Benchmark

White Paper

Failure Analysis for Reliable 5G mmWave Infrastructure

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Introduction

Fifth Generation (5G) cellular wireless networks are being erected worldwide to keep pace with growing demands for mobile communications services. The infrastructure for these systems provides wider bandwidths than previous generations, enabling users to access the internet almost anywhere and while on the move. Users of mobile communications networks such as 5G and its predecessors depend on those systems more than ever, so those systems must provide reliable operation. Achieving widespread 5G coverage at millimeter wave (mmWave) frequencies of 24 GHz and higher will require large numbers of printed-circuit-board (PCB) assemblies working at those frequencies and production lines capable of producing them with high quality in high volumes. Failure analysis (FA) helps improve the production of electronic products at RF/microwave frequencies, and it can also be applied to achieve production success with mmWave systems.

Modern communications networks such as 5G and satellite communications (Satcom) systems support users of all kinds, including sensor-based Internet of Things (IoT) devices. As the number of users increases, more bandwidth is needed, with 5G and Satcom systems finding available spectrum at mmWave frequencies.

Designers of 5G systems must cover wide frequency ranges: 0.410 to 7.125 GHz in the RF/microwave range and 24 to 52 GHz in the mmWave range. While mmWave assemblies have long been part of military systems, they are still new to commercial applications and high-volume production lines. FA is one tool to improve the yields and the quality of higher volume mmWave production lines.

The generous bandwidth in 5G networks supports growing wireless network capacity. But compared to lower-frequency RF/microwave signals, the smaller wavelengths of mmWave signals result in shorter propagation distances than for signals at lower frequencies, with more attenuation through some materials, such as glass windows, than at lower frequencies. 5G networks rely on more significant numbers of smaller, closely spaced base stations and antenna towers than at lower frequencies. But despite the need for dense spacing, the wide bandwidths of mmWave infrastructure equipment offer advantages over lower-frequency bands.

The wide bandwidths enable 5G network upload/download speeds to 10 Gb/s. But producing high-quality mmWave circuit assemblies will pose challenges for manufacturers with new materials, novel components such as system-in-package (SiP) devices, and the fabrication capabilities to support finely dimensioned transmission lines and interconnections such as plated-thru holes (PTHs). FA can prepare manufacturing processes for circuit assembly production at mmWave frequencies.

Learning from Failure

When a product fails reliability testing, FA determines which component or connection failed, why the failure occurred, and provides insights into how to correct the failure. An assembly can fail due to mechanical, material, electrical, or environmental reasons; FA consists of inspections, analyses, and procedures to determine why an electronic circuit assembly failed. The failure may be due to a poor solder joint, a misaligned interconnection, or the failure of an individual component. Some failures may be related to a poor design, while others stem from a poor manufacturing process. While failures can occur at room temperature, they more often occur under severe environmental conditions. FA procedures attempt to find reasons for the failure and fix them. FA can be applied at different levels, such as device, component, bare PCB, and circuit assembly levels, to find the root cause for a product failure.

FA may not be simple to perform, but it can significantly improve yields and manufacturing processes, thus reducing production delays. Reducing failures at the PCB or assembly level due to manufacturing problems reduces the amount of waste generated in the manufacturing process, achieving both cost savings and environmental benefits. Reducing failures can also help a manufacturer shorten the time required to bring a product to mass production, especially critical for rapidly emerging markets such as for 5G infrastructure equipment. For products built for new operating regimes, such as 5G networks operating at mmWave frequencies or even within Satcom networks that will also occupy mmWave bandwidths, FA is an essential step in supplying high-volume products with consistent, repeatable performance.

It is challenging to solve a problem until it's cause has been identified, and this is what FA attempts to do. FA equipment and systems search for fault mechanisms and potential problems in an electronic product design by duplicating the conditions that will cause failures, such as too high an operating temperature or a high supply voltage. FA helps to identify problems within circuits or systems which may be related to a specific component. In such cases, component-level FA is done by the component supplier, informed with good data and instrumentation results provided by skilled technical personnel at the assembly site. The component manufacturer is responsible for its materials, design, and manufacturing processes. FA is most effective when detailed information is shared among component and manufacturing partners.

For example, an electronic assembly may fail due to various causes, such as improper manufacturing, improper soldering, or operating at too high a temperature or voltage. Since mmWave products deal with very small signal waveforms, even minor flaws in a product can lead to poor performance or failure.

Automated optical inspection (AOI) is typically performed as part of failure analysis to find visible flaws associated with a failure. AOI instruments look for poor solder joints, poorly placed surface-mount-technology (SMT) components, misoriented pick-and-place components, and other physical problems that can be visibly detected. Modern AOI systems can scan in two dimensions (2D) and three dimensions (3D) to find any physical faults that might have caused the failure of a component, circuit, or assembly, even those constructed with the small dimensions of components designed for mmWave frequencies. AOI systems are among the tools that contribute to the total data collected on a failed electronic design to pinpoint the source/cause of the failure. Working in conjunction with a temperature/humidity chamber, for example, AOI systems can detect physical evidence of a failure during thermal cycling.

Tools of the Trade

Inspection and test equipment required for failure analysis represents a significant investment, but FA can help boost the quality and yield of a production line. With the growing importance of mmWave frequency bands in 5G networks and Satcom systems, even in automotive electronic systems, mmWave assemblies must transition from specialized devices most often in military systems to higher-volume, lower-cost commercial products. A properly equipped FA laboratory features the tools needed for the FA services that can help mmWave production lines make the transition to higher volumes. FA laboratory equipment can provide invaluable insights into how a system will behave under a wide range of operating conditions.

Temperature/humidity chambers (Fig. 1) are vital tools for stress testing electronic devices under thermally related operating conditions that can cause failures. Within an FA process, temperature/humidity cycling can take on several forms, including burn-in testing, highly accelerated stress screening (HASS), temperature humidity biasing (THB), highly accelerated life testing (HALT), and environmental stress screening (ESS). Burn-in testing, for example, is performed during the early stages of product development to filter out any components that might lead to the failure of a PCB or circuit assembly. Burn-in testing involves subjecting a device or circuit to high temperature and voltage conditions for a certain period; it can be performed with or without test signals, such as mmWave 5G signals. Burn-in testing may cause a failure, but it is the mission of a FA facility to find the cause of the failure.

FA inspection equipment includes analyzers and microscopes based on different forms of light and energy, including infrared (IR), visible light, and x-ray sources. A Fourier Transform Infrared (FTIR) analyzer (Fig. 2) is a measurement tool capable of detecting different forms of organic contamination on the surface of a DUT.

Figure 1. An essential tool for FA is a temperature/humidity chamber with wide control ranges.

The output helps determine whether a device's operating environment or even its production process could be leading to the contamination that causes the failure. X-ray analyzers provide internal views of a component or within layers of a multilayer PCB for defects and cracks causing an assembly failure. Two-dimensional (2D) x-ray analyzers can study surfaces across the length and width (x and y axes). In contrast, three-dimensional (3D) analyzers can include the thickness (z-axis) of an assembly's base materials when searching for structural defects.

Figure 2. Fourier Transform Infrared (FTIR) analysis provides surface detection of organic contamination and flux characterization analysis using full and single wavelength mapping.

Example FA Facilities

As an example of the power of FA for reducing production costs and improving high-volume manufacturing yields, Benchmark's Failure Analysis Labs serve sites regionally and around the world. With over 15 years of experience manufacturing and designing microwave and mmWave systems, the FA lab engineering team has successfully supported design development and diagnosed and overcome many RF system production issues. The FA facilities consist of five laboratories: materials analysis, component analysis, mechanical analysis, reliability analysis, and packaging analysis laboratories. The five laboratories check for mechanical, electrical, and environmental problems at PCB and higher levels. They have the capabilities

Figure 3. An x-ray fluorescence (XFR) spectrophotometer enables measurements of RoHS and coating thicknesses to less than 0.1 µm.

Figure 5. This SEM/EDX system provides 130,000×total magnification with 10-nm feature resolution, a built-in EDX, and BSE detector in support of surface and metallurgical analysis in

to perform FA to detect and resolve flaws and failure mechanisms on circuits and assemblies operating from DC through mmWave frequencies.

On-site analysis equipment includes an x-ray fluorescence (XFR) spectrophotometer that can measure coating thicknesses of less than 0.1 µm (Fig. 3) and a 3D x-ray inspection system (Fig. 4) with 45,000× magnification power that can resolve features as fine as 350 nm for the study of mmWave transmission lines and circuits. Higher magnification, such as when

Figure 4. A three-dimensional (3D) x-ray system with computer tomography provides a total magnification of 45,000× for nondestructive FA with 350-nm feature resolution of cracks and faults.

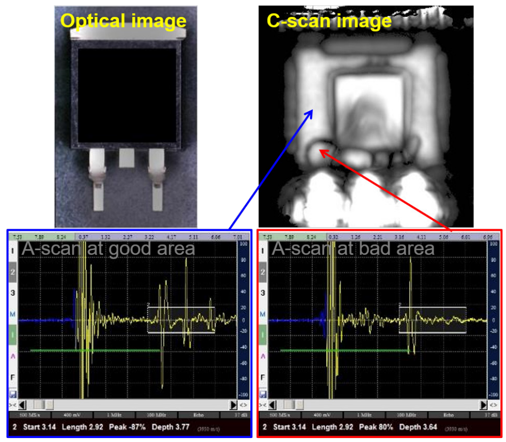

Figure 6. This confocal scanning acoustic microscope (C-SAM) provides ±1 µm scanning repeatability across as many as 20 layers and can analyze delamination in PCBs.

performing RoHS analysis, is available with a scanning electron microscopy/energy-dispersive x-ray (SEM/EDX) system capable of 130,000× total magnification and 10-nm feature resolution (Fig. 5). A confocal scanning acoustic microscope (C-SAM) provides ±1 µm scanning repeatability when checking for material defects (Fig. 6).

Benchmark's FA capabilities are backed by extensive thermal capabilities and robust software support. For example, a large temperature chamber features interior dimensions of 48 × 48 × 52 in. to handle temperature processing of multiple units of the largest circuit assemblies and components. The chamber (Fig. 1) controls a temperature range of -65 to +180°C and relative humidity (RH) of 10% to 98%. It can increase the temperature at rates as fast as +4.5°C/min and decrease the temperature at rates as fast as -4.0°C/min. Software tools include programs from some of the leading suppliers of design and test software to speed the development and improve the effectiveness of computer-controlled FA processes for electrical, mechanical, and environmental testing.

In Conclusion

Millimeter wave active and passive components have been in development and production for some time, but rarely for commercial use other than meteorological science applications. With the expansion of 5G cellular wireless communications networks into the mmWave frequency range for much-needed bandwidth, mmWave assemblies are becoming part of 24-hour/day, seven days/week communication systems essential to all markets, including commercial, business, and military users. FA can help manufacturers of mmWave products achieve high-yield, high-volume production lines to support rapidly growing demands for those products.

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