Mixer Burnout

Previously, mixer damage was measured mainly for a continuous microwave pulse stream. These authors present data obtained with a refined measurement technique that reveals mixer damage for single pulses and the progressive deterioration with successive pulses.

Chance M. Glenn
Robert V. Garver
Harry Diamond Laboratories
Adelphi, Maryland

Most mixer damage measured to date is for a continuous train of pulses. We have devised a method for measuring mixer damage for single pulses and observing the progressive damage for successive pulses [1]. This method has been refined [2], and new data obtained with a large number of 1N23 mixer diode pairs for a range of pulse widths and peak power levels. Pulse widths ranged from 25 nanoseconds to 1 microsecond, and with pulse risetimes below 2 ns.

The dynamic damage properties of 74 pairs of 1N23 X-band mixer diodes have been measured using a train of 30 short pulses at a 1 pulse-per-second (pps) repetition rate. The results showed that a first 30 microjoule pulse caused a 3 dB degradation in mixer conversion loss. The damage of successive 16 microjoule pulses asymptotically caused a further deterioration of an additional 3 dB.

Test Procedure

The refined measurement circuit is shown in Figure 1. The device under test (DUT) is a balanced mixer (diode pair) mounted in X-band waveguide. The local oscillator (LO) is fed directly into the

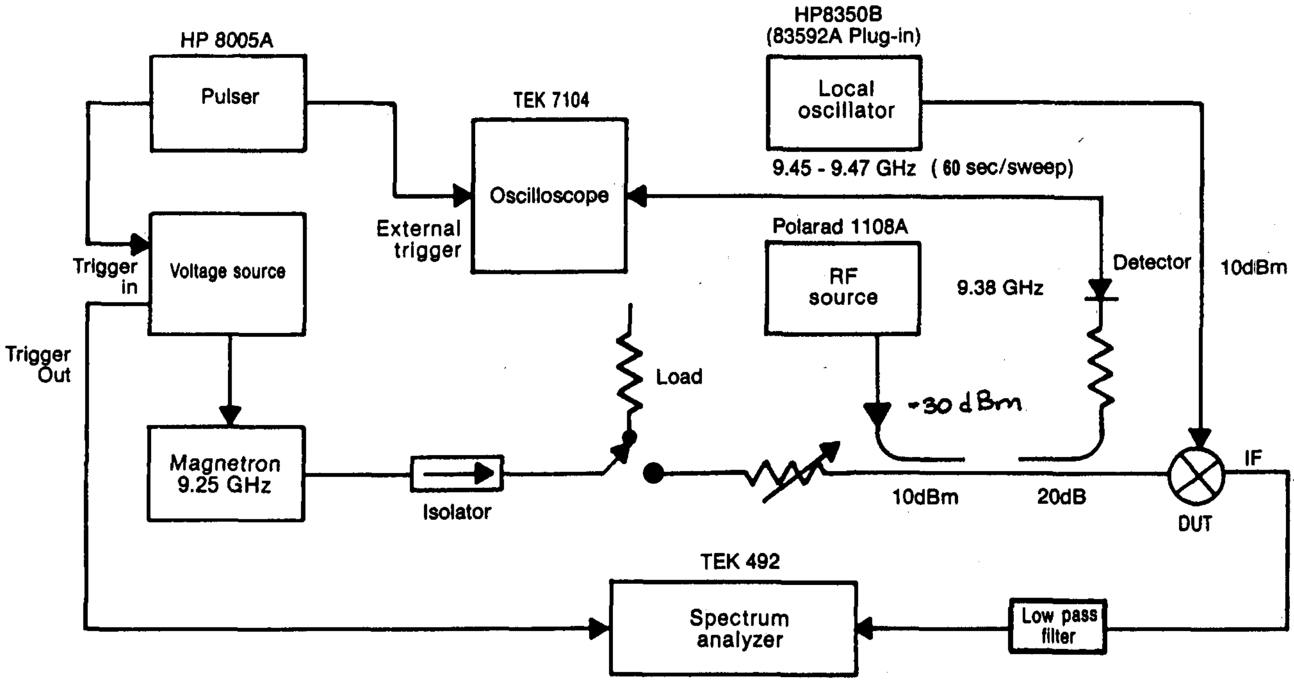

Figure 1. Block diagram of mixer diode damage setup.

mixer while the RF test signal is introduced into the 10 dB arm of a directional coupler. The signal incident on the mixer is at -40 dBm to insure that the mixer is not overdriven.

The intermediate frequency (IF) output of the mixer is fed to a spectrum analyzer. A low-pass filter is placed between the IF output and the spectrum analyzer to prevent transients from the high-power pulses from entering the spectrum analyzer. The frequency of the signal remains fixed while the frequency of the LO is swept so that a 20 MHz sweep is achieved across the display of the spectrum analyzer. The damaging pulses are at 9.25 GHz with adjustable pulse widths and peak power levels.

The spectrum analyzer and high power pulser are synchronized so that one damaging pulse occurs each second, and there is one sweep of the display in the same second. The sweep of the LO is adjusted so that the line for the IF output walks slowly across the screen of the spectrum analyzer, one line with each sweep of the spectrum analyzer.

With the spectrum analyzer in the memory mode, each line is added to the display, giving a picket fence presentation for the successive conversion loss measurements of the mixer. When the conversion loss of the mixer changes, as it does due to deterioration from high power pulses, the display of the spectrum analyzer gives a histogram of the conversion loss. The use of the spectrum analyzer is particularly advantageous in that it displays a wide range of conversion loss values linearly.

The refinement made in the testing procedure consisted of a pulser set at a 1 pps repetition rate to externally trigger the high voltage pulser, the spectrum analyzer and the oscilloscope.

Results

The purpose of the experiment was to measure the damage threshold of mixers when subjected to one or a few RF pulses, a condition wherein the pulses are sufficiently separated in time that the heat from each pulse is dissipated before the arrival of the next pulse. Accordingly, the damage incurred from each pulse is separable from that of any other.

Figure 2 is the spectrum analyzer display obtained when the mixer was subjected to successive 1 microsecond, 1 kW, 9.25 GHz pulses at a repetition rate of 1 pps. In order to establish a reference conversion loss before damage (0 dB), several pulses were applied at power levels below the damaging power level and then the damaging pulses were applied. The progressive degradation during the application of 28 pulses is revealed in Figure 2.

There is a rapid decline in conversion loss. The first pulse caused 18 dB of degradation; the degradation from successive pulses leveled off at greater than 50 dB.

An example of a more gradual degradation is shown in Figure 3. Successive 1 microsecond, 100 W, 9.25 GHz pulses at a repetition rate of 1 pps were applied. The first pulse degraded the conversion loss 9.5 dB. The damage due to subsequent pulses leveled off around 28 dB; however, there

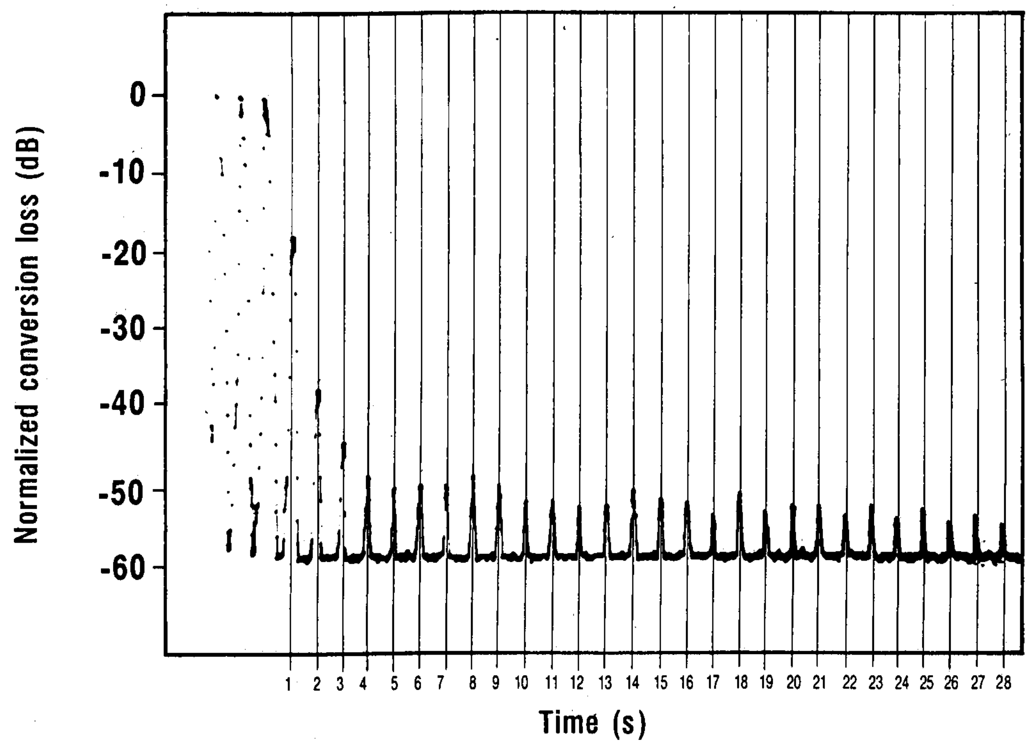

Figure 2. Spectrum analyzer display of mixer response to 1 microsecond, 1 kW, 9.25 GHz pulses.

were fluctuations between degradation and partial recovery. This behavior can be interpreted as partial annealing of the damage. This annealing phenomenon appeared in many of the responses.

Two mechanisms may explain the degradation pattern with its annealing (improvement or healing) phenomenon. The first explanation is that the first pulse heats up the very tiny volume of the junction to a high enough temperature that impurities are moved, degrading the properties of the junction. At the next pulse the volume absorbing the heat is larger because the damage has caused the active area to be enlarged (as well as degraded). Spreading the energy of the pulse over a larger volume causes a smaller temperature rise which may be amenable to annealing. Consequently the next pulse can cause annealing to take place in the junction. Depending on how much healing has taken place, subsequent pulses either can cause even more annealing or revert again to degradation.

The second mechanism by which an improvement might be explained derives from the practical fact that diodes are manufactured with a diode contact whisker under spring tension, essentially resting on three points of the semiconductor. When it is damaged, one of thee points becomes soft enough to yield, and three new points are defined for the contact. With each new pulse, new points are defined, giving a random but slowly degrading conversion loss, which finally settles into a structure based on the local metallurgy surrounding the whisker point.

The resulting pictures from the spectrum analyzer (such as Figures 2 and 3) were used to analyze the data. Plots of damage differentials versus the number of pulses were created to identify trends in the damage profiles. Figure 4 is an example of such a plot. This plot corresponds to the damage profile in Figure 2. As shown, there are large increments of damage for the first few pulses.

Data points below zero correspond to annealing, while positive ones correspond to damage. Note that the annealing and damage stop after many pulses. There are primarily two points of interest in each set of data: the magnitude of damage from the first pulse and the plateau for damage from many pulses.

A summary of the first pulse damage profiles is shown in Figure 5. A plot of peak power versus first pulse damage was made for each pulse length, and

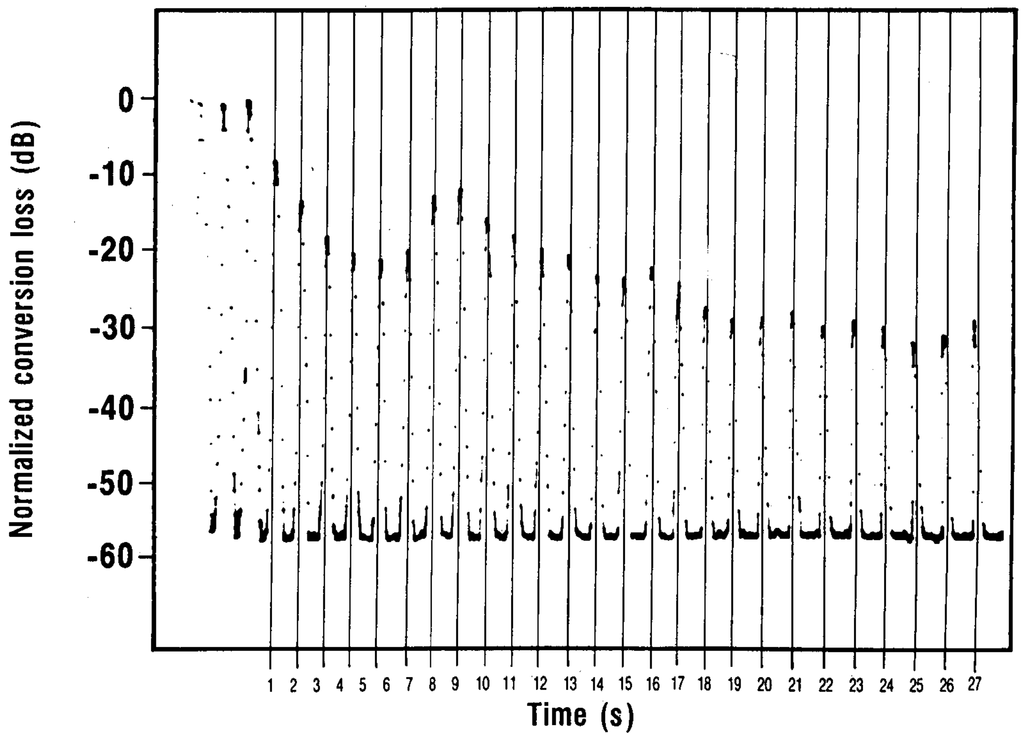

Figure 3. Spectrum analyzer display of mixer response to 1 us, 100 W, 9.25 GHz pulses.

the points for 3 dB, 5 dB, and so forth were interpolated from them. These curves were then combined to yield the parametric set of curves shown in Figure 5, giving a total picture of first pulse damage.

All of the damage points measured are shown. A 45 degree slope in the pulse width damage profile corresponds to constant energy damage, which was observable with all of the sets of data. The constant energy property for short-length pulses is due to uniform heating of the junction under adiabatic conditions, that is under conditions for which the pulse is too short for any appreciable amount of

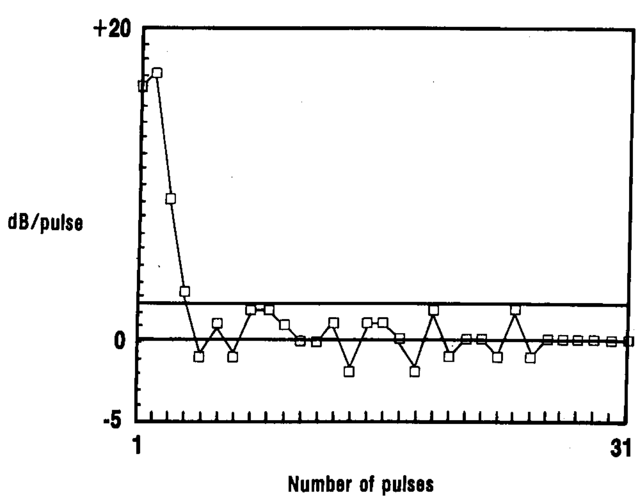

Figure 4. Damage differential versus the number of pulses for 1 us, 1 kW, 9.25 GHz pulse response.

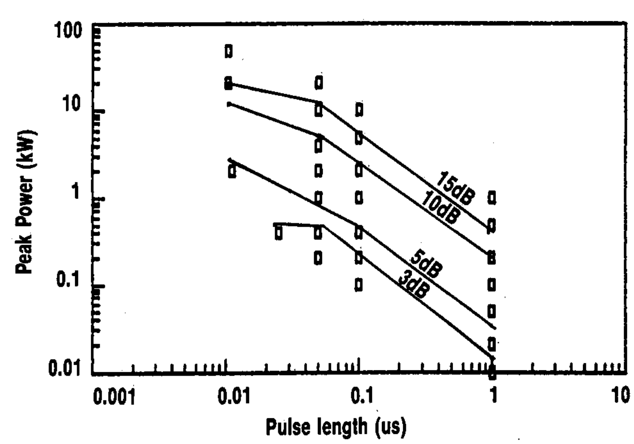

Figure 5. First pulse damage profile (power versus pulse length).

heat to flow away from the junction during the pulse. Note that the 3 dB line became horizontal at 400 W for very short pulses. Not enough data has been collected yet to make any significant conclusions about this trend. The energies for first pulse damage are given in Table 1. No first pulse damage above 20 dB was observed.

CONVERSION LOSS DEGRADATION (dB)	ENERGY FOR FIRST PULSE DAMAGE (uJ)	ENERGY FOR FINAL DAMAGE AT 1 uS (uJ)
3	16	12
5	31	21
10	210	36
15	420	54
20	850	80
30	-	200
40	-	350

Table 1. Summary of mixer degradation

Figure 6 is a summary of the final damage profiles. As in Figure 5, all of the damage pulses observed are shown. The general trend in the final damage data also suggests energy dependence of failure, except at 10 dB degradation and the longer pulse range for 20 dB degradation. The inverse square root slope with temperature suggests a linear heat flow path and intermediate time constants. This is termed the Wunsch-Bell characteristic. Very long pulses give constant power, and very short pulses give constant energy. Intermediate length pulses give damage power, P, proportional to inverse square root of temperature, T, characteristics. There is 1 second between each mixer damage pulse, and the entire experiment takes 30 seconds. There does not appear to be good cause for the inverse square root of temperature performance other than a gradual transition from constant power to constant energy.

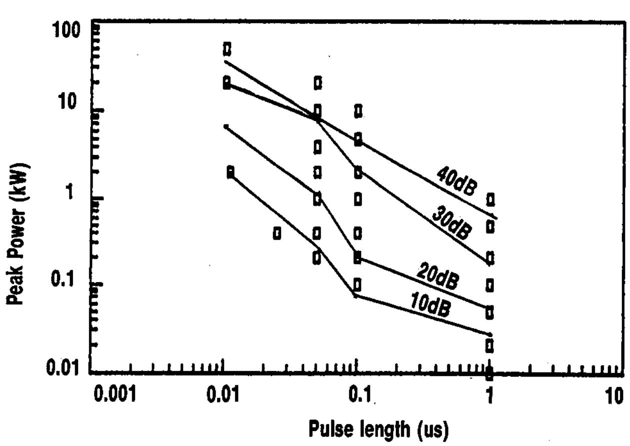

Figure 6. Final damage profile (power versus pulse length).

Conclusion

Conversion loss degradation of mixer diodes caused by single or multiple microwave pulses can be measured effectively by the methods outlined. Two trends in the degradation of the mixers were observed. The first was that there was an initial damage slope that was either steep or gradual depending on the energy of the damage pulse. The damage slope determines how fast degradation occurs with respect to the number of pulses. The second trend was the leveling off of the degradation.

Only one occurrence of constant power damage for very short pulses was observed in this experiment. More experiments could be conducted with pulses shorter than 20 nanoseconds to determine whether this lower energy realm is of any importance. A leveling off of the damage curves is expected.

References

1. R. Garver, C. Fazi, and H. Bruns, "Dynamic Diode Mixer Damage Measurements," 1985 IEEE MTTS International Microwave Symposium Digest, May 1985, pp. 535-536.
2. C. M. Glenn and R. V. Garver, "Trends in Mixer Damage," 1989 IEEE MTT-S International Microwave Symposium Digest, June 1989, pp. 475-477.

Chance M. Glenn *joined Harry Diamond Fuze Laboratories in 1986. Since then has been concentrating on computer controlled microwave experiments.*

Currently, he is also an undergraduate in Electrical Engineering at the University of Maryland.

Robert V. Garver *was with the Harry Diamond Fuze Laboratories from 1956 to 1989. He has broad experience with semiconductor switches, limiters and phase shifters.*

He is the author of a reference text Microwave Diode Control Devices, *published by Artech House, Norwood, Massachusetts.*

He is currently an active consultant in microwave device engineering and production at the Garver Product Company, Boyds, Maryland.