UNACCELERATED RELIABILITY TESTING FOR T/R MODULES: NEED, METHODOLOGY AND SUPPORTING DATA

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ABSTRACT

MMIC temperature accelerated test data often does not capture many reliability degradation mechanisms present in transmit/receive (T/R) modules Unaccelerated T/R module reliability testing can be used to help identify these mechanisms. This paper will identify several T/R module degradation mechanisms, a test methodology to obtain the maximum amount of information from unaccelerated test data, and supporting experimental data.

INTRODUCTION/NEED FOR NEW MEASUREMENTS

T/R modules are a critical component for phased array systems. One of the advantages of distributing the transmitter function across an array is graceful performance degradation, as opposed to catastrophic failures which can be associated with a centralized transmitter. T/R module failure mechanisms play an important role in determining an active array's degradation characteristics. MMIC lifetimes derived from temperature-accelerated data are typically used in T/R module reliability predictions to minimize the cost of reliability data collection. These data may not accurately reflect the actual MMIC failure rate, however, due to degradation mechanisms which are not solely dependent upon temperature. Inaccurate module lifetime predictions are also created when bias and/or compression levels, which can both have a strong influence on device lifetime, differ from accelerated test conditions.[1]

Another difficulty in projecting T/R module reliability arises because MMIC output power can reduce gradually during an accelerated life test, and failure is typically defined when a device has lost 1 dB of output power. Several MMICs in series are typically required in a T/R module to generate sufficient transmit amplification. The T/R module transmit failure prediction must then consider the sum of the degradation of each transmit chain MMIC. If the module failure criteria is 1 dB of output power degradation, the individual MMIC failure criteria must be considerably lower than 1 dB. An accurate lifetime prediction would also consider power combining losses due to amplitude and phase imbalances created by soft-degradation mechanisms.

A final issue is that accelerated MMIC failure rates typically do not take into account the different environment created by integration of MMICs into a module. Packaging-related mechanisms, such as hydrogen-induced output power degradation, will not be evident until the MMIC is assembled in its final hermetic housing.[2] Likewise, high VSWR conditions that can lead to higher than anticipated voltage stresses would not be captured by accelerated life tests performed with 50Ω loads.

TESTING METHODOLOGY

For these reasons, there is a strong need to perform reliability tests on the final T/R module assembly in support of failure rate predictions based on individual MMIC lifetime data. T/R module reliability evaluation can not be completed in 100's of hours, however, because epoxy cure and other maximum component temperatures are typically below desired accelerated temperatures. Testing at the highest allowable temperature condition still has utility, however, in evaluating the preceding degradation concerns. Hydrogen poisoning and RF overdrive degradation can be seen without temperature acceleration in 100's of hours of operation.

Operation with a module in its highest output power mode at its highest allowable baseplate temperature will typically create the highest possible MMIC power amplifier junction temperature. This requires a relatively simple test set-up as shown in Figure 1. While this stresses the power amplifier, driver amplifier, phase shifter, and attenuator MMICs no stress is placed on the low noise amplifier and post amplifier MMICs. If data on these MMICs is desired, the source and power meter in Figure 1 can be transposed.

Alternately, a test set-up can be created to switch between transmit and receive, which may provide additional data on controller failure mechanisms, but this test configuration requires additional switches and greater test set-up complexity.

0-7803-4603-6/97/$5.00 (c) IEEE

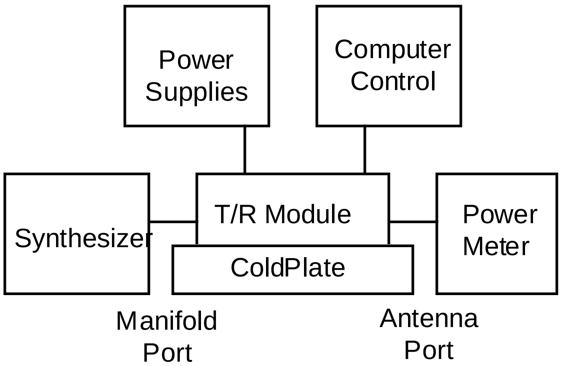

Figure 1: Block Diagram for T/R Module Transmit Reliability Evaluation

An important consideration in T/R module testing is the use of a reference module at the start and completion of testing. This module, which does not undergo the reliability testing, monitors any changes in the test equipment and fixturing which can occur during the 1000's of hours of testing.

Automated data recording of both current and RF output power also helps to insure unambiguous data by providing insight into whether degradation is gradual or sudden. Shifting bias points or degradation of driver amplifiers in front of a compressed output amplifier stage can lead to small changes in RF output power, which are often attributed to RF measurement drift and/or errors. The more accurate DC current measurements provide a method to evaluate whether these small changes are meaningful. RF output power also needs to be monitored, however, since shifts in bias point created by physical changes in the device structure can lead to RF power degradation in the absence of significant current changes.

Finally, it is useful to monitor the output power and current at several frequencies across the band of interest during automated data recording. A power amplifier typically has different levels of compression across the band of interest and degradation due to insufficient drive will be more apparent at frequencies with the lowest level of compression. Shifts in the output power amplifier's bias point may also change the device impedance and can have a strong frequency dependence. Modules should be operated at the frequency of highest compression to insure proper evaluation of voltage stress mechanisms.

FIRST EXAMPLE TEST DATA

Data from two reliability evaluations can be used to demonstrate how some of the previous degradation mechanisms were found without the use of raised temperatures for acceleration. The first experiment tested three modules at a +60 °C baseplate temperature for approximately 1,000 hours. The output power and current were monitored daily at three frequencies across the operating bandwidth, referred to as fl, fm, and fh. These modules are designed for operation in a linear or compressed mode. The modules were operated in their compressed mode at the center frequency, fm, during the evaluation.

Figure 2 shows the output power in the compressed mode over time measured at FL. Similar data was measured at FM and FH. A loose connector was found on one of the output couplers at the beginning of the test. This coupler was replaced with the resulting coupling value shift causing a shift in recorded power.

This data shows that two of the units showed no appreciable change in output power. The third unit failed, however, after several hundreds of hours of operation. This failure was due to catastrophic damage of the output power amplifier MMIC. While X-ray of the module was not feasible, solder voiding was identified as a possible cause. Subsequent manufacturing analysis indicated poor control of the eutectic solder process.

Further data was necessary to properly evaluate module degradation mechanisms. Figure 3 shows the output power in the linear mode over time at FL and FH. Again, data taken before the coupler replacement should be ignored. Also, the data taken by hand on this day is obviously invalid.

This data reveals that one of the two seemingly reliable modules actually had > 0.5 dB of linear gain degradation. This degradation was previously hidden by gain compression This data also shows a frequency dependence, with no linear gain degradation shown at fh as opposed to the fl and fm data. Failure analysis identified degradation in a driver amplifier as the likely cause. This degradation manifested itself as a shift in gate bias, with a subsequent frequency dependent impedance change.

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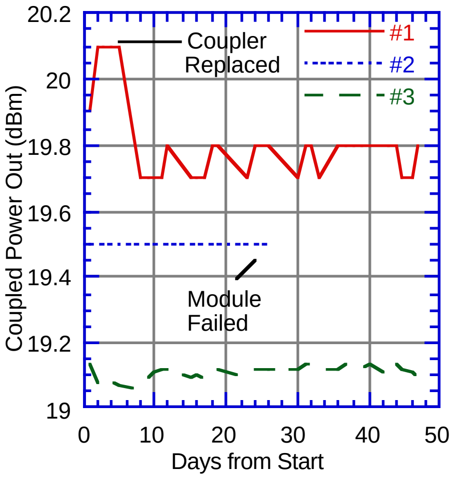
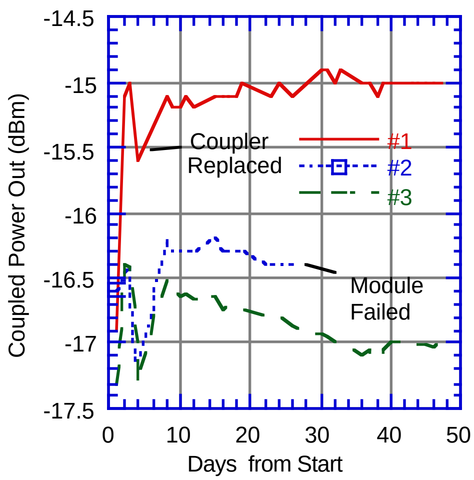
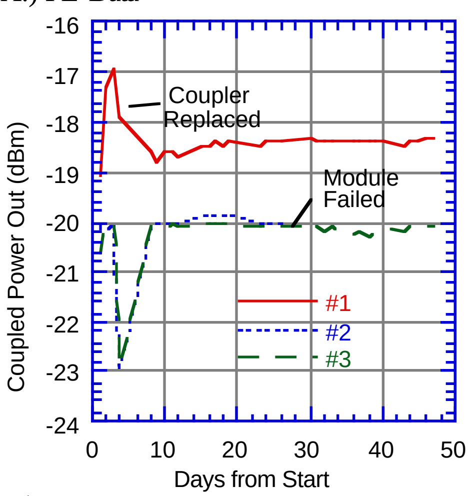


Figure 2: Test #1 Compressed Output Power Measured at FL



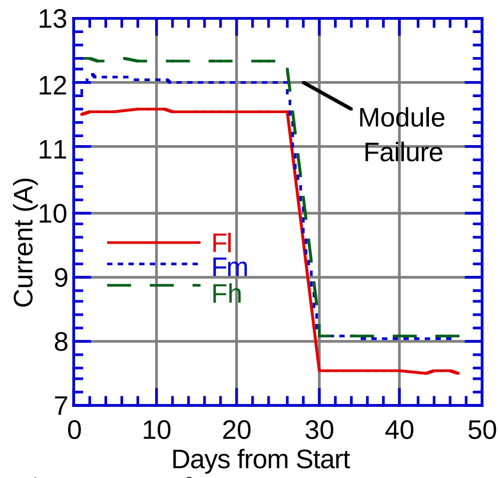
A.) FL Data



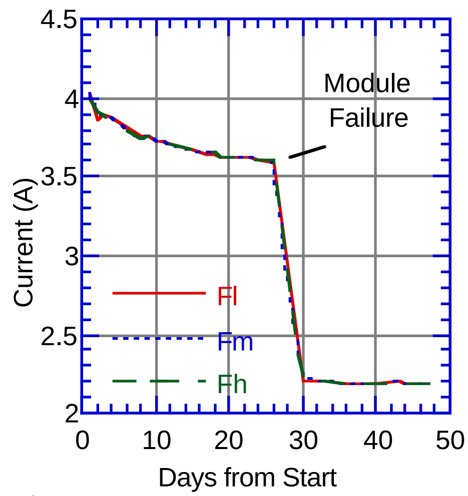
B.) FH Data

Figure 3: Test #1 Linear Output Power for FL and FM

This linear degradation was also revealed in the current data shown in Figure 4. The current was monitored for all three modules in parallel. This data shows an exponential decrease in the linear mode of operation without any appreciable decrease in the compressed mode of operation.



A.) Compressed Operation



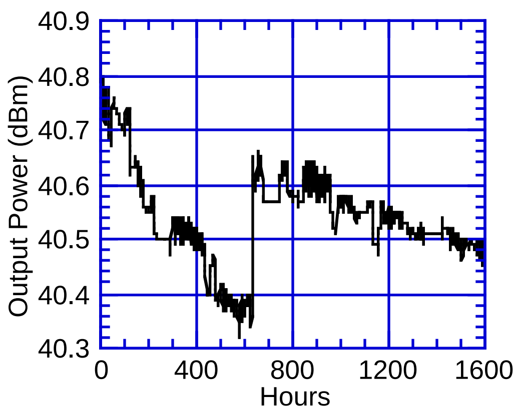
B.) Linear Operation

Figure 4: Test #1 Current Values in Compressed and Linear Modes

This experiment showed that level of compression and frequency, were both important factors for module reliability evaluation. The performance degradation was attributed to manufacturing and semiconductor processes which were not captured by power amplifier accelerated life data.

SECOND EXAMPLE TEST DATA

Another reliability test was done with one module operated at +80°C for 1,600 hours. Experience has shown that reliability data can greatly vary from module to module, but only one unit was available for this evaluation. The output power and current measured at one frequency over time are shown in Figure 5.



A.) Compressed Power

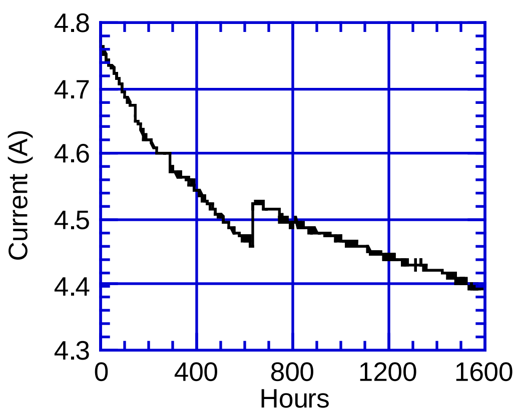


Figure 5: Test #2 Compressed Output Power and Current

The output power showed exponential degradation, which was similarly shown in the current. The compressed output power and current degradation were similar at all measured frequencies.. Due to test automation issues the linear output power was only evaluated at the beginning and ending of the test. The linear output power showed much more severe degradation than the compressed state, with a maximum loss of 5.2 dB. This power loss was accompanied by a 50% loss of current.

Research and failure analysis conducted by the manufacturer and APL identified hydrogen poisoning as the cause of the degradation. One cause of the hydrogen problem was created by the use of a nickel-plated lid, which acted as a hydrogen source. This packaging configuration had not been used previously by the manufacturer in conjunction with their PHEMT based parts. Another cause of this problem was a change in the PHEMT wafer supplier.

These packaging and supplier changes would not typically be considered from a reliability standpoint, but the data indicated otherwise. When the GaAs wafer supplier was changed and the housing lids subjected to a bake-out procedure as indicated in Ref. 2, the degradation was eliminated.

SUMMARY

MMIC temperature accelerated test data often does not capture many reliability degradation mechanisms present in T/R modules due to packaging and component interactions. Unaccelerated module level reliability testing can be used to help identify these mechanisms. Data should include several frequencies, both linear and fully compressed output power levels, and current levels to obtain the maximum value for the test investment.

REFERENCES

[1] Y. A. Tkachenko, C. J. Wei, and J. C. M. Hwang, "Hot-Electron-Induced Degradation of Pseudomorphic High-Electron Mobility Transistors," IEEE Monolithic Circuits Symposium, pp. 115-118, 1995.

[2] Y. Saito, R. Griese, J. Kessler, R. Kono, and J. Fang, "Hydrogen Degradation of GaAs MMICs and Hydrogen Evolution in the Hermetic Package," IEEE Monolithic Circuits Symposium, pp. 119-122, 1995.