When engineers go through the task of pinning down the cause of one or more field failures, the cause often turns out to be a damaged or failed multilayer ceramic chip capacitor. The nature of a field failure caused by a bad capacitor may range from total system failure to a failure of one or more system functions, to an intermittent failure, the latter of which can mimic a software problem.

Here, we look at the mechanical causes of failures in MLCCs from the fabrication of the capacitor through system assembly. Much of the detailed information comes from Sonoscan’s applications laboratories, which have imaged acoustically and analyzed tens of millions of MLCCs.

An understanding of how mechanical anomalies can cause electrical failure in MLCCs is important for three reasons:

1. End-of-line electrical testing usually does not detect a mechanical anomaly because the electrical signature of the anomaly is minute or absent at this time.

2. A mechanical anomaly may endure weeks or months of service use before it changes or expands enough to reveal itself as an electrical failure.

3. The number of field failures resulting from a single type of mechanical anomaly can be large.

**Defects introduced during manufacture.** MLCCs are made by laying down alternate layers of dielectric and electrode materials, and then firing the capacitors. Of the three most frequent types of internal damage (voids, delaminations and cracks), two – voids and delaminations – can form during the manufacturing process. Cracks as a result of manufacturing processes were frequent a decade or two ago, but have been made rare by more precise control over the processing. Voids are most often tiny air bubbles trapped within the capacitor. A void can be very much flattened – its width might be 100 times its height – but dielectric material will be missing from one or more layers. A delamination is simply a non-bonded area between layers, without loss of dielectric material. When an MLCC is cross-sectioned, a void is typically lens-shaped (because it is a bubble flattened by the pressure of overlying layers), while a delamination is simply a thin horizontal gap.

Voids and delaminations can be the precursors of cracks. Cracks also can be caused by variable porosity in the dielectric layers, a condition in which irregularly distributed microscopic air bubbles weaken the ceramic.

The photo on the cover of this month’s issue shows the acoustic image of an MLCC that contains a single void. In performing acoustic imaging of an MLCC, the scanning ultrasonic transducer of the acoustic microscope pulses ultrasound into the MLCC several thousand times a second as it moves back and forth across the MLCC. A fraction of a microsecond after pulsing, it also registers the return echoes from within the MLCC. System software typically accepts return echoes from just below the top surface of the MLCC to just above the bottom surface, a technique known as bulk imaging. A defect-free MLCC will send back no return echoes, but an MLCC having any gap-type defect such as a void, delamination or crack will send back very high amplitude echoes from the defect. (Here, the void appears red, which is highest level on the color map at left, because the solid-to-air interface reflects nearly all of the ultrasound.) The amplitude is very high because of the extreme difference in acoustic properties between the solid material of the capacitor and the air inside the defect. It is this interface between a solid and gas that reflects virtually 100% of the pulsed ultrasound and produces an acoustic image of the anomaly.

Voids such as the one shown on the cover are important because they can cause long-term failures in MLCCs. For example, a void may be located in the middle of one layer of dielectric. This may seem like a harmless location, and in some capacitors it is harmless. But the electric field between two electrodes may cause metal to migrate and to plate the inner surface of the void. Eventually, a weak current may begin to flow between the electrodes. Ultimately – weeks or months after the beginning of field service, perhaps – the metal plating becomes substantial enough to cause a short. Many of the MLCCs imaged in Sonoscan’s laboratory are destined
for aerospace or military applications, where a slowly developing short or other internal anomaly can have catastrophic results.

A crack, like a void, also can experience metal migration and become plated. Under some conditions, the metal plating within the void or crack may diminish or disappear. This is likely to happen if the capacitor is exposed to infrequent higher voltages. If a capacitor is suspected of having a short, it may intentionally be exposed to a high-voltage current. This crude method may repair the capacitor temporarily, although the resumption of normal lower voltages may restart the plating process. Intermittent failures can occur in this manner (but see the information on cracks below). A crack also can cause a short with no metal migration at all. If the crack extends through multiple electrode layers, thermal or mechanical forces can move layers until electrodes having different polarities come in contact with each other.

Less frequent types of anomalies also can occur during fabrication of an MLCC. Very occasionally, airborne organic particles can find their way into the layers. The small white spots in the acoustic image of the capacitor in Figure 1 are ordinary, microscopic dust particles trapped during fabrication and burned off during firing of the capacitor. They leave tiny empty voids that are strong reflectors of ultrasound. The longer feature (left of center) is a microscopic fiber of organic material, which, when burned off, leaves a characteristically elongate void that, like any other void, has the potential to cause an eventual short.

When adjacent layers in the MLCC are not bonded during manufacture, the result is thin air-filled delamination. Delaminations can be large in area, and a single MLCC may have multiple delaminations at different depths. When the MLCC is imaged acoustically from above, the delaminations may overlap (Figure 2), where essentially the entire area of the MLCC has a delamination at least at one depth, and where the yellow edges (marked by arrows) of some of the individual delaminations can be made out.

Delaminations are generally very thin, but they can be imaged acoustically even if the vertical extent of the gap is as few as 0.01 µm. Unlike some voids, delaminations are not typically in a location where they can breach a dielectric layer, yet they can cause shorts, presumably because delaminations may make it easier for a crack to form.

Defects in the unmounted MLCCs that flow into Sonoscan’s applications laboratories for imaging are most likely to be voids or delaminations. Cracks are occasionally seen, but are more likely to result from handling rather than manufacture. Special techniques are sometimes needed for imaging. Some newer MLCCs have acquired additional layers in order to increase capacitance without increasing footprint; as a result, the MLCC has become square in end view, and the operator of the acoustic microscope cannot tell which side is up. A delamination that is obvious when horizontal is hard to image when it becomes a vertical knife-edge. To avoid the tedious labor of turning square MLCCs by 90° and imaging them twice, Sonoscan has developed a technique (Figure 3) that images cracks and delaminations, regardless of orientation.

Defects introduced during assembly. Damage to MLCCs during the early stage of assembly is likely to be caused by handling. The MLCC is picked up by a vacuum tool or tweezers and is either placed on bond pads in preparation for reflow, or glued to the board in preparation for wave soldering. In either case, damage – usually in the form of a crack – is possible.

Damage also can occur during reflow and wave soldering, when the MLCC receives a thermal shock that can aggravate existing internal stresses until a crack forms. MLCCs are much less sus-
ceptible to moisture-related damage than plastic-packaged ICs. In theory, moisture can collect within a capacitor and fill an existing void (with destructive results when the moisture flashes into steam), but such events are far less common in MLCCs than they are in plastic-packaged ICs. The very small dimensions of some MLCCs also may make it harder for moisture-related damage to occur because the much higher ratio of surface area to volume lets moisture escape more rapidly.

Whether a damaged MLCC can be identified during end-of-line electrical testing depends first on the extent of the damage. A small crack or other anomaly that has not (yet) created contact between adjacent electrodes will not be identified, even though it may expand and cause an electrical failure later. An anomaly that has created a leakage current within the MLCC might be found if the MLCC serves an essential function within the signal path. But an MLCC in a decoupling role can be found only by examining the noise level in the supply lines.

These constraints make acoustic imaging of MLCCs after reflow or wave soldering an important tool. Finding cracks in a significant number of MLCCs, or in MLCCs at specific locations on the board, gives the opportunity to change process parameters and remove the stresses generating the cracks. Acoustic imaging is often carried out during R&D or during pilot production, but also may be used periodically during full production to eliminate the possibility of field failures.

During assembly, large panels are in some fashion separated into individual printed wiring boards. Cracks can form in MLCCs during the separation process. These cracks are most likely induced when the panel sections are snapped apart, but they can occur with other methods of separation and are sometimes more frequent near the edges of the board, where mechanical stresses are presumably higher. They are generally more likely when Pb-free solders are used, because Pb-free solders are quite rigid. SnPb solder is more plastic and better at absorbing mechanical stresses. Separation-related cracks are likely to be near the terminations and are likely to be vertical, and are most easily found with the method for vertical crack detection developed at Sonoscan.

When cracks caused by the panel separation process are suspected of causing field failures, their role can be clarified by first performing acoustic imaging on unmounted MLCCs, preferably from the same lot. Unmounted MLCCs with no internal defects go through assembly and are imaged acoustically again after reflow or wave soldering, to remove those steps as causes of the cracks. The panel is then separated by the same method used for the MLCCs that caused field failures, and the boards examined acoustically for telltale vertical cracks near the terminations.

Tom Adams is a consultant at Sonoscan, Inc. (sonoscan.com); tom100adams@comcast.net.