Acoustic Microscopy Analysis of Die Attached for Satellite Applications

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ABSTRACT

Acoustic Microscopy and Acoustic Micro Imaging (AMI) techniques are now becoming accepted technologies for the nondestructive testing of materials and microelectronic assemblies. However, since the AMI techniques are becoming more "accepted" it is even more important to understand the specific capabilities and limitations an analyst may encounter for specific applications. As an example, the analysis of die attach quality for satellite applications will be reviewed in detail.

Prior to analysis with AMI techniques, such as SLAM™ (Scanning Laser Acoustic Microscope) or C-SAM™ (C-Mode Scanning Acoustic Microscope), it is important to know the construction of the die attach assembly. The construction of the die attach assembly can affect how it can be examined or which technique would be best. For example - What type of board/laminate is being used? What type of die attach material is being utilized? Will the die be over coated?, etc. Each of these factors will help determine what technique, which frequency, when the die attach should be analyzed in the process and other steps or procedures that may need to be followed.

Guidelines are provided for the proper analysis of die attach based on various constructions. When applicable, the limitations that an analyst may encounter are also provided.

INTRODUCTION

Microelectronic assemblies in general rely heavily upon the bond quality of the die attach. There are several factors that will determine the quality of the bond and the ultimate reliability of the assemblies in space. These factors include:

- Die attach material
- Die material
- Substrate/board material
- Bond area size
- Thermal mismatch (CTE)
- Thermal issues (heat spreading)

Many of the factors listed are "known" properties that can be evaluated or calculated for various process conditions or ideal cases. Unfortunately, when the assemblies are manufactured you can not always predict the actual bond area size, the percentage of coverage or the location of voids or delaminations within the die attach material. These "unknowns" can affect the strength of the bond, the stresses on the die and the dissipation of heat from hot areas of the die.

The use of AMI techniques such as Scanning Laser Acoustic Microscopy (SLAM) or C-Mode Scanning Acoustic Microscopy (C-SAM) can help determine these unknown factors on a nondestructive basis with great accuracy and reliability. The key to utilizing the data obtained with AMI techniques is understanding their capabilities and limitations for the type of materials or construction you would like to examine. The best place to start is by understanding the basics of AMI techniques and then applying that knowledge to various microelectronic constructions.

BASICS OF AMI TECHNIQUES

The main AMI techniques utilized for die attach analysis are the SLAM and C-SAM. There is a third type of AMI technique called Scanning Acoustic Microscopy (SAM), but it is limited to acoustic surface wave investigation of samples which can not penetrate through the substrate or the die to the die attach level.

The SLAM is basically a real-time through transmission mode acoustic imaging system. As indicated in Figure #1, acoustic energy (ultrasound waves) is introduced into the sample from one side of the sample and received on the opposite side by a scanning laser detector. The most commonly used imaging mode of the SLAM is its amplitude mode which obtains images via a shadowgraphic technique. The images obtained with this mode are called acoustic micrographs.

The SLAM has other useful features that are good for die attach analysis. Acoustically, the SLAM can also provide Interferograms, which provides speed of sound data through the sample. This feature is especially useful for confirming if the die attach is poorly bonded or if there is an extreme amount of porosity within the die attach material that scatters or delays the transmission of the ultrasound. A change in the thickness of the die attach material can also be determined.

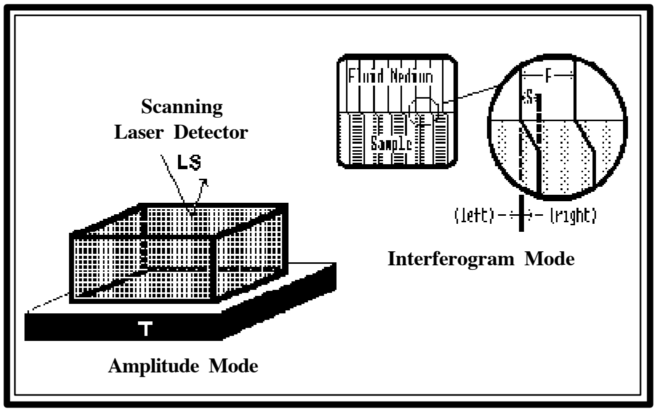


Figure 1: SLAM Block Diagrams

The C-SAM is a reflection mode acoustic imaging system. As indicated in Figure #2, it operates by sending a pulse of acoustic energy into the sample and then the returned echoes at each point are examined. It can provide images at bond interfaces, nondestructive cross sectional views, through transmission images, 3D views of cracks, etc., via time-of-flight data, bulk material analysis and can be programmed to obtain the images on an automated basis at various locations on a COB.

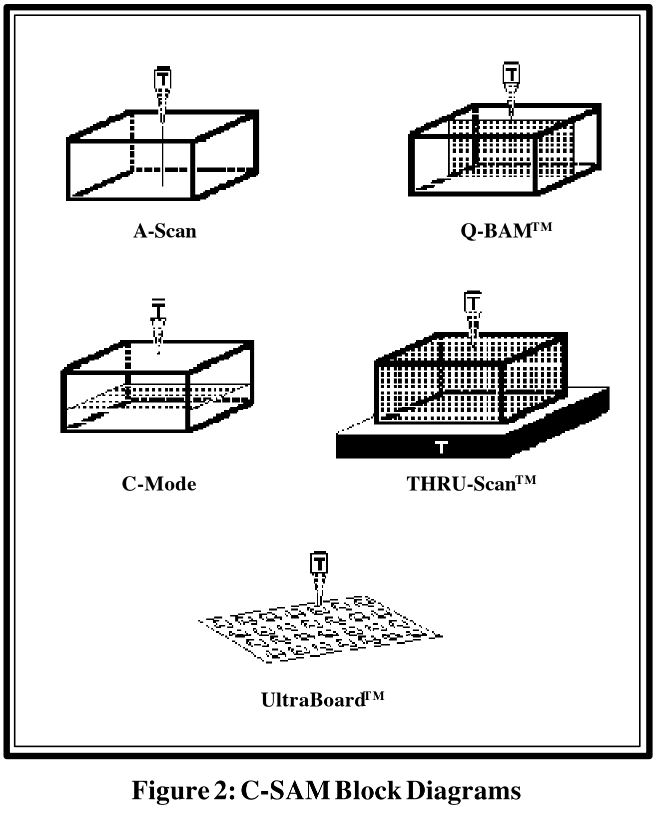


Figure 2: C-SAM Block Diagrams

AMI and X-ray techniques are commonly considered as complimentary methods. However, X-rays are only sensitive to density variations such as voids or eutectic formation for die attach applications. The SLAM and C-SAM can easily detect delaminations at material interfaces as well as any discontinuities within the die attach material. Therefore voids, porosity or cracks within the die attach material as well as any delaminations at the interface between materials can be observed. Figure 3 indicates the typical sensitivity of an AMI technique in comparison to an X-ray technique for die attach applications.

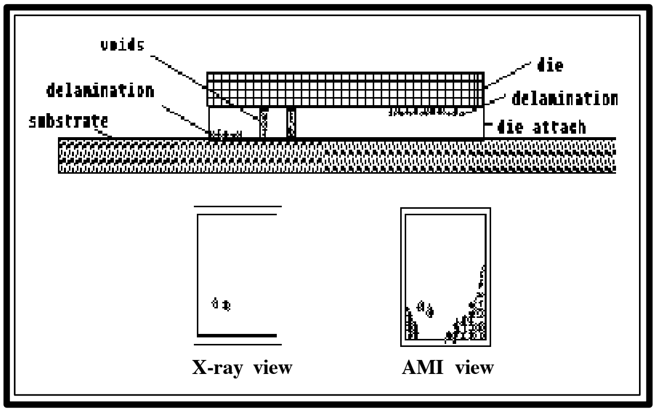


Figure 3: AMI and X-ray views of Die Attach

One of the general limitations of AMI techniques is that they can be affected by surface contours or irregularities. If a surface has a curvature or is extremely rough it can deflect or scatter the ultrasound, thereby obscuring the acoustic data in the area of investigation. In some cases the curvature or surface roughness can be compensated for by various techniques, such as main bang focusing instead of first interface echo focusing.

Since most dice are relatively flat there is no need to worry about curvature or surface roughness. However, if the die is to be encapsulated, either by molding or glop topping, it would be best to check the die attach before encapsulation as a precaution and for more detailed analysis at higher frequencies.

EFFECTS OF DIE MATERIALS ON AMI ANALYSIS

All of the die material used today are either Silicon (Si) or Gallium Arsenide (GaAs) with some sort of passivation film applied, such as silicon dioxide, silicon nitride or in some cases polyimide. None of these materials have any extreme effects on the transmission of ultrasound. However, if the die is cracked or if the passivation layer is not properly adhered to the die surface it will affect the die attach acoustic data.

A crack in the die will disturb the path of the ultrasound and will be indicated by a "line" that follows the pattern of the crack within the die. Obviously this type of defect should also be picked-up by an electrical test and the die attach quality would be rather insignificant.

A poorly adhered passivation layer can completely reflect the transmission of ultrasound, thereby blocking the ultrasound from observing the die attach under that area of the die. This is not common with silicon dioxide or silicon nitride passivation films and may be observed with polyimide passivation films on an irregular basis. In any case, the passivation layers are considered the first line of protection against corrosion of the die circuitry due to moisture, etc. Therefore if poor adhesion is noticed as shown in Figure 4, an evaluation of its failure rate in its intended environment would be advisable.

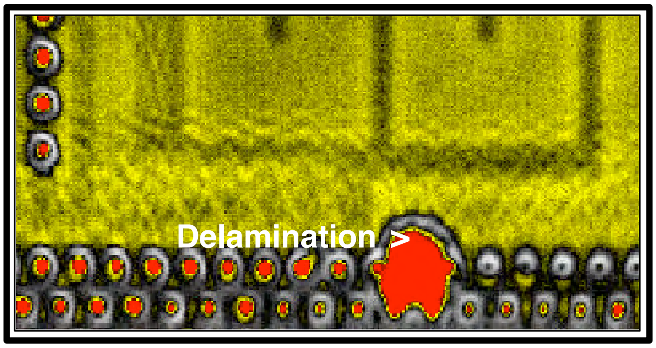


Figure 4: The delamination between the die and the passivation layer is indicated by the arrow for this flip chip type device.

EFFECTS OF SUBSTRATE MATERIALS

The substrate material chosen can dictate which AMI technique is most appropriate. The most commonly used substrate structures are FR-4 (Epoxy), FR-4 BT (Bismaleimide-Triazine Epoxy) or GPY (Polyimide), which are all variants of a glass fiber/organic resin board structures. Most of them are multilayer. Other substrates include unreinforced polyimides (Flex circuits) and ceramics (MCMs and Hybrids). In general, unreinforced polyimides and ceramics have minimal effects on obtaining acoustic data in comparison to the glass fiber/organic substrates. Fortunately, microelectronic assemblies for satellite and other high reliability applications typically use the latter.

If the substrates are of a single layer there is a good chance that either through transmission techniques, such as SLAM, or reflection mode techniques, such as C-SAM can be utilized effectively. For multilayer substrates there are limitations on through transmission techniques due to the attenuation of the ultrasound by the materials and the reflection losses at each interface. A refection mode technique can also be effected if there is only access to the die attach level through the substrate side. If possible it is preferable to access the die attach through the die side with reflection mode techniques.

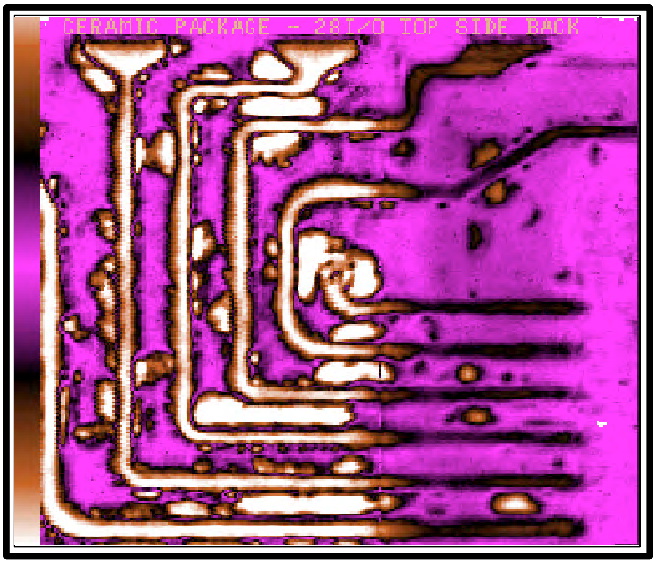


Figure 5: The C-SAM examination of this ceramic substrate indicated numerous delaminations between the traces as indicated within the multi-layered package.

As a general rule a dense, uniform materials will transmit ultrasound with the least amount of attenuation. Therefore it is possible to inspect a die attach through several more layers of a ceramic substrate than a FR-4 type. The maximum number of layers for unreinforced polyimides is in-between for any operating frequency chosen. Figure 5 provides an example of looking at multi-layer ceramics for delaminations.

EFFECTS OF DIE ATTACH MATERIALS

All types of die attach materials can be examined for defects. The types of die attach materials that can be examined by AMI techniques include:

- Conductive Epoxies
- Eutectic
- Non-conductive Epoxies
- Polyimides
- Solders
- Silver/Glass
- Other Organic Adhesives

If properly formed, flowed or cured it does not matter what type of die attach material is used. Since ultrasound is very sensitive to material continuity it will detect porosity, voids, cracks and density changes within the die attach material. Plus, its lack of adhesion to or delaminations between the die attach material and the die or the substrate surfaces.

Figures 6 and 7 provide examples of die attach analysis. From these images, a lot of information can be obtained about the die attach assembly process utilized. This information can then be helpful in solving a process problem.

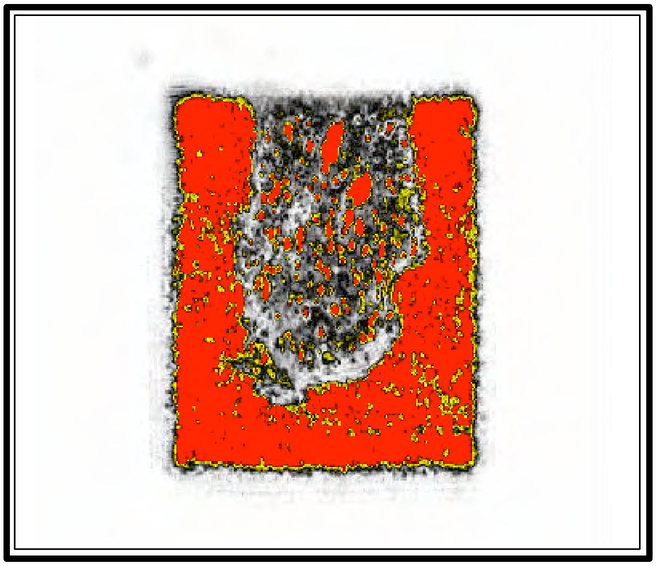


Figure 6: Solder die attach evaluation through the die side. The actual area of die attach bond is indicated by the dark areas. The bright areas within the die attach region indicate a lack of bonding, delamination and voids in those

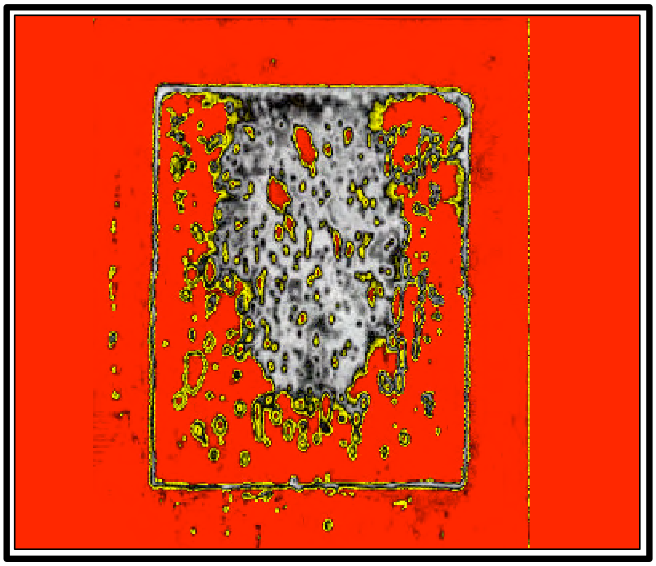


Figure 7: The same die attach evaluation, except through the substrate side. Proper bonding is indicated by the dark regions. The opposite side of the substrate and voids or nonbonded regions are indicated by the bright areas within the die region outlined acoustically.

As an example in Figure 6, it appears that one or more of the following problems occurred during the process due to the lack of coverage under the die region:

- Not enough solder was applied
- The solder was not properly heated
- The flux or preform was not properly applied
- The elevation of the die was not even, therefore the solder is too thick and not spread properly

The image provided in Figure 7, which is a C-SAM image obtained through the substrate side. Since all the edges of the die are not bonded, except for the top, it appears that the solder was unevenly applied or that the die was uplifted during the solder reflow process. The possibility of a contaminated solder preform or substrate die pad should also be considered, as well as the improper application of any flux that may be used in the process.

FLIP CHIP ATTACHMENT ANALYSIS

Beyond the normal die attachment processes some assemblies rely upon flip chip attachment for board to die electrical interconnections. While it is possible to determine the quality of the flip chip interconnections with AMI techniques, it is beyond the scope of this paper. Instead the use of non-conductive epoxy backfills shall be evaluated.

Since the interconnections themselves are not strong enough to reliably keep the die in place, epoxy backfill material is often utilized for structural integrity. Many of the same problems associated with normal epoxy die attach occur with the epoxy backfill material and more. Since the die is already attached in place by the flip chip interconnections you can not directly apply the epoxy in a pattern or preform underneath the die. Most processes rely upon some variation of a capillary action to evenly distribute the epoxy underneath the die. The flow pattern of the epoxy underneath the die is often disturbed by the flip chip interconnections, which can lead to voids and large areas of incomplete backfill. An example of an incomplete backfill is provided in Figure 8.

EFFECTS OF ENCAPSULANT MATERIALS

As previously mentioned it would be best to examine the die attach quality before encapsulating it on the assembly or board. But it is still possible to examine the die attach quality through the encapsulant if it is properly bonded to the die and

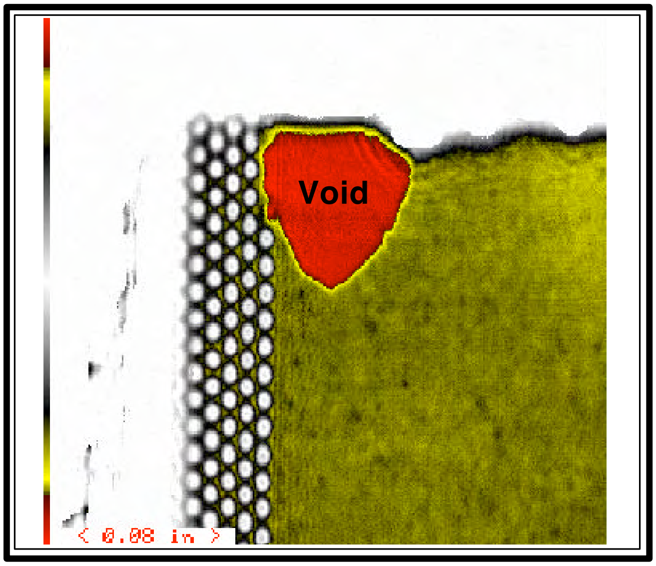


Figure 8: The bright area in the underfill is a void that caused the failure of several solder joints.

if the encapsulant's surface contours are not to extreme or rough. In addition, if the encapsulant is very thick or is heavily loaded with some type of filler material a lower frequency ultrasonic transducer may be required to access the die attach for investigation.

ESTABLISHING ACCEPTABLE AND REJECTABLE DIE ATTACHMENT REQUIREMENTS

Once the AMI data is obtained then a judgement must be made about the quality of the die attach. Is it acceptable or rejectable, and why? There are several factors that may affect or prejudice the final judgement. These factors include:

- Application/Environment of use
- Strength of the bond
- Location of voids, cracks or delaminations
- Stresses on the die
- Military or other standards

Initially the type of application or environment in which the die attach assembly will be utilized should be considered. Is the application a critical or non-critical function? Will there be any flexing of the board or is the environment harsh to the type of die attach utilized. If so, a strict requirement will be necessary.

The strength of a bond is not just determined by the strength of the die attach material. It also depends upon the actual area of the bond relative to the surface area of the die. As an example, eutectic type bonds are much stronger than solder type bonds. Therefore a smaller bond area for the same size die can be accepted strictly on a strength of bond basis.

The actual location of voids, cracks or delaminations can be critical to the long term reliability of the die. The two main factors that can affect the reliability are CTE and thermal conductivity. The thermal mismatches caused by the different CTE of materials has long been known to cause cracks or delaminations to grow due to thermal cycling. The thermal conductivity of materials is fairly well understood, but there have been limited investigations into the long term affect of "hot spots" on the die due to voids, cracks or delaminations in the die attach. Some work has been done by Yerman(8) in the past and further investigations by organizations such as RL/ERDL(9 & 10) with AMI and other techniques have been done more recently.

Stresses within the die should also be considered due to the tensile or compressional forces generated on it during power up or down conditions. If the die is bonded at the center but not at the edges the die will experience tensile forces. If the die is bonded at the edges but not in the center it will experience compressional forces. What is acceptable for the particular assembly design being utilized should be considered. Figure 9 provides an example of what stress can due to a die due to die attach problems.

Standards are always a good place to start for establishing an accept/reject criteria. One of the currently accepted and available standards is MIL-STD-833, Method 2030: Ultrasonic Inspection of Die Attach. Within Method 2030 accept and reject criteria have been established based mainly on a strength of the bond criteria. As shown in Figure 10, there are three main criteria. Voids larger than 15.0% and corner voids larger than 10.0% of the die attach area are grounds for rejection. Breaking the die area into quadrants, if any of the quadrants is more than 70.0% disbonded, it is also rejected. The actual criteria chosen for the acceptance or rejection of a die attach assembly should be based on all of these factors and discussed with the end user. If in doubt, examine some "as

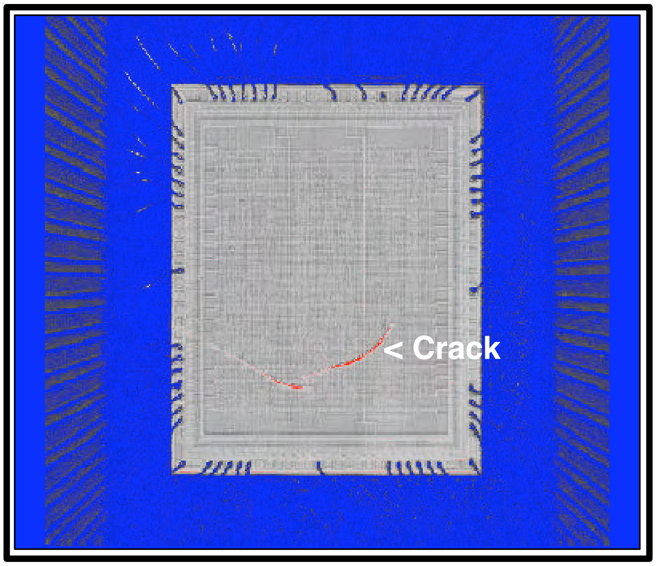
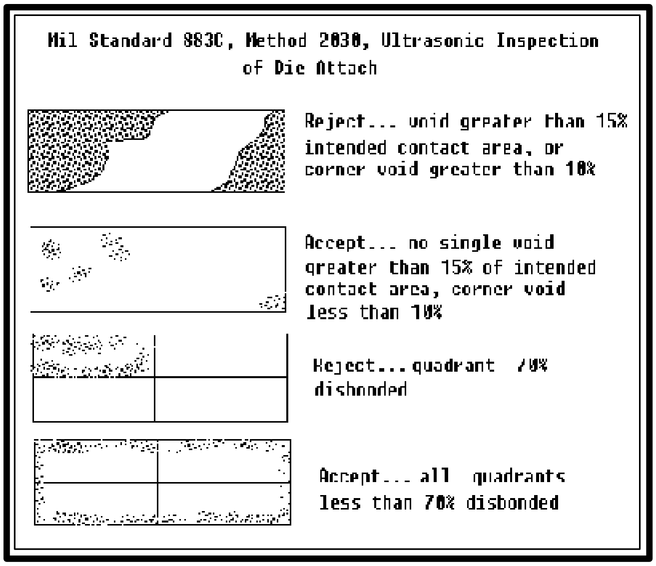


Figure 9: The same device as shown in Figures 6 & 7, has a crack in the die, as indicated, that is associated with poor die attach.


Mil Standard 883C, Method 2030, Ultrasonic Inspection
of Die Attach

Reject... void greater than 15%
intended contact area, or
corner void greater than 10%

Accept... no single void
greater than 15% of intended
contact area, corner void
less than 10%

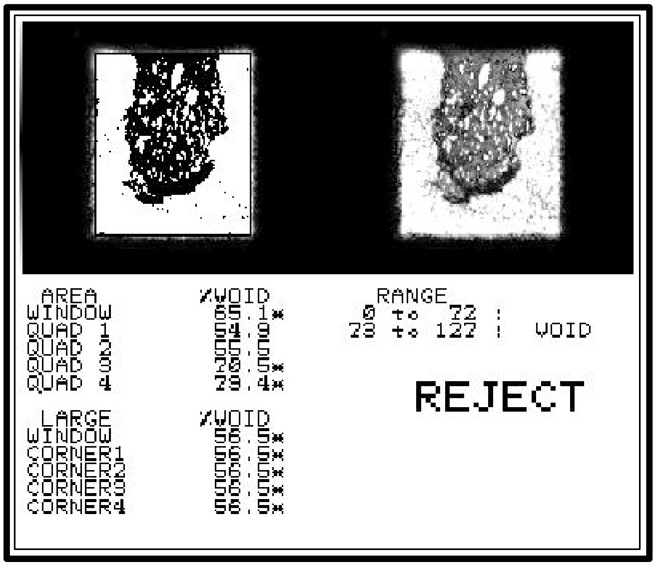
Reject...quadrant 70%
disbonded

Accept... all quadrants
less than 70% disbonded

Figure 10: MIL-STD-883; Method 2030: "Ultrasonic Inspection of Die Attach" accept/reject criteria.

built" assemblies with AMI techniques and run environmental tests on them. The degradation of the die attach bonds can then be tracked and characterized over time.

Figure 11 provides an example of performing image analysis on a die attach acoustic image.



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 AREA          %VOID          RANGE
WINDOW          65.1*      0 to  72 :
QUAD 1          54.9      73 to 127 :   VOID
QUAD 2          55.5
QUAD 3          70.5*
QUAD 4          79.4*               REJECT

 LARGE         %VOID
WINDOW          56.5*
CORNER1         56.5*
CORNER2         56.5*
CORNER3         56.5*
CORNER4         56.5*
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Figure 11: The same image as shown in Figure 6 is shown with digital image analysis results. Note that the area of the die attach is 65.1% disbonded.

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