Pulsed Laser Single-Event Transient Testing of the MiniCircuits RAM-3+ MMIC InGaP HBT Amplifier

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1. Introduction

The RAM-3+ is a Darlington configuration wideband amplifier offering high dynamic range, fabricated using InGaP technology. The device was monitored for transients on the RF output and for any destructive events induced by exposing it to a pulsed laser beam at the Naval Research Laboratory (NRL) laser test facility.

2. Devices Tested

2.1 Mini-Circuits RAM-3+ Background

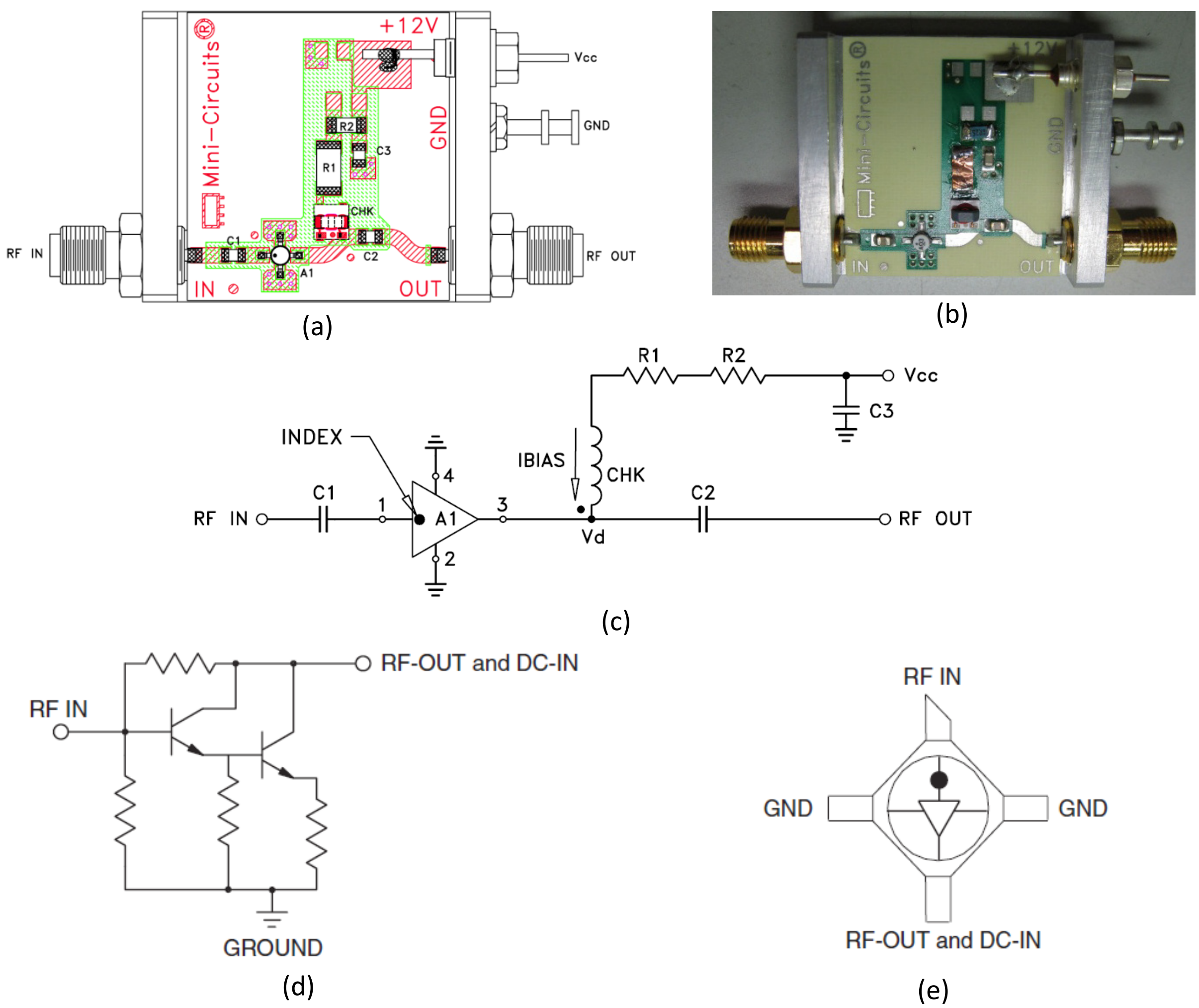


Figure 1: (a) Schematic drawing of the DUT evaluation card for the Mini-Circuits RAM-3+, (b) photograph of the evaluation board, (c) the accompanying circuit schematic, (d) the simplified equivalent circuit, and (e) the pin diagram. The passive component values are given in Table 1.

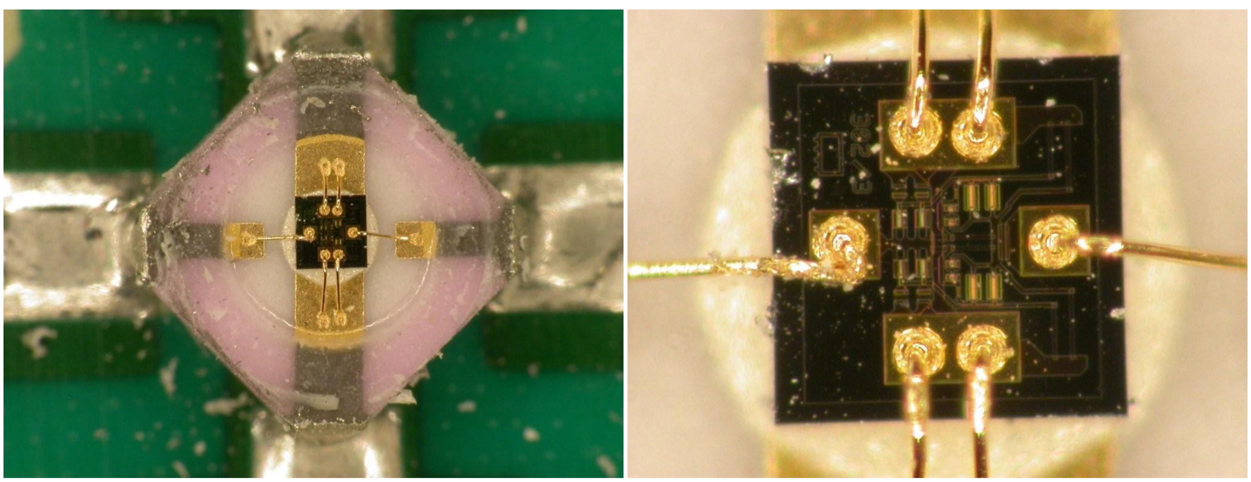
Table 1: Passive component values for the evaluation PCB shown in Figure 1

COMPONENT	VALUE
A1	RAM-3(+)
C1†	2400 pF
C2†	2400 pF
C3 (bypass)	0.1 μF
R1	200 Ω, 0.75 W
R2	0 Ω, 0.25 W
CHK	Mini-Circuits TCCH-80+ (50 Ω RF choke)

† Capacitors, C1 & C2, should be free of resonance up to the highest frequency specified (2 GHz).

The configuration of the Mini-Circuits test board is shown in Figure 1. DC bias was applied to the V_{CC} and GND pins. A SMA cable was connected to the RF OUT jack. The RF IN jack was either terminated (50 Ω) or connected to another SMA cable when RF IN was stimulated with a signal generator during transient testing. The component values of the evaluation board shown in Figure 1 are given in Table 1.

After removing the ceramic lid of the package, the die within was photographed at modest magnification to reveal the sensitive structures. These images are shown in Figure 2.



(a) (b)

Figure 2: Die images of the RAM-3+ following de-lidding on an example part (*i.e.*, not used for testing). The sensitive InGaP HBT targets are visible in (b) as the eight "strip-like" structures next to the single left and right ball bonds. These structures produced transients when stimulated with the pulsed laser.

2.2 Device Under Test Information

Two devices were exposed to the pulsed laser beam at the NRL. The device lot date code was 0918. The DUT was packaged in a ceramic surface-mount AF190 package with tin/silver/nickel (RoHS) leads. The DUT was prepped for test by Timothy Irwin by first delidding the package and then soldering the DUT to the evaluation board.[1] This analog single-event transient (ASET) test is not application-specific and simply uses the factory-provided evaluation board show in Figure 1. Table 2 lists the pertinent information about the DUT.

Table 2: RAM-3+ Sample Information

Part Number:	RAM-3+ (SMD: Non-DSCC Audited Part)
Manufacturer:	Mini-Circuits
Date Code:	0918 LDC is not marked on package
Additional Case Markings:	A03
Quantity Tested:	2
Part Function:	RF MMIC Amplifier
Part Technology:	InGaP HBT Monolithic Microwave Integrated Circuit
Package Style:	AF190 ceramic surface-mount

3. Test Setup

The test setup is shown in Figure 4 and consists of laptop running LabVIEW for instrument control and data capture, a Tektronix DSA72004B digital storage oscilloscope (20 GHz, 50 GS/s), an HP 83712B synthesized CW generator, and an Agilent N6702A MPS mainframe 4-channel power supply. The DUT evaluation board schematic diagram and photo are shown in Figure 1.

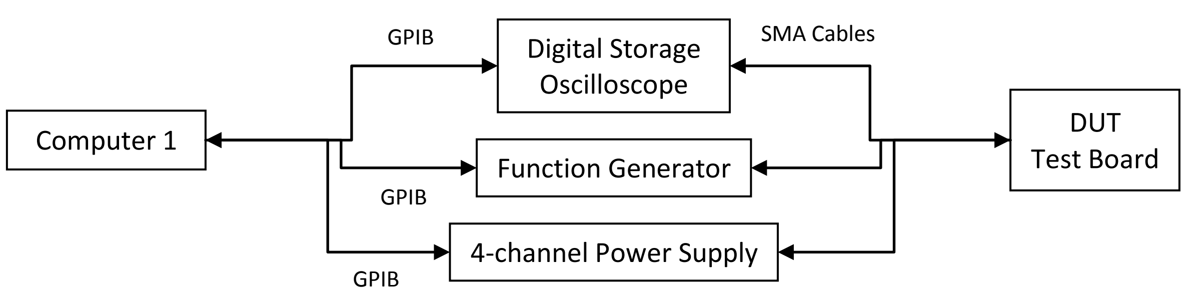


Figure 3: Block diagram for test setup of the RAM-3+.

[1] This occurred after the OEM RAM-3+ on the evaluation board was removed since it didn't belong to the flight lot.

We conducted tests with both DC and AC RF input conditions. In the case of a DC input, the oscilloscope was triggered off of the RF output signal using an edge trigger. However, for a small signal AC input, a external triggering system was set up that synchronized the laser dump/pulse signal and the CW generator so that the oscilloscope would trigger at the same time that the pulse hit the DUT. This enabled high-precision triggering that did not rely on the nature of the ASET signal from the DUT as a trigger.

4. Test Description

4.1 Irradiation Conditions

The tests were performed at the NRL using their single-photon absorption (SPA) setup. This system has been discussed in several refereed publications and will not be covered in detail [1-3]. The laser wavelength is 590 nm, has a pulse width of approximately 1 ps, and is operated at a 1 kHz repetition rate. A 100x microscope objective was used to focus the laser beam down to a full width half maximum (FWHM) Gaussian spot of approximately 1.2 μm. Throughout the test, the pulse intensity, as measured on a NRL oscilloscope, was varied using a waveplate polarizer and multiple neutral density filters with different optical densities for logarithmic coverage. Given these conditions, the resulting charge generation in the sensitive layers beneath the back end of line (BEOL) material stack is sufficient to conduct a conservative ASET analysis.

4.2 Test Parameters and Bias Conditions

The laser was focused onto the RAM-3+ die and scanned across the surface to produce transients on the RF output. This was done for different bias conditions, which are detailed in Table 3. This was not an application specific test; the only variables were the RF input conditions and the laser pulse energy. Transients were captured for all test conditions. In order to convert from laser pulse voltage to pulse energy, the conversion applied is 0.224 pJ/mV at an optical density of 1. The optical density of the neutral density filters used logarithmically modulates the laser pulse irradiance according to $\left({}^{I}/_{I_0}\right) = 10^{-d}$, where I_0 is the un-attenuated irradiance and d is the optical density.

Table 3: Test Conditions Examined

Laser Pulse Voltage (mV)†	Neutral Density Filter Optical Density	RF Input Frequency (MHz)	Laser Pulse Energy (pJ)
0.01	2.2	DC	0.1
0.01	2.0	DC	0.2
0.02	2.0	DC	0.4
0.004	1.0	DC	0.9
		1500	0.9
0.005	1.0	DC	1.1
0.007	1.0	DC	1.6
0.015	1.0	DC	3.4
		20	3.4
		100	3.4
		1500	3.4

- The relative humidity throughout the test was constant at 45%.
- The ambient temperature was constant at 21° C.

† Note that laser pulse voltage is a relative measure of the laser pulse energy and depends upon an independent calibration to calculate the pulse energy.

5. Results

The laser was scanned across the RAM-3+ die for each of the laser pulse energy and RF input conditions specified in Table 3. The InGaP HBT transistors on the die were capable of producing transients at the RF output port of the evaluation board and were recorded by the oscilloscope. There was little difference between the transients produced by the input and output transistors. These results are summarized in the plots shown below. One key feature to note is that the transient widths shown in Figure 4 and Figure 5 are measured at 10% of the transient peak.

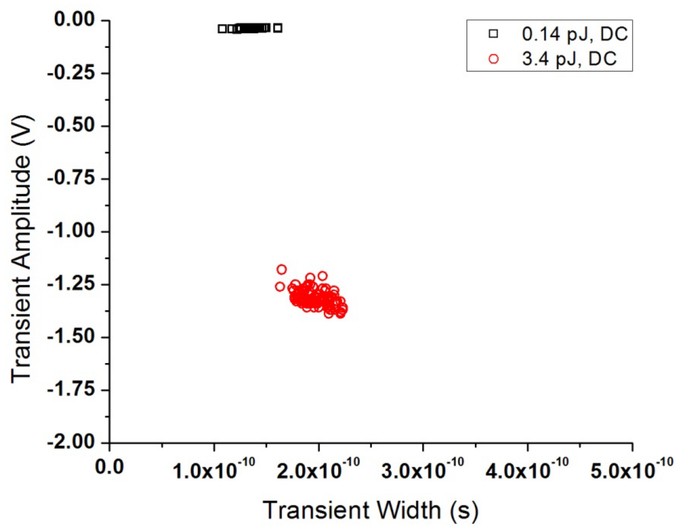


Figure 4: ASET amplitudes and widths for DC RF input conditions. It is clear that the laser pulse energy has a large effect on the overall transient characteristics. The transients shown as black squares were nearly at the threshold of measurement for this setup and are approximately 50 mV with a 10%-10% width of between 100 and 200 ps. All transients are negative.

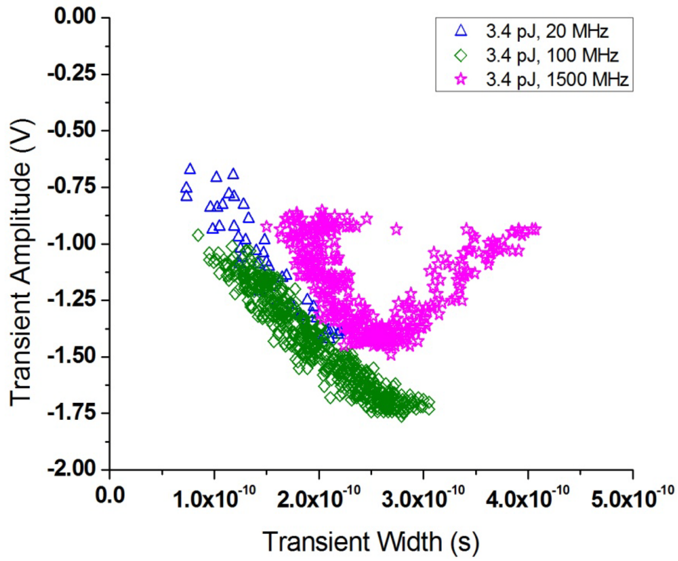


Figure 5: ASET amplitudes and widths for AC/dynamic RF input conditions. The transients are superimposed on the various input sine waves, though at the higher frequencies it seems the distortion can become more dramatic. Regardless, the transients have a 10%-10% width of between 100 and 400 ps. The transient amplitude is approximately 1.3 V, though depending on where in the sine wave period it occurs changes the perceived amplitude. All transients are negative.

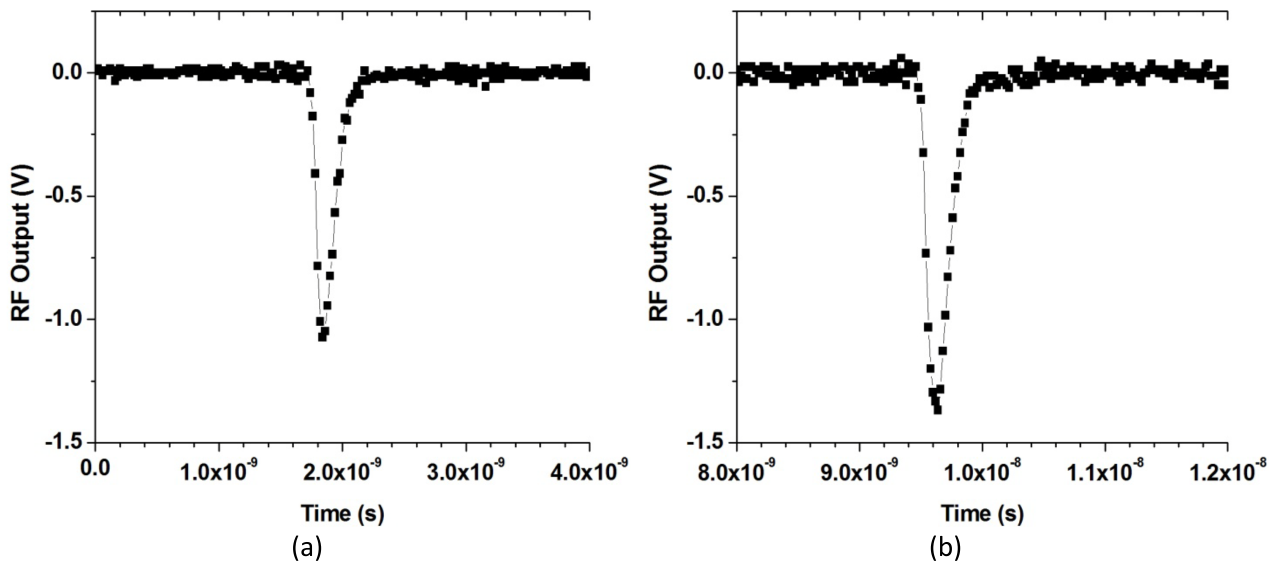


Figure 6: These figures show ASETs for DC RF input characteristics at pulse energies of 1.1 pJ (a) and 3.4 pJ (b). The transient width at the higher energy is slightly longer and the amplitude is larger by about 35%.

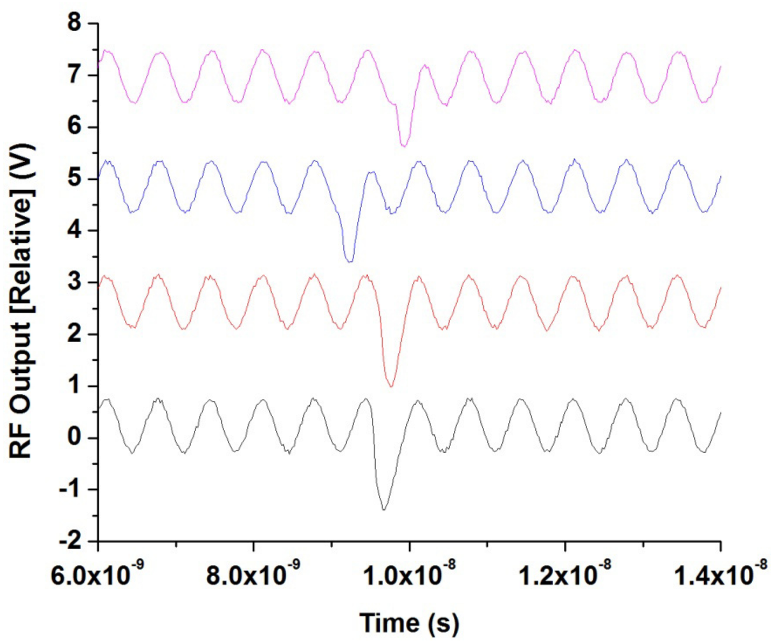


Figure 7: This stacked graph shows ASETs on the RF output of the evaluation board for a 1500 MHz sine wave on the RF input. The laser pulse energy is 3.4 pJ. The transients from Figure 6 are basically superimposed on the sine wave at the output of the evaluation board. In most cases only one period is affected, though in the top two cases more than one period is affected. Note that the voltage on the *y*-axis is relative, as the individual data sets are stacked.

6. Conclusions and Recommendations

The Mini-Circuits RAM-3+ tested here showed transients less than 1.5 V in amplitude for both DC and dynamic RF input conditions under all laser pulse energies. The transients widths, measured at 10% of the peak voltage, ranged from 50 to 450 ps. The transients measured with an AC input spanned the entire width range at the higher frequencies.

Heterojunction bipolar technologies, while ionizing dose robust, generally suffer from large single-event cross sections due to high carrier mobilities and large charge collection efficiencies. These results need to be interpreted carefully since the absorption coefficient of InGaP is not as well defined as it is for silicon and GaAs. Thus, it is difficult to know how far into the device substrate charge is generated during a laser pulse event. The results shown here seem to indicate that the response saturated quickly with increasing laser pulse energy. We assume that these ASETs bound the heavy ion response of the device.

Based on the pulsed laser test results, the Mini-Circuits RAM-3+ is recommended for use in NASA/GSFC spaceflight applications, but may require transient mitigation (*i.e.*, filtering) techniques to reduce the effect of ion-generated transients.

7. References

[1] Melinger, J. S.; Buchner, S.; McMorrow, D.; Stapor, W. J.; Weatherford, T. R.; Campbell, A. B.; and Eisen, H., “Critical evaluation of the pulsed laser method for single event effects testing and fundamental studies,” *IEEE Trans. Nucl. Sci.*, vol. 41, no. 6, pp. 2574-2584, Dec. 1994.

[2] McMorrow, D.; Melinger, J. S.; Buchner, S.; Scott, T.; Brown, R. D.; and Haddad, N. F., “Application of a pulsed laser for evaluation and optimization of SEU-hard designs,” *IEEE Trans. Nucl. Sci.*, vol. 47, no. 3, pp. 559-565, Jun. 2000.

[3] Buchner, S.; McMorrow, D.; Sternberg, A.; Massengill, L.; Pease, R. L.; and Maher, M., “Single-event transient (SET) characterization of an LM119 voltage comparator: an approach to SET model validation using a pulsed laser,” *IEEE Trans. Nucl. Sci.*, vol. 49, no. 3, pp. 1502-1508, Jun. 2002.