

Commercial-off-the-shelf MMIC components offer high reliability

Demands on reliability of commercial-off-the-shelf (COTS) components are increasing. Responding to this need, Mini-Circuits has instituted rigorous new design guidelines and reliability inspection verifications to ensure Mini-Circuits components will last longer than the lifetime of the customer's end product. This paper presents the details of design and quality assurance programs, which will help designers decide on incorporating COTS components into their military or other high-reliability applications.

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The life of semiconductor products is a function of junction temperature. The hotter the junction gets, the shorter will be the life. Unless a product is properly designed, no amount of testing will ensure reliability. Packaging materials should include specially developed lead frames and highly heat-conductive die-bond epoxies and mold compounds to efficiently dissipate heat.

Die designers need to ensure low junction temperature by:

1. Using bigger devices or several small devices connected in parallel to spread the heat.
2. Laying out the die so as to physically separate the heat-generating elements.

Using bigger devices tends to degrade high-frequency performance. With smaller devices in parallel, one needs to ensure that power is combined in such a way that manufacturing tolerance does not favor current flow in one device over another, as this can

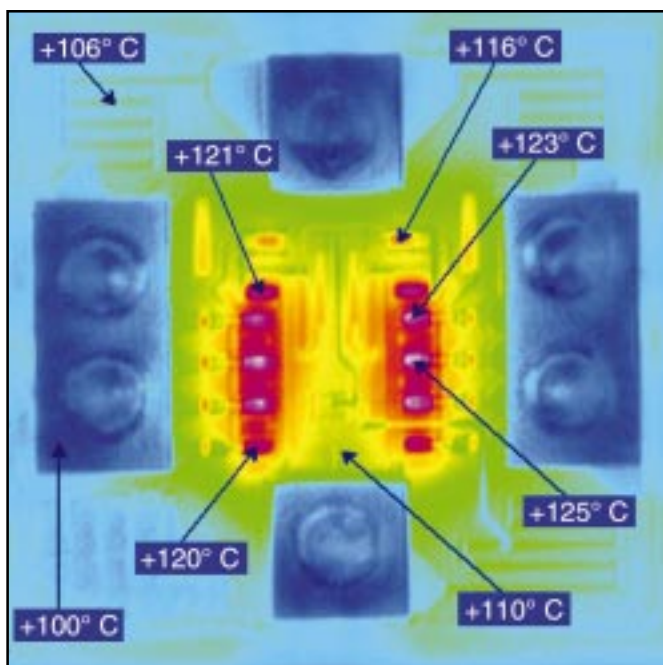


Figure 1. Infrared image of a gain block amplifier. Note the heat sources are widely separated and hot spot temperature is below 130° C.

result in overheating and thermal runaway.

Theoretical prediction of junction temperature is the first step in the design. Three-dimensional finite element modeling of the die and package is one of the methods used to analyze heat distribution and predict hot spot temperatures.

After the die is manufactured, it is packaged. Packaged devices are selectively etched to expose the die while retaining the mechanical integrity of the device. High-resolution infrared images are then taken to validate the thermal predictions. Figure 1 shows the infrared thermal image of a medium-power gain block amplifier.

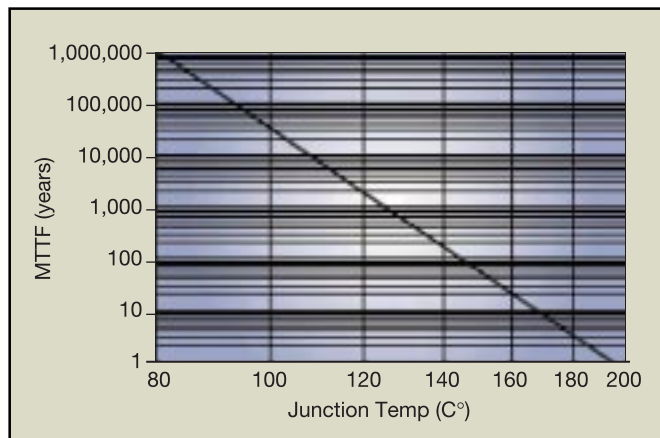


Figure 2. MTTF vs. junction temperature.

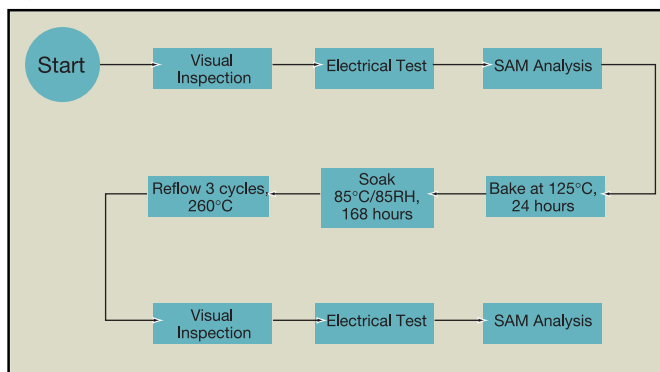


Figure 3. Qualification flow chart for moisture sensitivity test.

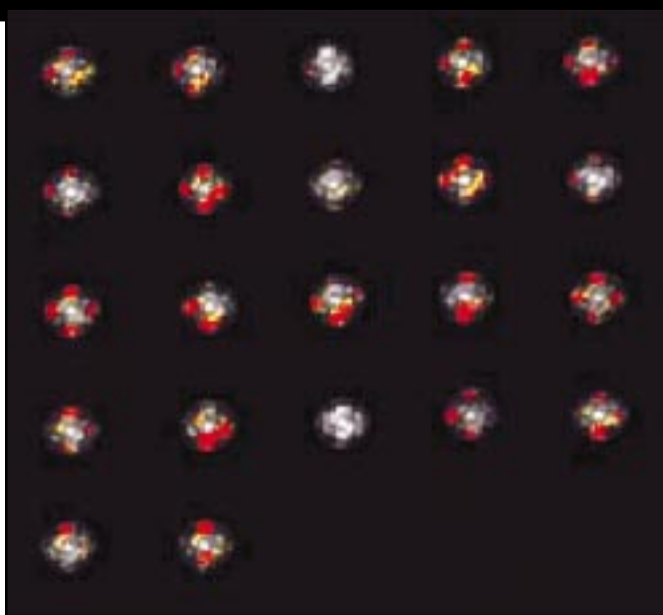


Figure 4a. Picture shows the scanning electron microscope analysis result of the top surface of Micro X plastic control units (conventional design). Red indicates delamination. A total 20 out of 22 units were detected positive for delamination after moisture sensitivity level 1 test.

This image is taken with the device package mounted on a base plate with temperature held at 85° C, which is the highest specified ambient operating temperature of the device. It is a good practice to add another 5° C or 10° C to this temperature to account for the temperature rise of the user's printed circuit board (PCB) over the

Figure 4b. Picture shows the scanning electron analysis result of Micro X plastic units that were built by using improved design. No delamination was observed after.

ambient. Most of the dice are designed to have hot spot temperature less than 130° C at the highest specified ambient.

Important information required for mean time to failure (MTTF) prediction is the relationship of MTTF to hot spot temperature. Standard industry practice is to perform accelerated life tests to

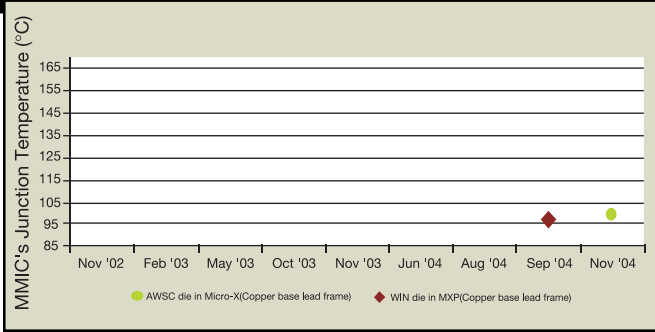


Figure 5. Hot spot temperature of the die measured with diode technique.

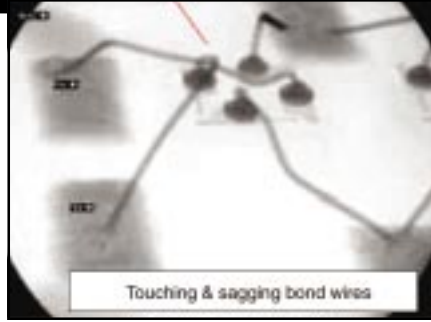


Figure 6. X-ray image of a wire bond defect.

Table 1. Moisture sensitivity tests required per IPC/JEDEC J-STD-020C.

No.	Test	Condition	Standard	Quantity
1	Visual inspection	Low-power microscope magnification 40x	MIP-IN-003 (internal spec)	45
2	Electrical test	Room temperature	Internal production spec (which is tighter spec than catalog)	45
3	SAM analysis	Less than 10% growth in terms of delamination	J-STD-020C	45
4	Moisture sensitivity level 1	Bake at 125° C for 24 hours; Soak at 85° C /85% RH for 168 hours; Reflow 3 cycles at 260° C peak	J-STD-020C	45

derive this relationship. Circuit designers should, therefore, use the device-specific MTTF graph given in data sheets (example: Figure 2), instead of general prediction models such as MIL-HDBK-217 (reliability prediction of electronic equipment). Those models tend to give overly pessimistic values for modern commercial semiconductor devices.

Figure 2 shows MTTF vs. junction temperature for HBT devices such as Mini-Circuits ERA and Gali series amplifiers^[1,2] as an example. Note the MTTF of the device shown in Figure 1 is about 500 years at 85° C ambient temperature, which is adequate for most applications. To increase reliability, lower device current needs to be used (readily accomplished as this is a current-controlled amplifier) at the expense of lower output power.

Package design and reliability verification

Vapor pressure of moisture inside a non-hermetic package increases greatly when the package is exposed to moisture followed by the high temperature of solder reflow^[3].

A proprietary technique has been developed to prevent delamination, after years of research, and has been qualified to meet J-STD-020C.

A scanning acoustic microscope (SAM) is used during qualification and process monitoring to detect delamination. The operation of SAM is based on simple acoustic principles. The devices under examination are submerged in a large container of de-ionized water. An ultrasonic transducer is placed near the surface of the device below the water line. The transducer generates a series of high-frequency waves that impinge upon the various package components. The acoustic wave will penetrate, and will be reflected fully or partially based on the nature of the material; the transducer detects the reflections. Based on the amplitudes and the phases of the reflected waves, the acoustic microscope can detect internal package cracks, die cracks, tilted die, voids in the die attach and interface delaminations.

Table 1 lists the tests, criteria, standard and sample size used. Figure 3 is a flow chart of the tests. Peak reflow temperature in the moisture sensitivity level (MSL) test is 260° C, which corresponds to the peak reflow temperature used with lead-free solders.

Figure 4a shows SAM images of an array of units of conventional design that have undergone MSL tests per Table 1. Red indicates delamination. Note 20 of 22 units have delamination.

Figure 4b shows the SAM image of an array of units of improved design, which have undergone MSL tests per Table 1. No unit failed.

JEDEC spec^[3] allows certain types of delaminations as long as the units pass electrical tests. Our criterion for success is units should pass the moisture absorption tests and C-SAM to show no voids at all. Voids affect thermal resistance as heat is dissipated from the junction to the ambient through the package. Most of the heat is dissipated through the die onto the lead frame on which it sits. Thus, the improved design package is of great value for applications requiring the devices to perform reliably for a long period of time, such as for the military.

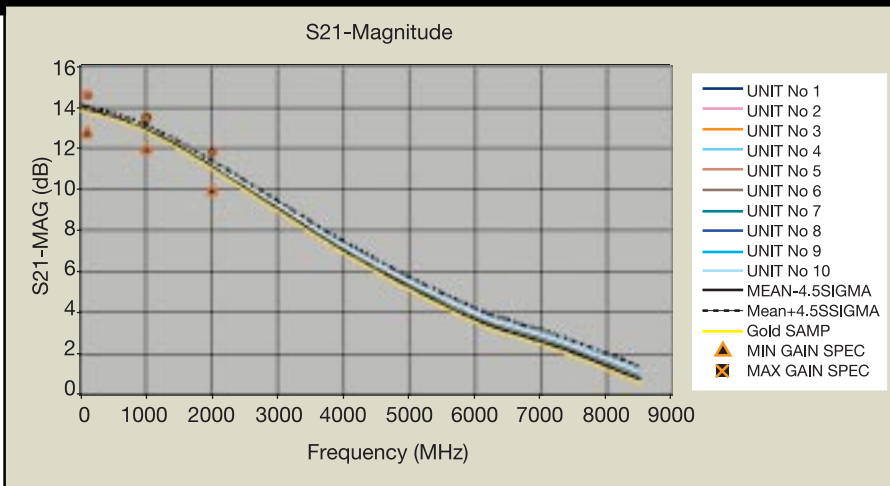


Figure 7. S21 magnitude as compared to golden sample.

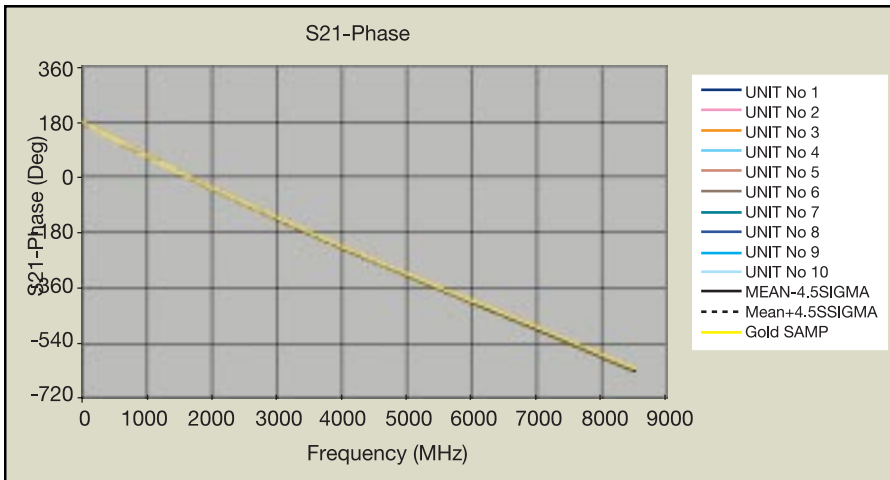


Figure 8. S21 phase as compared to golden sample.

Thermometer inside

Diode forward voltage varies with temperature. This characteristic is used to measure die hot spot temperature for each lot. For each MMIC amplifier product, a special die is designed that has a thermal-sensing diode close to the die hot spot. This die is part of each reticle and will, therefore, undergo similar process variations as the regular die under investigation. The special die is packaged and powered, a small current is passed through the diode, and diode voltage is measured to determine the hot spot temperature. Figure 5 shows hot spot temperature of a typical device. This type of quality assurance test ensures the thermal resistance is a parameter of concern, and any change will trigger a review and process changes if required to bring it under control.

Extended HTOL tests

Some manufacturers subject samples to life tests at maximum specified ambient temperature for 1000 hours. We use 125° C ambient, which is 40° C above the 85° C maximum ambient specified, and which is also used by other quality-conscious manufacturers. What distinguishes Mini-Circuits is the use of extended life test for 5000 hours instead of 1000 hours. This tough life test would bring out defects that ordinarily would not be caught. The disadvantage of this process is that it takes a long time to correct design defects. In order to minimize design cycle time, small manufactured lots go through these tests and results are used to correct the design of production lots.

X-ray inspection

X-ray equipment is used in the assembly process as a process

control monitor to look for wire sweeps at molding or wire bond defects. Figure 6 shows an assembly defect. Such information is used for applying corrections to manufacturing processes in real time.

S-parameter tests for each manufacturing lot

Most manufacturers test S-parameters during qualification on one sample, and rarely on a few samples, irrespective of the production quantities. Production tests are at spot frequencies and for few parameters such as gain and dc current.

At Mini-Circuits, we believe variations need to be continuously monitored. For this purpose, each manufacturing lot of the devices undergoes full S-parameter tests. The data is compared to a golden sample from the original qualification lot. This enables a tight process control on variations of parameters that may affect our customers' applications. Figures 7 and 8 are examples of plots obtained.

Qualification tests

Industry-standard qualification tests are done in addition to the aforementioned tests. These include HTOL, HAST, vibration and shock, and thermal cycling and satisfy traditional qualification requirements of the industry.

Conclusion

Demands on quality of very high volume commercial products exceed the requirements specified for most military products.

Extensive reliability and physical analysis capabilities at the assembly operations such as C-SAM tests and X-ray inspection are used not only for product qualification and failure analysis but also for in-process quality and reliability monitors. This gives real-time data to manufacturing for process controls to ensure production of a high-quality product.

Mini-Circuits employs traditional qualification tests, extended life tests and lot S-parameter characterization to ensure that the quality and electrical performance of the product far exceeds the requirements of commercial products. Designers of military products should closely review the quality of commercial-off-the-shelf products produced by quality-conscious manufacturers to save money and time in high-quality component procurement. **DE**

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1. <http://www.minicircuits.com/> type ERA in quick search.
2. <http://www.minicircuits.com/> type Gali in quick search.
3. J-STD-020C Moisture/Reflow Sensitivity Classification for Non Hermetic Solid State Surface Mount Devices, July 2004.

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