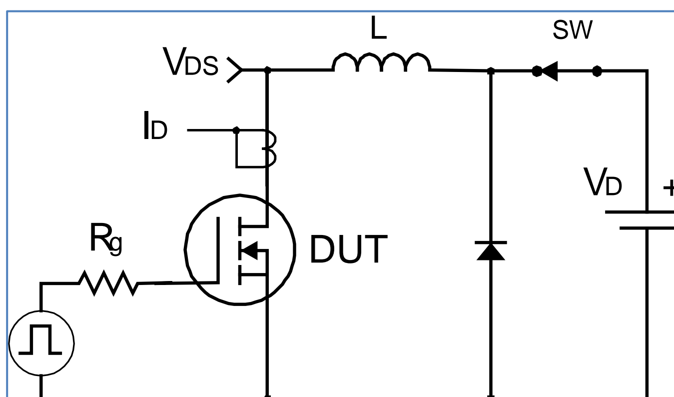

Figure 3 · UIS Test Schematic

The drain voltage V_D is usually set at the operating voltage. The inductor is chosen to provide a given pulse energy level. The gate is turned on. When the inductor charges to the target drain current, the gate is turned off. The inductor's stored energy is released into the device. Ideally, the drain voltage will rise to the breakdown level of the device and then be clamped there until the inductor energy is dissipated in the device. To determine the UIS capability of the device, the inductance is increased until it fails. The maximum energy absorbed by the device is $E = \frac{LI^2}{2}$. This energy, E_{as} for a single pulse or E_{ar} for repetitive pulses, is one measure of device ruggedness but it does not correlate directly to VSWR capability. Because this whole sequence happens in less than 10ms, well inside the thermal time constant of the device, no amount of heat sinking can prevent this type of failure. These avalanche energy parameters are common on switchmode MOSFET datasheets but have not yet appeared in RF datasheets.

The maximum operating voltage for an RF amplifier is determined by the RF breakdown voltage of the MOSFET. While difficult to measure, the RF breakdown voltage is typically 25 to 30% higher than the static DC BV_{DSS} of the device.[2] In Microsemi's VRF series of RF VDMOS parts, the minimum BV_{DSS} is 170V. These parts, while nominally operated on a 50V supply, can easily run on 65V. Assuming that a 2.5 times higher breakdown voltage is required for normal class AB operation, 65V operation means the RF BV must be >162.5 V. This is easily met by the DC BV_{DSS} and the additional ruggedness is provided by the 25 to 30% of RF BV headroom and its inherent UIS capability.

VSWR Ruggedness Testing

VSWR testing requires that the device be operated in an amplifier. The amplifier is generally operated in class AB and the operating frequency is determined by marketing or customer requirements. The amplifier itself must be unconditionally stable under all conditions of loading. The drive conditions are often determined by the application. For example, in linear broadband service, the drive is usually a two tone signal and the amplifier PEP is set at device's rated peak power. For CO_2 laser driver applications where the initial load presented by the un-struck laser is essentially an open circuit, the test signal is usually a 20% duty cycle 200μs pulse. In either case, the peak RF drain voltage generally determines the maximum VSWR ruggedness. The 200μs pulse is used because it is generally less than the thermal time constant of the device junction so that the breakdown failure can be divorced from a thermal failure.

The VSWR test load can be realized in several ways. Brounley[3] uses a series inductance to establish the reflection coefficient. This terminates several different lengths of coaxial cable that can be assembled to move the angle of the reflection coefficient around the Smith Chart. See Figure 4.

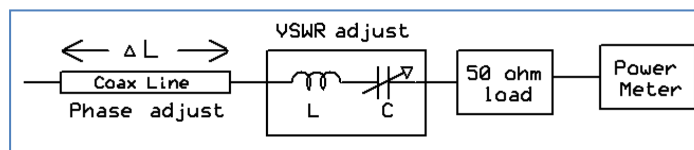

Figure 4 · VSWR Test Load Using Coax

Another means uses a split variable capacitor in a tunable dual LC network.[4] The network impedance can be adjusted from a series to parallel resonance and back again over a 180° rotation of the capacitor shaft. Nearly 100% reflection can be obtained with inductors of reasonable Q. If this load follows a length of cable with loss or a suitable power attenuator, any VSWR at any angle can be readily obtained. See Figure 5. In a production test environment, the worst case VSWR reflection angle load for the particular test fixture is known and a simple switch between it and 50Ω can be used to provide a reasonably fast production VSWR test. If all phase angles must be tested, a motorized fixture can be constructed.

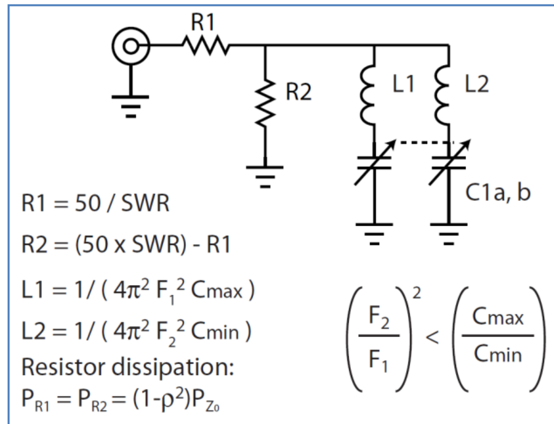

Figure 5 · Variable Phase VSWR Test Load

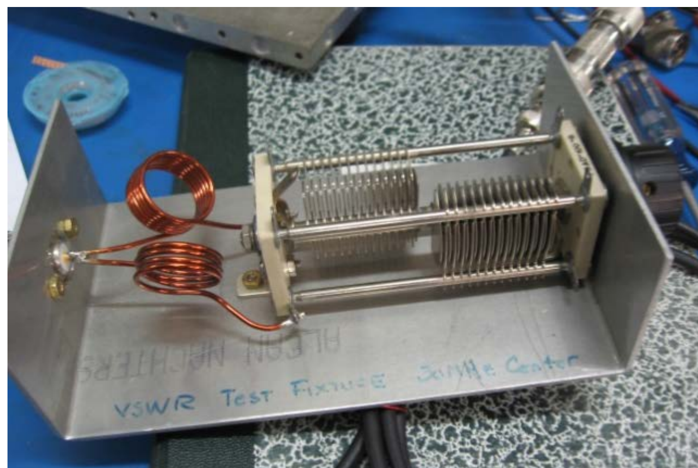

Figure 6 · Manual VSWR Phase Shifter

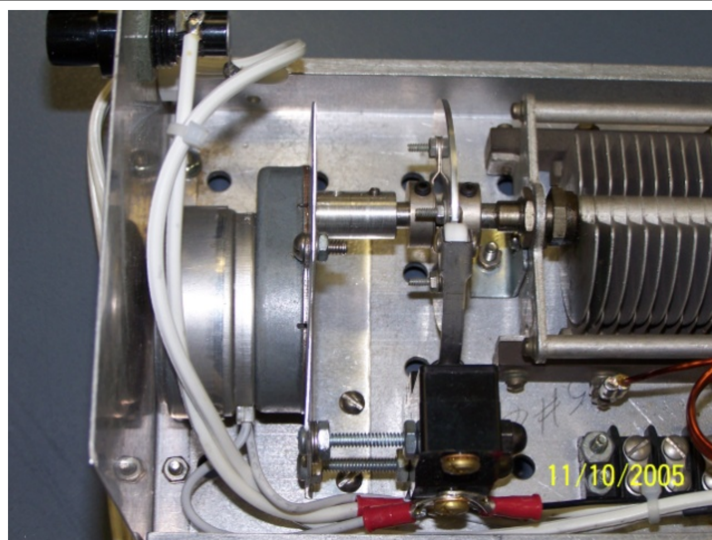

Figure 7 · VSWR Phase Shifter with Motor Control

Since the aim of VSWR testing is to determine the device ruggedness, the 20% duty 200µs pulse testing is probably the best choice. This divorces most of the changes in efficiency and power dissipation in the test amplifier from the VSWR-induced voltage breakdown failure within the device. Since no standardized VSWR test exists as there is for UIS testing, this represents a best method for evaluating the VSWR ruggedness of both lateral and vertical MOSFETS.

Up to now Microsemi devices have had their VSWR ruggedness specified using either a two-tone or CW test signal. Under these tests, survivability was primarily determined by the thermal management of the parts and/or the duration of the test. As a result of the discussion above, Microsemi has decided to change the standard VSWR testing method and use the 200µs 20% duty cycle pulse test signal. We have retested the entire VRF product line using the 20% duty 200µs VSWR waveform. All of the devices passed this new test.

New test using 0.2ms x 20%

Part	VSWR	Test condition	Frequency
VRF150	70:1	150W CW	30 MHz
VRF151	70:1	150W CW	30 MHz
VRF152	70:1	150W CW	30 MHz
VRF154	70:1	600W CW	30 MHz
VRF157	70:1	600W CW	30 MHz
VRF161	70:1	200W CW	30 MHz
VRF191	70:1	150W CW	30 MHz
VRF2933	70:1	300W CW	30 MHz
VRF2944	70:1	400W CW	30 MHz
VRF3933	70:1	300W CW	30 MHz

Summary

VSWR ruggedness specifications have always been a bit of a mystery. Test conditions were poorly defined and the test methods were usually undefined. VSWR failures have two basic causes, thermal and voltage breakdown. We have described a test that divorces the thermal failure from the breakdown failure and in so doing, defined a test that is both repeatable and easily duplicated.

Watch the YouTube video, “Microsemi VSWR - Load mismatch ruggedness”, for more information.

[1] Integrated Technologies Corporation Unclamped Inductive Load Tester, model#ITC55100B

[2] Dye, Norman. and Helge Granberg, *Radio Frequency Transistors – Principles and Practical Applications,* Boston: Butterworth-Heinemann 1993

[3] Brounley, R. "The Design and Test of a 600-Watt RF Laser Driver Using LDMOS Transistors" *High Frequency Electronics*, Dec 2010.

[4] Franke and Noorani, "Lumped-Constant Line Stretcher For Testing Power Amplifier Stability", *RF Design*, Mar/Apr 1983.

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