AN565
APPLICATION NOTE

MEDIAN-TIME-TO-FAILURE (MTF) OF AN L-BAND POWER TRANSISTOR UNDER RF CONDITIONS

W. E. Poole - L. G. Walshak

1. INTRODUCTION.[1]

At last year's Symposium (1973), two papers presented preliminary data from the *first* known comprehensive life-tests on any microwave power transistor operated *under RF conditions*. This paper will report the latest findings of RF life-testing on two 30-watt L-band power transistors reported by the author last year. The preliminary purpose of this work is to determine the median-time-to-failure (MTF) of the MSC-1330/A and a higher efficiency version known as the MSC-1330/B, under the actual RF conditions used in the several solid-state phased array radar systems under development which use these devices. A second objective is to identify the failure mode(s) and failure mechanism(s) with the goal of improving device reliability by possible design modifications.

With the field history of microwave power transistors less than 10 years, the true long-term reliability of this class of devices is unknown. In the meantime, reliability predictions must be made on the basis of accelerated life-tests. In the past, however, accelerated life-tests have been run only under DC operating or high temperature reverse bias conditions. Unfortunately, the relationship between these DC tests and the real-world of RF operation has never been determined -- if indeed it even exists.

2. TEST PROGRAM.

The MTF of the two L-band test devices are measured under two pulse conditions and under worse case system conditions:

Frequency	=	1.4GHz
Pulse width / Duty Factor	=	120µs/30%
		1500µs/15%
Collector Voltage	=	28VDC

To determine the MTF for each pulse condition within a reasonable length of time, life-tests were run under the RF conditions using elevated device junction temperature (Tj) as the accelerating factor. The test matrix consists of a total of nine (9) separate tests. For the MSC-1330/A device, the MTF was measured under two (2) pulse conditions and at three (3) junction temperatures each. The MTF of the MSC-1330/B was determined for one (1) pulse condition at three (3) junction temperatures.

1. This paper was presented at the 12th Annual IEEE Reliability Physics Symposium April 1974

Specifically, the test matrix used is as in table 1.

Table 1: Test Condition Matrix

TEST	DEVICE	RF PULSE	JUNCTION TEMPERATURE
T1	MSC-1330/A	120µs/30%	340°C
T2	MSC-1330/A	120µs/30%	280°C
T3	MSC-1330/A	120µs/30%	250°C
T4	MSC-1330/A	1500µs/15%	340°C
T5	MSC-1330/A	1500µs/15%	280°C
T6	MSC-1330/A	1500µs/15%	250°C
T7	MSC-1330/B	120µs/30%	340°C
T8	MSC-1330/B	120µs/30%	280°C
T9	MSC-1330/B	120µs/30%	250°C

Thus, for each pulse condition and each device type, the measured MTF at three (3) values of Tj can then be plotted as a log-Normal function of reciprocal temperature, 1/Tj(°K). The straight line drawn through these points (the so-called Arrhenius curve) can then be extrapolated to the lower junction temperatures found under actual operating RF conditions and thus, predict the MTF at normal Tj. Since normal operating Tj falls into the ranges 75-100°C, extrapolation down from the 250°-340°C range used in these tests involves definite risks -- namely, the possibility that failure mechanism(s) and failure rates produced at elevated Tj may not be the same as those at normal Tj. On the other hand, the elevated Tj tests used in this matrix has given first order MTF data in a minimum length of time and early enough to be useful in system planning and design.

Each test consists of from 8-11 devices for a total sample size of 81. Although a larger sample is obviously desirable, the cost and complexity of RF testing forces this compromise. It is for this very reason, in fact, that extensive, RF life-testing has not been attempted in the past. However, this sample size should be adequate for at least a first order MTF approximation.

The mechanics of setting-up the various accelerated tests at elevated Tj are relatively complex. For example, before any one of the tests can be run, some reliable means of forcing each device to have the desired maximum Tj value must be found. In the specific case of T1, external heating of the device must be used to artificially raise Tj from its normal value of ~100°C to 340°C. To do this, the specially designed RF life-test racks incorporate a heated block beneath each test amplifier. The entire test circuit is heated up to a maximum of 175°C and device dissipation must then raise Tj to the desired value of T1=340°C.

The actual determination of device junction temperature can not be left to calculated values based on nominal thermal resistance values. Instead, each device is tuned-up on the bench under the exact test conditions in its own particular test amplifier and Tj is measured directly using an Infrared microscope. After suitable calibration, the IR microscope can give instantaneous Tj as a function of time during the RF pulse. Thus, each device is tuned-up and the peak Tj during the pulse is set equal to the desired value of Tj (i.e. T1=340°C, T2=280°C, etc.) by minor circuit adjustment. In this way, each device test is accurately known to be operating at the desired Tj value. Without such a direct measurement, the variation of Tj between devices would seriously affect the data since MTF is a strong function of Tj.

Following IR scanning, each device can then be hermetically sealed and proceed to process conditioning to weed-out infant mortalities. This condition consists of:

- Visual pellet inspection;
- High temperature storage (non-operating) 200°C (168 hours);
- Temperature cycling -65°C to +200°C (10 cycles);
- Hermeticity test, Fine and Gross (10^{-8}cc/sec);
- RF burn-in (pulsed) Tj=175°C 1500µs/15% duty (168 hours);
- DC test.

3. TEST RESULTS.

At this time, seven (7) of the nine (9) programmed tests are complete with the remaining two (2) tests (T4 and T6) in progress. Analysis of this data allows the following conclusions to be drawn:

1) The extrapolated MTF of the MSC-1330/A and MSC-1330/B is *of the order of 10^6 hours or 100 years* at normal operating Tj under pulsed RF conditions with duty factors approximately 30%.

2) The first order MTF of these devices is *inversely* related to the RF pulse *duty factor* i.e. MTF is inversely related to the time that the device is “on”. MTF α $(DF)^{-1}$.

3) The MTF is a function of pulse width -- the MTF decreasing with increasing pulse width. Over the range 120-2000µs, this decrease is typically 50%.

4) MTF is also a weak function of the total temperature rise during the pulse, ΔTj. For typical values of ΔTj, MTF can vary by 10-40%.

These results are based upon analysis of the following test data:

3.1 Short Pulse Tests (120µs/30%).

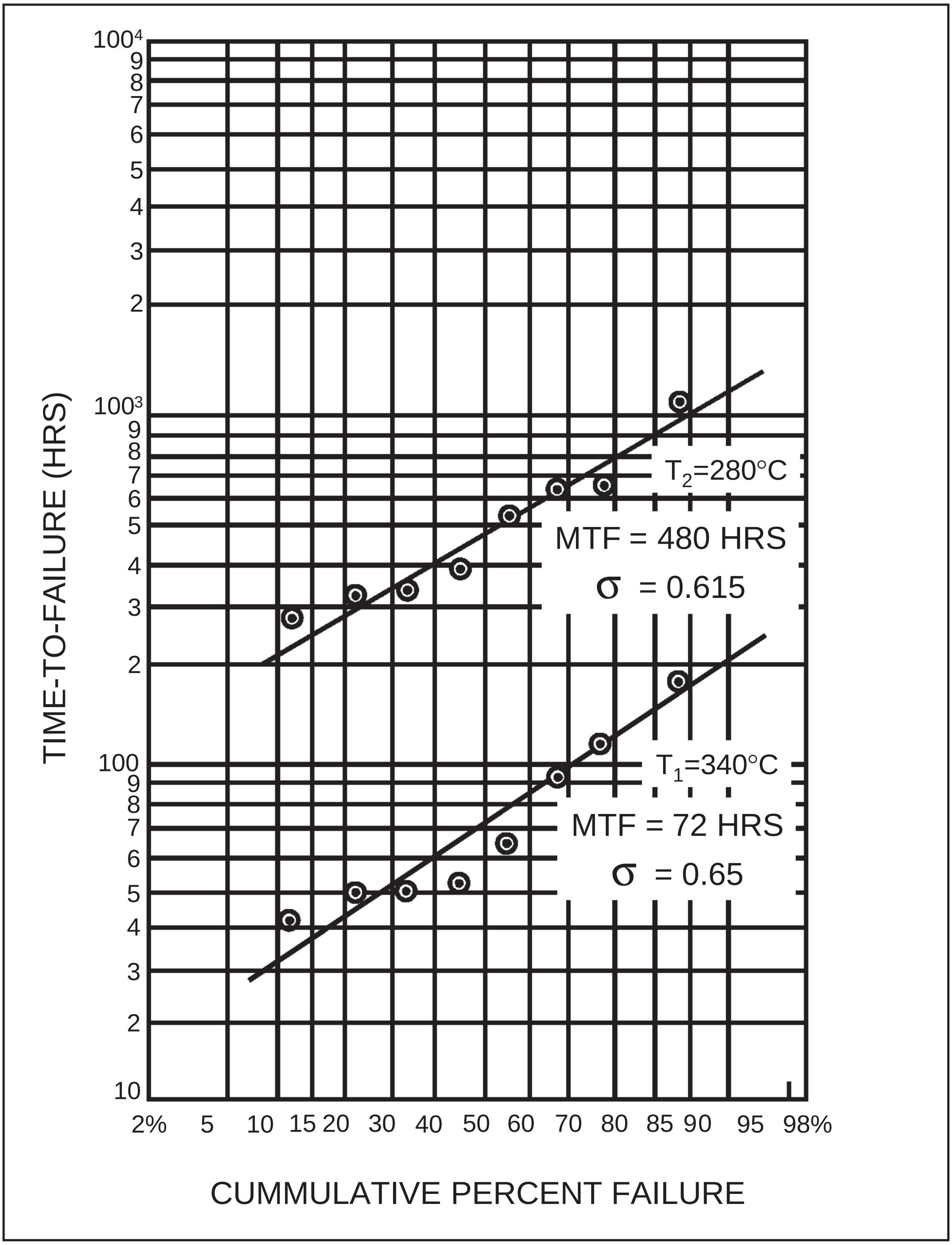
Short pulse test on the MSC-1330/A (T1, T2, T3), each with a sample size of eight (8) devices, were run with elevated Tj=340°C, 280°C, and 250°C respectively. In each test, devices were run until “failure”. Failure was arbitrarily defined as the point at which output power dropped to one-half its original value (-3dB). To determine the MTF for each Tj value, the failure distribution was plotted, as in the example of T1 and T2 in figure 1, and the MTF value read-off as the time corresponding to 50% cumulative failure. Note also that the straight line relationship between time-to-failure and cumulative percent failure implies a log-Normal failure distribution, characteristic of wear-out mechanisms.

Along with similar log-Normal plot for test T3, the measured MTF of the three (3) short pulse tests on the MSC-1330/A devices are shown in table 2.

Table 2: MTF Results of the 3 Short Pulse Test on MSC-1330/A Devices

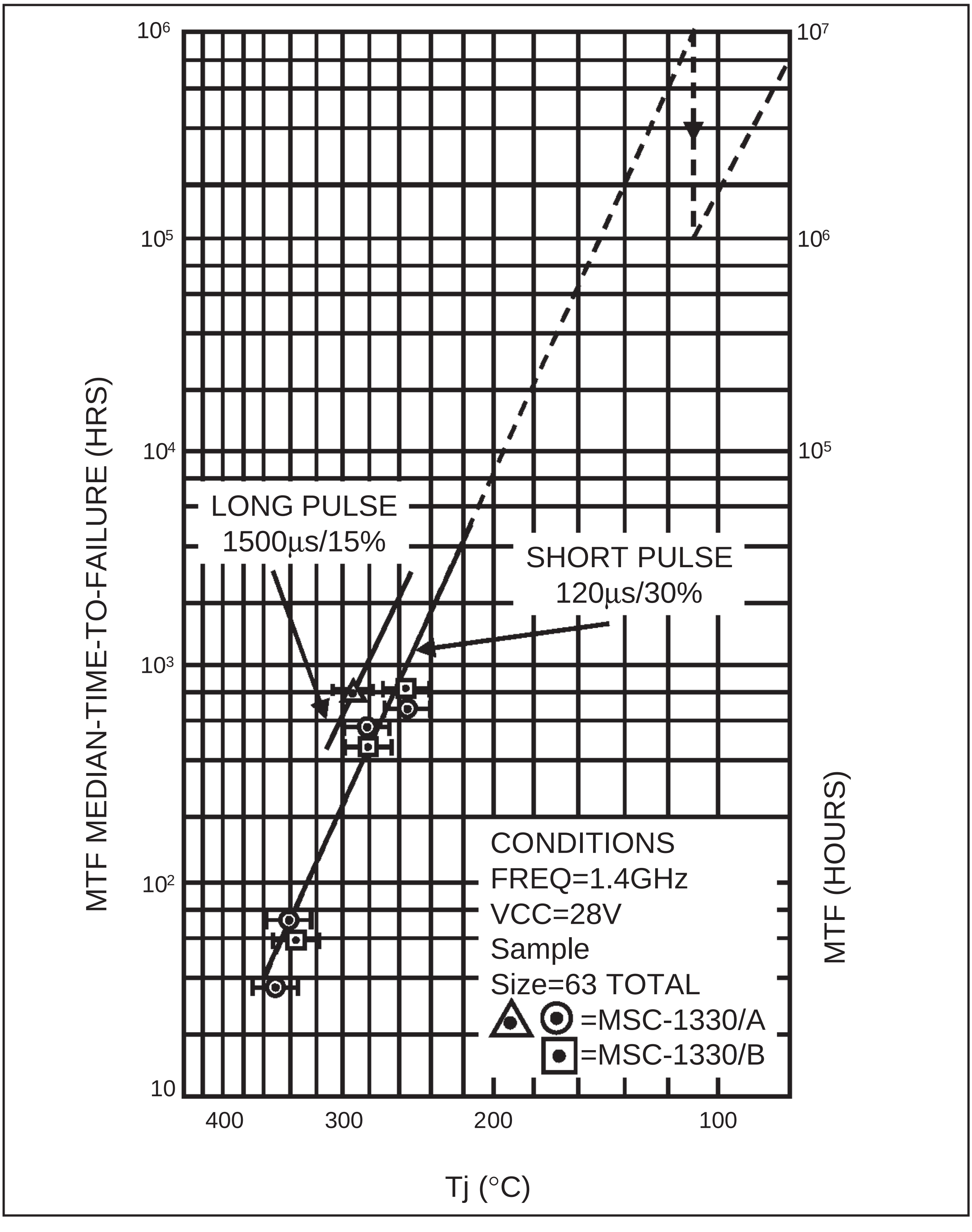
TEST	DEVICE	RF PULSE	Tj	MTF (-3dB)
T1	MSC-1330/A	120µs/30%	340°C	72 hrs
T2	MSC-1330/A	120µs/30%	280°C	480 hrs
T3	MSC-1330/A	120µs/30%	250°C	660 hrs

Figure 1: Failure Distribution: Test T1 and T2



Having thus determined the MTF at three (3) elevated Tj values, MTF is then plotted as a function of 1/Tj (°K) on log-Normal coordinates as shown in figure 2. Note temperature scale in °C.

Figure 2: Median-Time-To-Failure vs. Peak Junction Temperature



Similar tests on the MSC-1330/B device were also conducted under the same 120µs/30% pulse conditions and Tj. These three (3) tests (T7, T8, T9) also resulted in log-Normal failure distributions with measured MTF shown in table 3.

Table 3: MTF Results of the 3 Short Pulse Test on MSC-1330/B Devices

TEST	DEVICE	RF PULSE	Tj	MTF (-3dB)
T7	MSC-1330/B	120µs/30%	340°C	53 hrs
T8	MSC-1330/B	120µs/30%	280°C	450 hrs
T9	MSC-1330/B	120µs/30%	250°C	820 hrs

Plotting these three (3) data points on the MTF vs. 1/Tj curve figure 2, we find that these points essentially coincide with those found for the MSC-1330/A. So, to a first approximation a single straight-line can be drawn through all six (6) points. Note, however, that although the MTF vs. 1/Tj curve for the MSC-1330/B is essentially identical to that of the MSC-1330/A, the reliability of the MSC-1330/B device is actually *4 times higher* at normal operating conditions. This results from the fact that the maximum value of Tj for the MSC-1330/B is typically *20° lower* than the MSC-1330/A as a result of its higher collector efficiency.

With this set of data, we can now make first order predictions of the MTF of these devices at normal operating condition where Tj≈75-100°C (depending on duty factor, efficiency, heatsink temperature, etc.). Referring to figure 2, we find that at Tj≈75-100°C the MTF under 120µs/30% duty is of the order of *10^6 hours or 100 years*. Of course, extrapolation of this sort involves definite risks as mentioned earlier. However, at this point there is simply no practical alternative for generating this kind of essential data short of putting the devices in the field and waiting a few hundred years. [To the best knowledge of the authors, the longest field application of microwave transistors in sizeable quantities are the approximately 900 MSC-3003 -- 3W/3GHz devices -- which have run without device failure under conditions CW operating for greater than three (3) years (24 million unit-hours). An additional 3,000 of these devices have also run greater than two (2) years without failure (54 million unit-hours)].

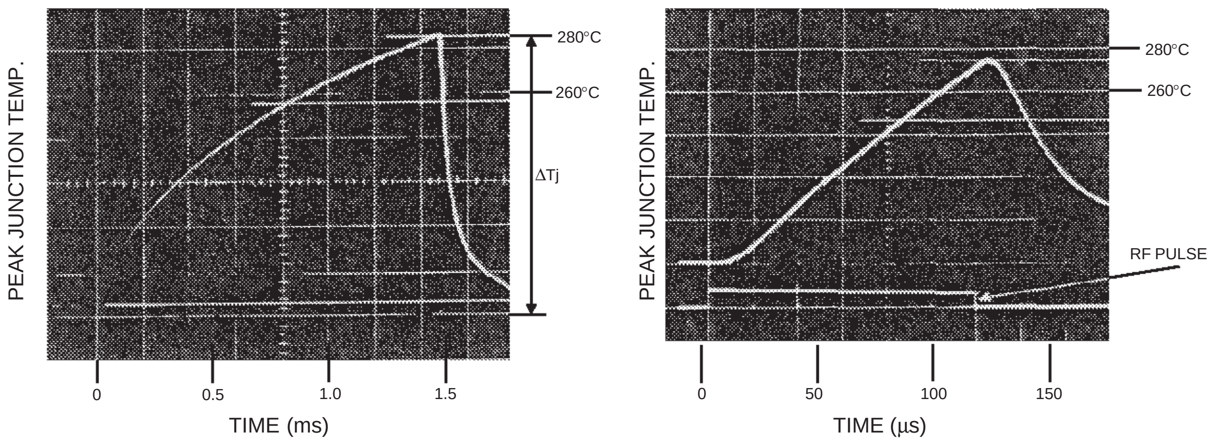
3.2 Long Pulse Tests (1500µs/15%).

Three (3) long pulse tests (T4, T5, T6) using the MSC-1330/A were included in the original test matrix to evaluate the effect of pulse width on device MTF. To give direct comparison with the short pulse tests, T4, T5 and T6 are run at the same time Tj as the three (3) short pulse test series (T1, T2, T3) i.e. Tj=340°C, 280°C and 250°C respectively. At this point, the 280°C test, T5, is complete with T4 and T6 in progress.

The log-Normal failure distribution of T5 gave a measured MTF of 1100 hours. By comparison, test T2 with the same device at the same Tj (280°C) but under short pulse operation had a MTF of only 480 hours. At first thought this roughly two (2) times higher MTF for the long pulse case appears to be contrary to normal expectation. However, further thought will recall that the pulse duty factor for the long pulse was only 15%, while for the short pulse duty factor was 30%. Or, in other words, although the device sees greater stress *during* the long pulse, the total stress for the short pulse case is greater simply because the device is “on” twice as long as the long pulse case. This follows directly from the 30% duty factor for the short pulse vs. the 15% duty factor for the long pulse case.

This argument can be seen more quantitatively from the following analysis of the actual time spent at or near the peak Tj during both pulse conditions. Figure 3a and 3b show the measured transient Tj vs. time during both the long and short pulse peak Tj of 280°C in both cases. Assuming the device failure mechanism is a relatively strong function of temperature, its rate of reaction at the higher values of Tj during the pulse must be significantly greater than the rate at lower Tj. For example, referring to the MTF vs. 1/Tj data of figure 2, we see that the difference in MTF between Tj = 280°C and Tj = 260°C is about a factor of 2. Thus, to a first approximation, assume that the net effect during the time 260°C ≤ Tj ≤ 280°C is significantly greater than the net effect during the time Tj ≤ 260°C.

Figure 3: Peak Junction Temperature vs. Time



a) T5 – LONG PULSE (1500µs / 15%)

b) T2 –SHORT PULSE (120µs / 30%)

As shown in figure 3a and 3b 260°C≤ Tj ≤ 280°C for 646µs during each long (1500µs) pulse and 54.4µs during each short (120µs) pulse. Since the given duty factor is 15% for the long pulse and 30% for the short pulse case, there are 100 long pulses/second and 2500 short pulses/second respectively. Consequently, 260°C ≤ Tj ≤ 280°C only 6.46% of the time under long pulse and 13.62% of the time for short pulse.Thus, the ratio of the times during which 260°C ≤ Tj ≤ 280°C is 13.62 / 6.46 = 2.1. Or, the time during which “significant stress” is seen by the device during the short pulse case is 2.1 times longer than that experienced under the long pulse case. The ratio is within 10% of the ratio of actual measured MTF for these two cases:

$$\frac{MTF(T5)\ long\ pulse}{MTF(T2)\ short\ pulse} = \frac{1100hrs}{480hrs} = 2.3$$

Similar agreement is seen with the assumption of larger and smaller values of the significant Tj range as seen in table 4.

Table 4: Short/Long Pulse MTF Ratio for Different Tj Ranges

Tj Range	Time Within Tj Range Per pulse		% Time Within Tj Range		Ratio B/A	% Difference from Measured MTF Ratio
	Long Pulse	Short Pulse	A Long Pulse	B Short Pulse		
270-280°C	373µs	34.5µs	3.73%	8.62%	2.31	1.3
265-280°C	537µs	45.0µs	5.37%	11.20%	2.09	12
260-280°C	646µs	54.5µs	6.46%	13.62%	2.11	11
255-280°C	740µs	65.5µs	7.40%	16.37%	2.21	6

4. MTF CALCULATIONS.

As stated earlier, the primary objective of this work is to determine the MTF of the MSC-1330/A and MSC-1330/B transistors under actual RF operating conditions. If these conditions are at either the 120µs/30% or 1500µs/15% pulse conditions used in these life-tests, MTF calculations for normal operations reduce simply to extrapolation of the MTF vs. 1/Tj curve generated at elevated Tj values down to the Tj value under normal conditions. However, in general, it would be preferable to be able to extrapolate the measured MTF data to *any* pulse duty factor or pulse width. With this goal in mind, a separate series of tests were run to determine the relationship between MTF, duty factor and pulse width. As a result of these tests and the original series of nine (9) tests, the following parameters (shown in table 5) were found to be most significant in determining MTF (in decreasing order of importance).

Table 5: Major Parameters Effecting MTF

PARAMETER	RELATIONSHIP	TYPICAL MAGNITUDE
1. Junction temperature	MTF α Exp (Ø / kTj)	< 200X
2. Duty factor	MTF α 1/DF	< 30X
3. Pulse width	MTF α 1/PW	< 2X
4. ΔTj during pulse	MTF α ΔTj	< 1.4X

The specific relationship of each of the above parameters is as follows:

4.1 MTF vs. Tj.

Test T1, T2, T3 along with T7, T8, T9 give MTF vs. 1/Tj for the MSC-1330/A and MSC-1330/B by measuring MTF at three (3) different values of Tj for a given pulse width and duty. Thus, to predict the MTF of these devices at any other value of Tj for the same pulse width and duty, simply project the straight line drawn between the data down to the desired Tj as shown in figure 2 and read-off the corresponding MTF from the graph. Mathematically, this relationship can be expressed in the form:

MTF = C exp (Ø / kTj)
where MTF = median-time-to-failure (hrs)
C = constant (empirically derived)
Ø = activation energy for the mechanism(s) (eV)
k = Boltzman's constant
Tj = junction temperature (°K)

In this case: MTF = 2.425 x 10^{-5} (0.7875/kTj)

4.2 MTF vs. Pulse Duty Factor.

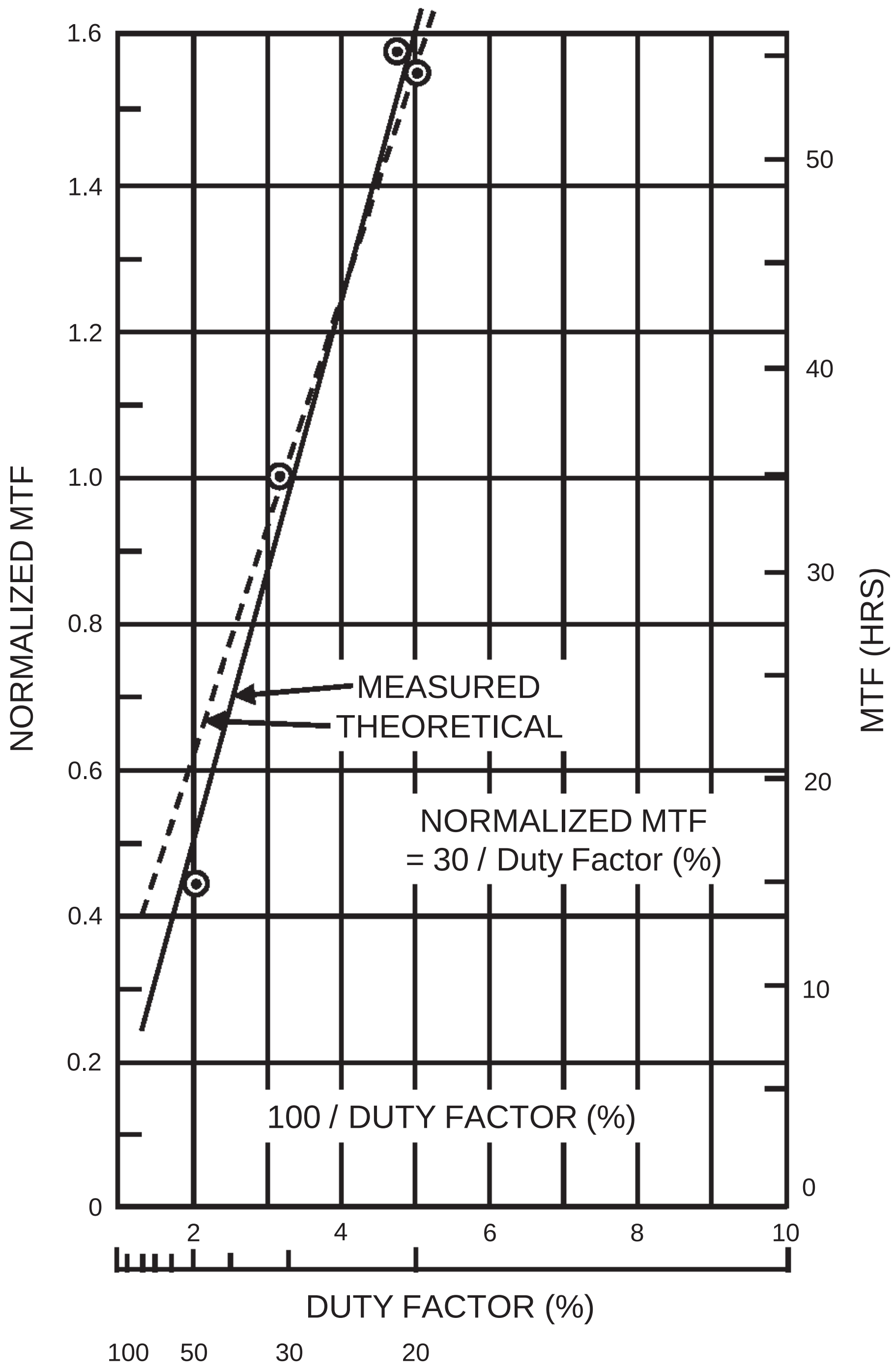
It was shown earlier that MTF was inversely proportional to the device "on" time. Similarly, it has also been shown experimentally that MTF is inversely proportional to pulse duty factor. In separate tests, a series of devices were life tested with the various duty factors but with Tj and pulse width constant (Tj=360°C, PW=120µs).

As shown in figure 4, the measured MTF of these devices plotted as a function of 1/DF shows a straight-line relationship. Normalizing the measured MTF to that under 30% duty:

$$\text{Normalized } MTF = \frac{30}{DF} \text{ (\%)}$$

Thus, the MTF of a device operated at 15% duty has approximately two times the MTF of one operated at 30% duty (all other parameters being equal) simply because the “on” time is one-half.

Figure 4: Median-Time-To-Failure vs. Pulse Duty Factor



4.3 MTF vs. Pulse Width.

To fully evaluate the MTF vs. pulse width relationship, one approach would be to place a minimal sample of devices on life test at various pulse widths and determine their MTF as done in the original nine-part test matrix. However, a simpler and considerably less time consuming approach was used which is based upon the experimentally confirmed relationship between MTF and device “on” time as illustrated in figures 3a and 3b as well as in the MTF vs. duty factor experiments. A series of devices were run at six different pulse widths between 120µs and 2000µs with Tj and ΔTj held constant. Note, Tj=280°C (peak) and ΔTj=115°C where ΔTj is defined as the total junction temperature rise during the RF pulse. At each pulse width, the transient Tj during the pulse was carefully measured using the IR microscope. Then, using the same technique used in explaining the two times higher MTF of the long pulse test, T5, the “on” time or time within an arbitrary 20°C of Tj (peak) for each pulse width is computed. Let this “on” time *within* the pulse be expressed as some fraction of the pulse width:

$$t = \frac{\text{“on” time during pulse}}{\text{pulse width}}$$

Since the number of pulses per unit time is DF/PW, the total “on” time per second is:

$$t(TOTAL) = \frac{DF}{PW}(t)(PW) = DF(t)$$

For any given pulse width, the MTF is inversely proportional to the total “on” time:

$$MTF \propto \frac{1}{t(TOTAL)}$$

Consequently, the ratio of MTF between any given pulse width PW_1 and PW_2 must be given by:

$$\frac{(MTF)_1}{(MTF)_2} = \frac{t_2(TOTAL)}{t_1(TOTAL)} = \frac{(DF)_2 \times t_2}{(DF)_1 \times t_1}$$

and for the case of constant duty factor ($DF_1=DF_2$):

$$\frac{(MTF)_1}{(MTF)_2} = \frac{t_2}{t_1}$$

That is, at constant duty factor, the ratio of MTF between any two pulse widths is simply the ratio of their fractional “on” times.

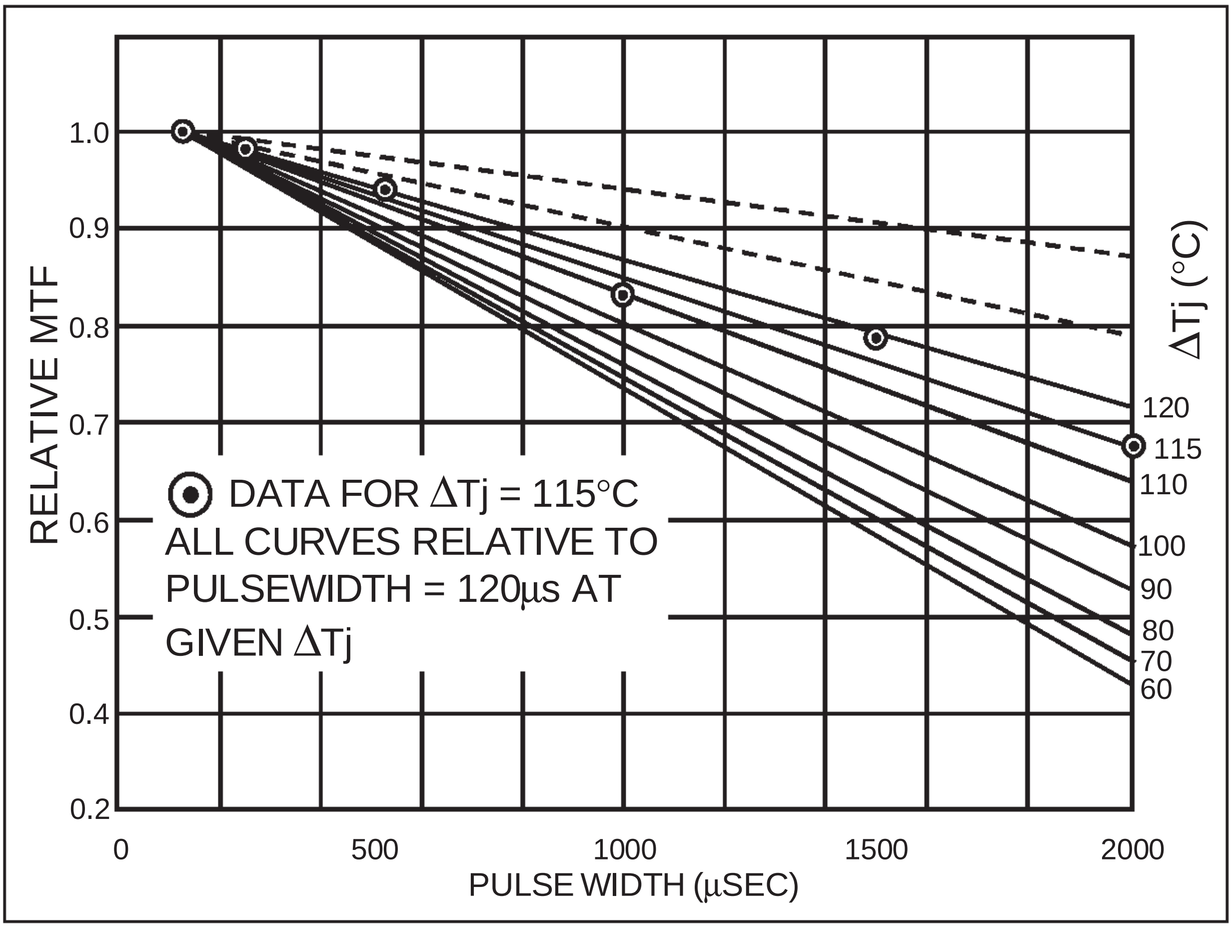
Thus, the relative MTF between the six different pulse widths of this experiment can be calculated by measuring the fraction of the time within each pulse when 260°C ≤ Tj ≤ 280°C and computing the ratio given above. Doing so for pulse widths of 120µs, 250µs, 500µs, 1000µs, 1500µs, and 2000µs, the following values are found in table 6.

Table 6: MTF vs. Pulse Width

Pulse width (µs)	“ON” time per pulse (µs)	t (%)	Normalized MTF
120	46	38.3	1.00
250	98	39.2	0.98
500	204	40.8	0.94
1000	465	46.5	0.82
1500	732	48.8	0.79
2000	1155	57.8	0.66
Note: Duty factor = 10% and ΔTj = 115°C			

This relationship is also presented graphically in figure 5 along with parametric values of ΔTj. The relationship of MTF vs. ΔTj will be discussed in the following section. In any case, we note from figure 5 that as pulse width increases, normalized MTF decreases (all other parameters being equal). Although not as significant a factor as duty factor, variations in pulse width over the 120µs -- 2ms range can result in a 2:1 change in MTF.

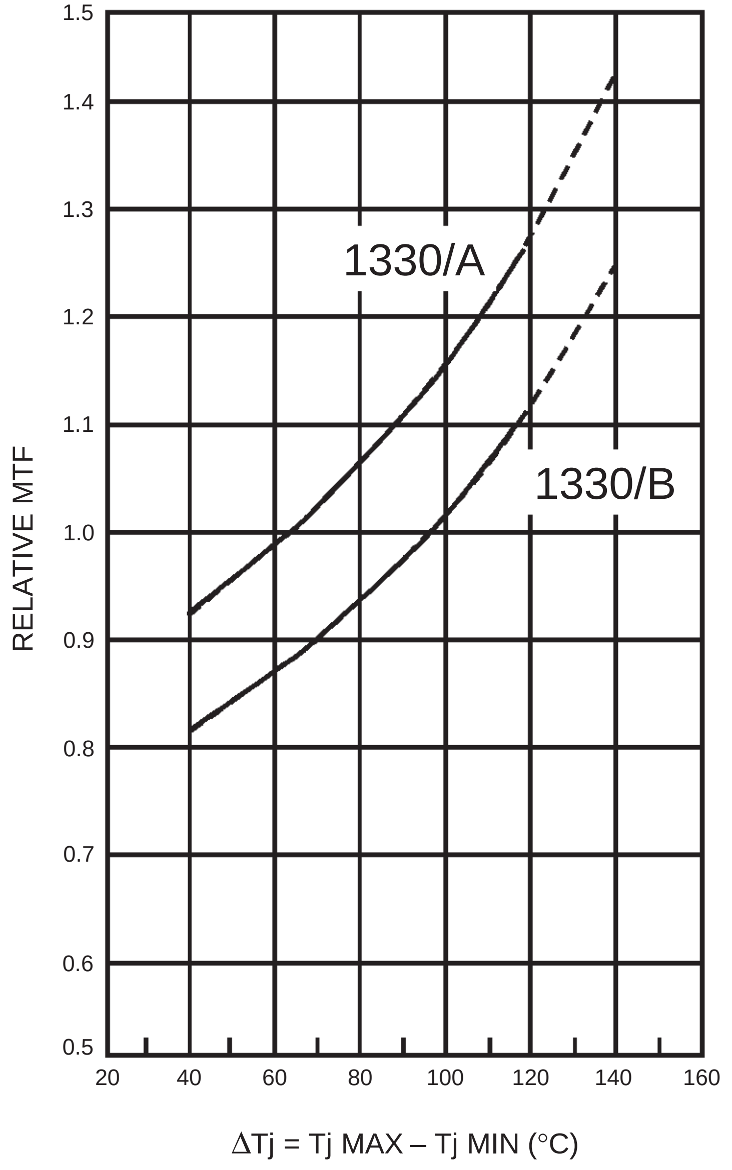
Figure 5: Relative MTF vs. Pulse Width for Different ΔTj During Pulse



4.4 MTF vs. ΔTj.

The fourth and least significant parameter affecting MTF has been found to be the junction temperature rise during the pulse, ΔTj. The relative magnitude of this term has been measured at two pulse widths (120µs & 1500µs) over the ΔTj range 60°C -- 200°C. Again, the technique used to determine relative MTF was to measure the “on” time for each case from the measure transient Tj response during the pusle (using an IR microscope). Normalizing to the MTF at ΔTj=65°C for the MSC-1330/A and ΔTj=95°C for the MSC-1330/B, the relative MTF vs. ΔTj at 120µs pulse width is plotted in figure 6. As seen in this plot, the relative MTF varies by less than 30% -- 40% over the complete ΔTj range. Using the MTF vs. ΔTj data at both 120µs and 1500µs, the effect of ΔTj was included in the MTF vs. Pulse Width curve of figure 5.

Figure 6: Relative MTF vs. ΔTj During Pulse (120µs)



5. SAMPLE MTF CALCULATION.

The above relationships can be used to extrapolate the MTF data for the MSC-1330/A and MSC-1330/B measured under 120µs/30% and 1500µs/15% pulse conditions to any other pulse width and duty factor. Such calculations could be used by system designers to:

1. Make reliability predictions for any given pulse conditions.
2. Evaluate RF performance/reliability trade-offs.

The variation of device reliability with pulse duty factor and pulse width has not been generally considered in system reliability studies up to now.

To illustrate such an extrapolation the following sample calculation will compute the MTF of a MSC-1330/B operating under typical L-band conditions.

1. Given:
Pulse width (PW) = 500ms
Duty factor (DF) = 15%
RF output (Po) = 30W (peak)
RF input (Pin) = 5W (peak)
Efficiency (Eff) = 60%
Peak thermal resistance (θjc) = 2.6°C/W
Case/flange temperature (Tc) = 25°C

2. First determine Tj (max). Measure this directly using IR techniques or calculate:

$$\begin{aligned} Tj(max) &= Tc + \Delta Tj \\ &= Tc + P_{diss}\theta jc \\ &= 25 + 25 \cdot 2.6 = 25 + 65 \\ &= 90°C \end{aligned}$$

3. Referring to the MTF vs. 1/Tj curve of figure 2, the extrapolated MTF of the MSC-1330/B at Tj=90°C~4x10^6 hours. This data, however, is under the 120µs/30% duty life-test conditions with ΔTj=95°C. Thus, this MTF value must be corrected to account for the different pulse duty factor, pulse width, and ΔTj of the given application. Making use of the empirically derived curves described earlier, a scale factor for each of the three term can be determined. Then, the MTF of the given condition relative to the life-test conditions can be computed as follows:

$$\frac{MTF\ (500\mu s\ /\ 15\%\ /\ 65°C)}{MTF\ (120\mu s\ /\ 30\%\ /\ 95°C)} = \left[\frac{DF\ (120\mu s\ /\ 30\%)}{DF\ (500\mu s\ /\ 15\%)}\right] \times \left[\begin{matrix}\text{pulse}\\ \text{width}\\ \text{factor}\end{matrix}\right] \times [\Delta Tj\ \text{Factor}]$$

Where the 65°C and 95°C notation refers to the value of ΔTj.

Computing each term individually:

4.

$$\frac{DF\ (120\mu s\ /\ 30\%)}{DF\ (500\mu s\ /\ 15\%)} = \frac{30}{15} = 2$$

5. Pulse width factor

$$= \frac{MTF(500\mu s/65°C)}{MTF(120\mu s/65°C)} = 0.88 \quad \textit{(from figure 5) at } \Delta Tj = 65°C$$

6. ΔTj Factor

$$= \frac{MTF(120\mu s/65°C)}{MTF(120\mu s/95°C)} = 0.89 \quad \textit{(from Figure 6)}$$

7. Thus,

$$= \frac{MTF\ (500\mu s\ /\ 15\%\ /\ 65°C)}{MTF\ (120\mu s\ /\ 30\%\ /\ 95°C)} = (2)\ (0.88)\ (0.89) = 1.6$$

8. Therefore, the MTF under the actual given conditions at a ΔTj=65°C is 1.6 times the extrapolated value based on life-test conditions and given by figure 2.

Or:

$$MTF\ (500\mu s\ /\ 15\%\ /\ 65°C) = (1.6)\ (4 \times 10^6)\ hrs$$

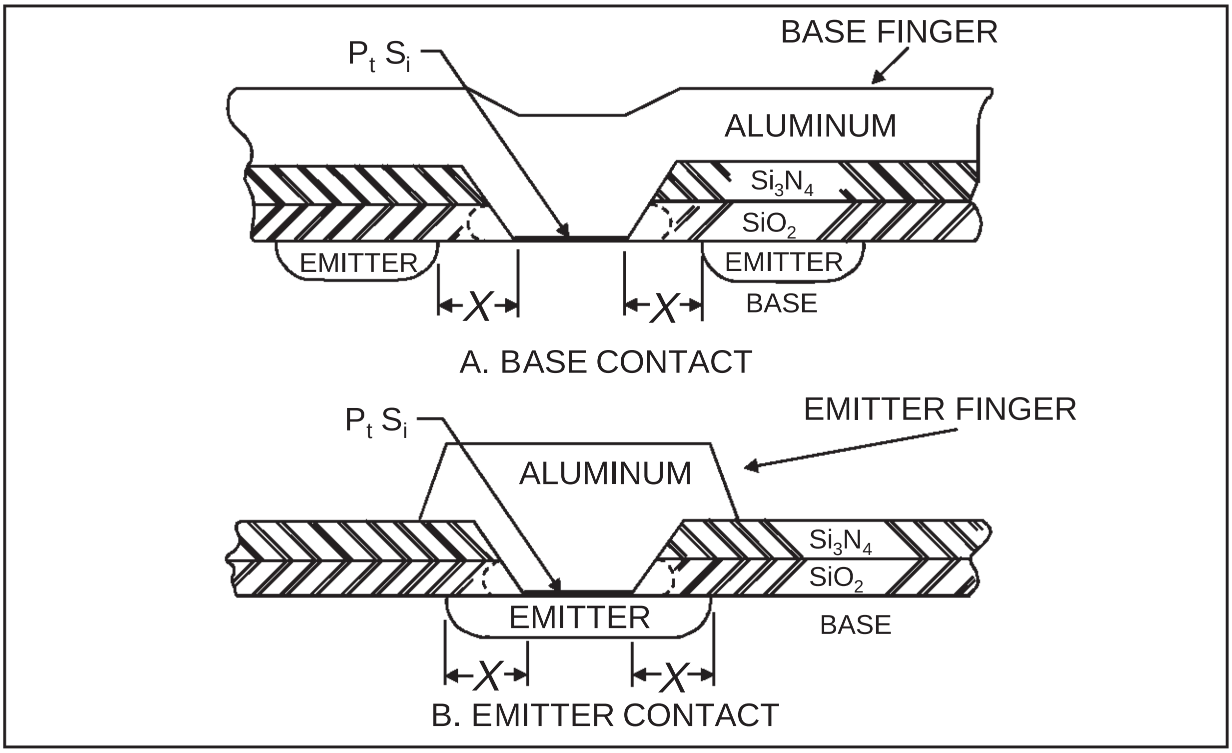
$$MTF\ (500\mu s\ /\ 15\%\ /\ 65°C) = 6.4 \times 10^6\ hrs\ (700\ years)$$

As this sample calculation clearly shows, the reliability of the transistor under pulsed RF is a direct function of many non-device related parameters. As a result, the system designer now has the tools available to evaluate possible design trade-offs between RF pulse conditions and device reliability. Such trade-offs have not been generally considered until now.

6. FAILURE ANALYSIS.

Detailed failure has shown one dominant failure mode for both long and short pulse tests -- degradation or shorting of the emitter-base junction. A possible model to explain this observation has been developed and described in detail in last year’s paper. Consequently, the following will only summarize the basic features of the model.

Figure 7: Cross-sectional View of Base and Emitter Contact Structure



The model developed is based upon scanning electron microscope (SEM), Energy Dispersive X-Ray Analysis (EDAX), and optical analysis of each of the many device dielectric and metal layers. The model explains the localized shorting of the emitter-base junction as the result of the reaction between the aluminum metallization and the silicon dioxide passivating layer in the contact openings as shown in the device cross-sectional view of figure 7. This aluminum -- SiO_2 reaction is accelerated with temperature. As this reaction proceeds, the SiO_2 in contact with the aluminum emitter metal makes a low resistance contact to the base doped area of the device. The low resistance leakage path thus formed, causes a localized current which raises the local temperature which, in turn, reduces the path resistance further in the classic run-away sequence events. As a larger and larger fraction of the device emitter periphery is effectively short-circuited, RF output must decrease until it is only supplying a fraction of its original output power.

This proposed failure mechanism is not new. In fact, such emitter base degradation in the early days of UHF transistors was in large responsible for the development of improved device geometries such as the overlay and matrix designs as well as improved dielectric isolation techniques. In contrast to the matrix structure used in the devices in this test program, early devices used interdigitated geometries with “washed emitters” which gave only about 1/10 the junction protection found in the matrix. In a matrix design, the distance, x, (see figure 7) from the edge of the contact or the metal to the emitter-base junction can be made about 10 times greater than that possible with “washed emitters” where the emitter is diffused through the same contact opening. In that case, the protection, x, is equal only to the amount of lateral emitter diffusion which can be less than 1,000 angstroms in which case, failure often occurs in a matter of minutes at 400°C. Thus, the 10^6 hours (100 years) measured MTF of the MSC-1330 is a direct result of the improved junction protection made possible by the matrix geometry and improved processing.

Similar failure mechanisms exist with other metal systems. Gold, for example, immediately forms an eutectic solution with silicon at approximately 400°C. Consequently, gold metallization must have barrier layers (such as tungsten) between it and the silicon service. Thus, device reliability is determined primary by the integrity of the barrier layer. Preliminary reliability data on gold systems are now being generated particularly at very high temperatures (>300°C). Meaningful comparison, however, will have to wait for the results of longer-term tests at lower temperatures. For example, accelerated life-tests by Pitetti of Bell Laboratories have shown that although gold appears to have improved reliability at very high temperatures, the margin of improvement decreased at lower temperatures and actually reached a cross-over point at about 150°C.

7. CONCLUSION.

Data from the first known comprehensive life-test of a microwave power transistor under RF conditions allows the following conclusions to be drawn:

1. MTF of the MSC-1330/A and the MSC-1330/B L-band devices is of the order of *10^6 hours* of *100 years* under 120µs/30% duty, pulsed RF conditions;

2. MTF is an exponential function of temperature, inverse function of pulse duty factor and pulse width, and a relatively weak function of temperature rise during the pulse;

3. Detailed failure analysis has shown one dominant failure mode -- degradation of the emitter-base junction;

4. Probable failure mechanism is the dissolution of the SiO_2 dielectric layer by the aluminum metallization in the vicinity of the metal contact openings.

AKNOWLEDGEMENT.

This work was partially supported by the Naval Research Laboratory and U.S. Marine Corp. under Contract No. N00014-17-C-0472 under the technical direction of Mr. Brooks Dodson. The contributions of Messrs. B. Dodson, W. Weisenberger of NRL, and P. Kalfus, W. Klatskin, and F. Stallone of Microwave Semiconductor Corp. are gratefully acknowledged.

REFERENCES.

1. W.E. Poole, “Median-Time-To-Failure (MTF) of Microwave Power Transistors Under RF Conditions,” *1973 IEEE Reliability Physics Symposium*, P.287.

2. K. Fisher, “Pulsed RF Life of an L-Band Power Transistor,” *1973 IEEE Reliability Physics Symposium*, P.293.

3. R.C. Pitetti, “Electromigration of Ti/Pd/Au Conductors,” *1972 IEEE Reliability Physics Symposium*, P.171.