

Trends and Considerations in Automotive Electronic Packaging

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The transition from mechanical systems to electronic assemblies continues to transform the automotive landscape. Automotive electronics currently represent one of the higher semiconductor growth segments with a CAGR of 6.8% (2012-2017).¹ This year, semiconductor content in the automotive sector is forecasted to produce \$25.9B in revenue. According to Freescale Semiconductor, today's electronic systems account for more than one-third of the total cost of new vehicles. Figure 1 highlights several of the major system drivers contributing to semiconductor content growth pursuant to Freescale's target markets.²

Safety is the most important consideration for consumers and to this end, government mandates have ensured a continuous flow of safety features designed to address factors from collision avoidance to survivability (should a collision occur). Surveys show that comfort is the second most important consumer requirement and a strong driving factor in the purchasing decision. Both safety and comfort are nonnegotiable expectations, with price point and branding defining specific features and performance. Connectivity is the third requirement coming from the next generation automotive customer and it represents a considerable and expanding market. Connectivity is also being legislated in multiple countries for purposes of safety. In Europe, for example, eCall legislation requires all vehicles to have connectivity to the cellular network with the ability to dial emergency services in the event of an accident. The draft legislation would require all new vehicles to deploy eCall after October 2015. Buyers will also demand vehicle designs that allow them to project their individuality more than in the past. The next generation sees the automotive platform as delivering an always on, always moving, connected lifestyle with as much customized individual expression as possible (music, contacts, mapping, alerts,

Automotive Electronic Content Growth

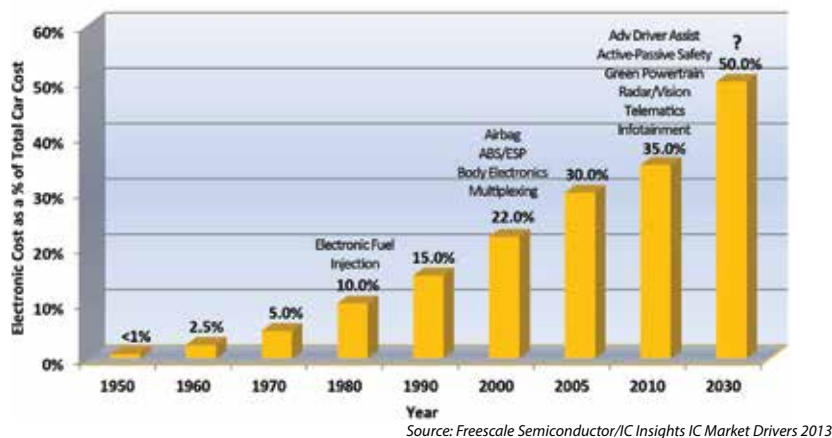


Figure 1. The proliferation of electronic content (semiconductors, sensors, etc.) in automobiles.

interior ambience, etc.) Safety, comfort, connectedness and individual expression will drive growth in automotive electronics over the coming decade.

Semiconductor usage can be represented by four broad categories as listed in Table 1. These electronic systems often overlap, addressing multiple categories concurrently. And, as more features are added to the vehicle, automakers must also reduce weight, providing additional impetus to replace mechanical systems with electronic ones.

Figure 2 identifies a number of high level functions identified in Table 1 that are controlled by today's electronic systems.

In addition, hybrid and electric vehicles are forecasted to integrate significant electronic content in automobiles. Electronic vehicles employ components such as an electric motor, inverter, dc-dc converter, control electronics, sensors, and high-voltage batteries in addition to/in place of conventional components.³

By Volume, Lead Frame Packages "Own the Road"

Lead frame products are by far the

largest type of automotive packaging as they have proven themselves very reliable components. Due to the long product life cycle, lead frame packages selected over a decade ago are still being manufactured for the same applications.

Lead frame packages are some of the most diverse found throughout the automobile. SOIC, TSSOP, SSOP, and PDIP packages support such functions as Tire Pressure Monitoring Systems (TPMS), drive train chassis and braking safety systems. TQFPs and MQFPs house microcontrollers for engine control systems. Even SOT/SCs, LQFPs, and PLCCs are found within the automotive platform. The most prevalent package is the *MicroLeadFrame*[®] (MLF[®]) and supports a considerable selection of device types.

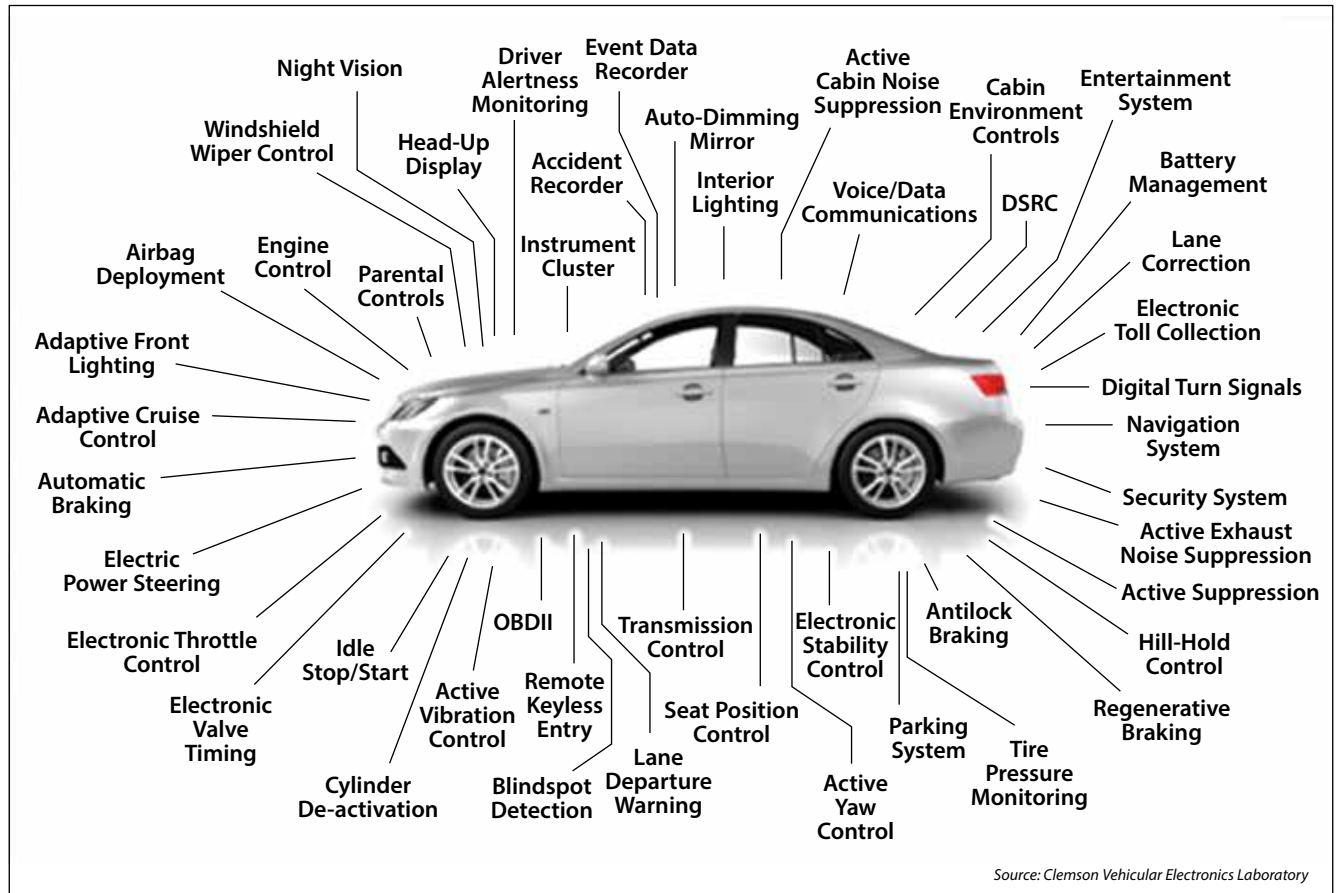
This is not to say that non-lead frame packaging is absent from today's vehicles. In fact, PBGAs, fine pitch FBGAs (ball pitch <1.0mm) and even Stacked Chip Scale Packages (SCSP) are present. Fine pitch packages of 0.5mm are being accepted for certain applications such as Transmission Control Unit (TCU) modules. Microcontrollers (MCU) are extremely

prolific within the automotive environment and, although found in MLF® packaging, they can also be found in PBGAs as well as high thermally efficient TEPBGAs within the engine control system. FBGAs support cellular connectivity, audio and GPS systems. Wafer Level Chip Scale Packages (WLCSP) are emerging in automotive systems and will proliferate over time.

Analog ICs, microcontrollers, and sensors now command the highest device volumes. Analog ICs accounted for an estimated 41% - and microcontrollers accounted for roughly 39% - of the automotive IC market in 2012. They are the most widely used ICs in cars today. There are anywhere from 25 to 100 MCUs located throughout the typical automobile and well over 300 in premium vehicles. New communications, entertainment and computing applications drive MCU content. Advanced parking systems such as self-parking, advanced cruise control, collision avoidance systems and driverless cars require MCUs, as do the growing number of positional, stabilizing, climate and engine performance sensors.⁴ Both 16-bit and 32-bit microcontrollers typically require higher lead count packaging such as PBGA or QFP type

| Automotive Feature | System Examples |
|---|---|
| Performance, Fuel Efficiency and Environmental Sustainability | Engine control/powertrain control modules, start-stop, motor driver, etc. Hybrid and fully electric vehicles (HEV/EV) systems. With internal combustion engines used in 87% of new vehicles, fuel consumption and emission regulations require constant control and monitoring systems, as well as suspension and braking stability, speed-distance control systems and advanced steering systems (influencing safety also). |
| Passive and Active Safety | Air bag systems and satellite crash sensors, anti-lock braking systems, Electronic Power Steering (EPS) and Electronic Stability Control (ESC), Near Object Detection Systems (NODS) and collision avoidance systems, Head-Up Displays (HUD) combined with Advanced Driver Assistance Systems (ADAS) such as parking assist, blind spot detection, advanced cruise control and Tire Pressure Monitoring Systems (TPMS). |
| Comfort, Aesthetics and Security | Remote keyless entry, climate control (HVAC), power windows/seat positioning (also heating and cooling), dashboard instrumentation; hands-free/noise cancellation; interior lighting, cabin ambiance driving this segment as an important differentiator for next generation consumers. |
| Infotainment | Audio/visual such as analog and digital radios, HDDs, TV and DVDs, USB connections; smartphones and other handheld devices interfacing with the dashboard supporting a continuous transfer of functions (telematics, navigation, other media); In-vehicle Ethernet will also be provided although not accessible by the consumer due to security reasons; Wi-Fi will be widely available and able to connect to the cellular network as a hot-spot. |

Table 1. Automotive Electronic Categories.



Source: Clemson Vehicular Electronics Laboratory

Figure 2. A significant number of electronic systems controlled by semiconductors and MEMS devices are found in today's automobiles.

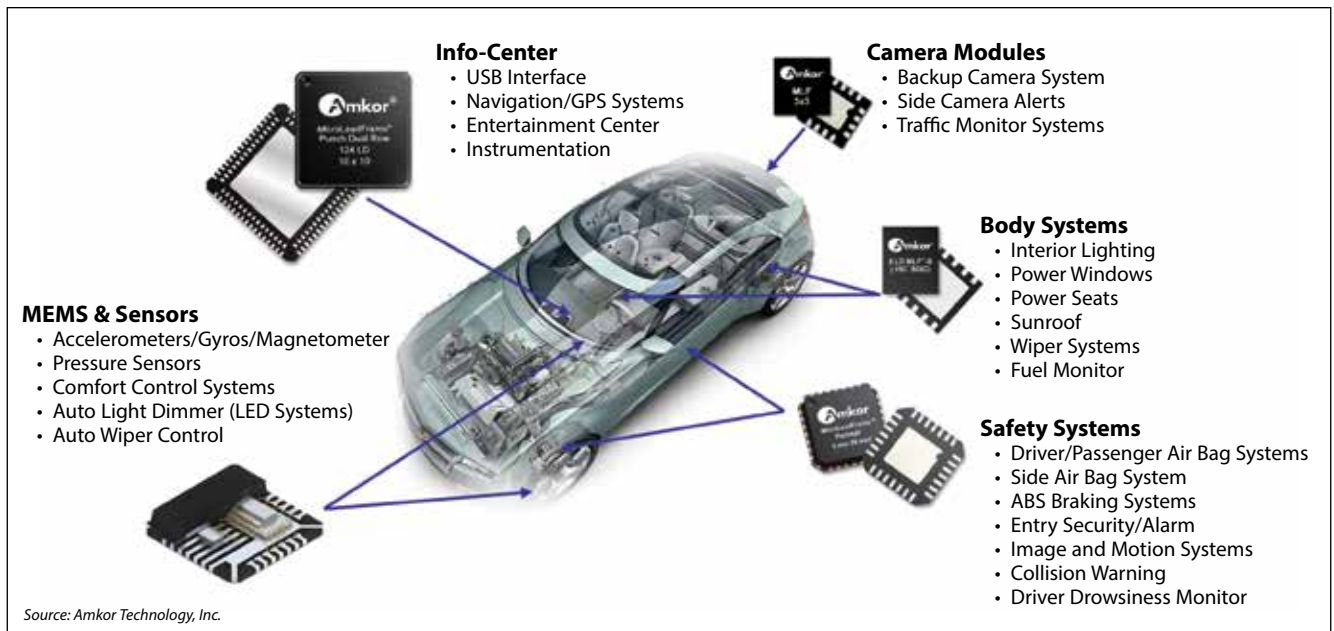


Figure 3. Several device types, from silicon ICs to MEMS, utilize MLF® packages for their wide variety of sizes, long history of excellent reliability, and mature HVM lines.

packaging to support engine control modules and emerging intelligent car systems, although they can also be found in TQFPs and MQFPs. Others are transitioning from PBGA to FBGA platforms.

Consider the MLF®/QFN/DFN

Amkor introduced the MLF® package in 1999 and today, it is one of the most commonly used leadframe packages in the world. The MLF® package ranges in size from sub-2x2mm (an extremely popular group of packages) to as large as 13x13mm. They support single ICs as well as multiple stacked die. MLF® packages are versatile and can be designed with features customizable to a particular application. Package height measures 0.35mm in High Volume Manufacturing (HVM) and a transition to 0.28mm using standard methodology is underway. Lead count as high as 180 in dual row configurations are available and there are no die stacking limitations. Wire sizes tend to run at 0.6mil for gold and 0.7mil for copper. Figure 3 illustrates a number of automotive systems that employ MLF® packages.

There is a very fast and growing migration of dual inline products and TSOP/QFPs to MLF® packages. Low resistivity and thermally enhanced epoxy and solder paste die attach materials have enabled this trend.

MLF® Mean Time to Failure (MTTF) is historically very good. Automotive customers will inspect the package lead to PCB joint looking for well-formed solder fillets to support increased reliability. In

anticipation of this value-added benefit, Amkor originated the side wettable fillets and concavity (or “dimple”) to allow for the formation of a rugged solder joint as well as its automated inspection. The dimple promotes formation of the fillet using a controlled quantity of solder that is deposited at the end of the lead. Both versions of the MLF® package - saw and punch singulation - offer this feature. Figure 4 shows a close up of the side wettable fillet and dimple (left) that produce solder fillets of controlled volume and location (right).

The Impressive Proliferation of Sensors

Government regulations around the world are playing a determining role in sensor and MEMS adoption. In the US, the 1970s saw fuel economy improvements with pressure sensors in air-intake systems such as Manifold Absolute Pressure (MAP) sensors and Barometric Air Pressure (BAP) sensors. In the 1980s and 1990s, crash detection for airbag deployment ushered in the use of additional pressure sensors and accelerometers. The TREAD Act in the 2000s required tire pressure monitor systems on all new passenger and light trucks to discover potential safety defects in tires, and Electronic Stability Control (ESC) propelled the emergence of both accelerometers and gyroscopes. Today, a growing number of automotive regulations around the globe are increasing the requirements for sensor systems in vehicles, driven by greater safety, reduced emissions and improved fuel consumption. In fact, sensor content in automobiles has grown from 10s

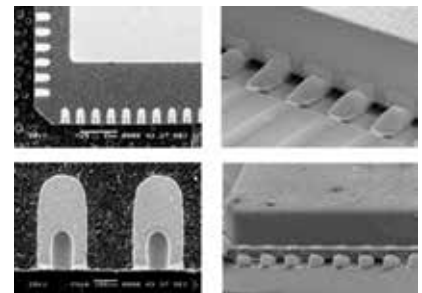


Figure 4. The side wettable lead with concavity (left) creates solder fillets of known volume that enables visual inspection of package to PCB joints. The top right view shows a saw singulated package with a 1.0mm lead pitch and the bottom right view shows a punch singulated package with a 0.5mm lead pitch.

to 100s of devices per vehicle.

Per Strategy Analytics, the demand for automotive sensors will grow at 6.8% CAGR between 2012 and 2017, rising from \$16.9 billion to \$23.5 billion.⁵ Sensor growth rates vary between the main automotive producing regions of the world. Safety system growth is the largest driver of sensor growth through 2020. Leading automotive suppliers saw 15% to 20% growth as more government regulations worldwide required electronic stability control units, and China adopted airbags en masse.

Sensors were initially introduced in hermetic packages for airbags and anti-lock braking systems. These were MEMS structures in cavity packages with pressure

sensors representing the highest volume. Although the first packaged MEMS sensors for airbags have remained unchanged in their design for more than twenty years, there has been a phenomenal amount of progress in automotive packaging during this time. Today's MEMS packages are tasked with integrating multiple sensors together. These "fusion sensors" often have diametrically opposing requirements regarding device stress management, package handling and signal propagation.

Sensors in backup systems, Head-Up Displays (HUD), infotainment and diagnostic interfaces are prevalent and moves toward standardization are being undertaken. MLF[®], LGA and "cavity MEMS" are three of the most popular package types. Optical sensors are easy to produce in in-frame MLF[®] and LGA formats. Flow sensors use a cavity in the over-molded format or create a hole in the lid of the package.

The key to sensor packaging is to utilize existing package platforms in order to rapidly ramp to HVM (tens of millions of packages per month), control costs, reduce time to market, and apply existing reliability and quality systems for new product introductions. There is a concerted effort underway to move from custom sensor packages to standard footprints even if the inside of the package may still be quite customized.

MEMS are well suited for a wide variety of automotive applications due to their reliability and ability to ramp quickly to high volume manufacturing. A sample list of sensor types and automotive end-applications are shown in Table 2.

Infotainment Reshapes the Cabin

Infotainment and the new "connected vehicle" will drive the adoption of many newer package families although modifications to pass stricter automotive certifications may dictate changes to materials or construction. Many packages for cellular and tablet applications are not acceptable or marginally so.

Today, OnStar will unlock your doors, start your vehicle remotely, provide tracking data, process diagnostic information and communicate through the smartphone. Voice activated systems as well as MEMS microphones providing in-cabin noise reduction are being designed into high end automobiles. Head-Up Displays (HUD) allow the driver to keep his eyes on the road with the intent of making driving safer amid the distraction of managing more information. Conversely, cars that communicate with each other and driverless automobiles are also being demonstrated for future adoption. Dual or other



Figure 5. Illustrated above is an example of head-up display (HUD) technology "leveraging night vision, navigation and camera-based sensor technologies to project images produced by ultra violet lasers onto the surface of the windshield." An alternate approach uses TI's DLP[®] technology which is fast becoming a new trend in HUD due to its imaging capabilities.

| Pressure Sensors | Accelerometers |
|---|---|
| Manifold Absolute Pressure (MAP) Sensor | Stand Alone Airbag Front Sensor |
| Barometric Air Pressure (BAP) Sensor | Airbag Peripheral Sensor |
| Boost | ESC Acceleration Sensor |
| Fuel Rail | Roll Over Sensing |
| Cylinder Pressure | Tire Pressure Monitoring System (TPMS) |
| Vacuum Boost Stop and Start | Integrated GPS |
| Oil Pressure | Active Suspension |
| EGR | Safety |
| Particle Filter | Vibration |
| Oil Transmission | Electronic Parking Brake |
| Fuel Vapor (Tank) | Gyroscopes |
| Brake & ESP | Roll Over Sensing |
| Suspension | GPS Navigation |
| Steering | ESC Gyroscope |
| Side Airbags | Inertial Combos (Accel + Gyro) |
| Tire Pressure Monitoring System (TPMS) | ESC, Rollover, Airbag, etc. Combos |
| HVAC Fans | Optical MEMS for Heads Up Displays |
| HVAC Hydraulics | Magnetometers |
| Seat Occupancy (Weight) | Microphones |

Table 2. Various Sensors and Their System Insertion

multi-row packages (MLF[®], LGA, cavity, etc.) are expected to emerge for these downstream opportunities. This said, the most popular Infotainment packaging is trending toward FCBGAs.

Summary

The dynamic and changing landscape of automotive electronics is exciting to witness and inspiring to support. Electronic adoption will continue to progress in almost every area of automotive design, transforming our driving experience beyond recognition. The accelerated adoption of so many package platforms within such a diverse environment presents an abundance

of opportunity that will fuel creativity and innovation down the road. ♦

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- 2 R. Lineback, B. McClean, B. Matas, T. Yancey, "Integrated Circuit Market Drivers 2013," IC Insights, Inc.
- 3 Randy Frank, "Hybrid Vehicles Propel Increased Electronics Content," Electronic Design, Oct. 2004.
- 4 R. Lineback, B. McClean, B. Matas, T. Yancey, "Integrated Circuit Market Drivers 2013," IC Insights, Inc.
- 5 Mark Fitzgerald, "Global Automotive Sensor Demand to Exceed \$25 Billion by 2020," Strategy Analytics, May 7, 2013.
- 6 Dashboardnews.com, "Technology continues to evolve in the auto industry," Dashboard News, March 6, 2012.



Automotive Assembly Differentiation

THE AUTOMOTIVE INDUSTRY assumes component lifetimes in terms of decades, not years – as well as an expectation of performance in extreme environments. Demanding environmental and reliability standards typically drive a four year development cycle which includes extensive reliability testing and field trials. In the assembly world, the automotive mindset is one of best practices and zero defects. Numerous factors are taken into account to achieve these goals. Systems such as stability control, airbag deployment and anti-lock brakes often require specialized manufacturing flows, materials or inspection protocols to ensure both performance and long term reliability.

Customer Criteria

The OSAT's customers ultimately determine the process and test flows necessitated by the particular automotive system. There are six classes within automotive specifications, each calling out different performance criteria. Therefore, visibility into end use is important in order to choose or design IC packaging with appropriate cost/performance goals in mind.

Material Selection

To tackle demanding automotive reliability requirements, the choice of materials must be considered during the early stages of device design and in consideration of the targeted application. Two examples of materials that can be optimized to address extreme temperature or high stress conditions are Epoxy Mold Compounds (EMC) and Die Attach (DA) materials. In many cases, a high thermal EMC material is required to meet demanding environmental conditions.

In addition, a material's potential exposure to harsh chemicals (oil, gasoline, grease, hydro-chemicals) or external environmental factors (rain, ice) must be considered. Furthermore, extreme vibrations and shock excursions during engine component operation, or within traction

Amkor Technology Philippines, an Automotive Center of Excellence



All five of Amkor's factory sites throughout Asia run automotive products in high volume. However, it is the Amkor Technology Philippines (ATP) operation that is home to the largest base of automotive qualified products, customers and OEMs. ATP maintains a diverse automotive package portfolio including lead frame, ceramic and laminate packages as well as system-in-package (SiP) products. ATP also provides a full range of test services including die processing and inspection, wafer probe, burn-in, strip test and test development.

Amkor has identified ATP as its *Automotive Center of Excellence*, offering designated manufacturing lines operated by highly skilled and automotive-trained personnel. Automotive demarcated bill of materials, controls and process flows are managed. Moving forward, ATP is further augmenting its focus to:

- Design-in quality across all business processes and manufacturing phases
- Implement firewall concept based process controls
- Endorse a "Zero Defect to Zero Error" philosophy

ATP has passed a significant number of VDA6.3 process audits by direct and 3rd party customers. The factory was awarded General Motors Supplier Quality Excellence Award for 2012. Suppliers who receive this award have met or exceeded a stringent set of quality performance criteria along with the cross-functional support of the entire GM organization.

The ATP factories contain over 1.3M square feet of manufacturing space and are ISO-9002, QS-9000, ISO 9001, ISO/TS 16949, ISO-14001, OHSAS-18001, ANSI/ESD S20.20 and DSCC / QML (military standard) certified.

control, suspension and steering systems, or in brake rotors or wheels may also require specialized materials such as proper wire sizing and type, wire coat, gel-coat, lead frame or special laminate substrate designs.

Supplier Management

It is important for the OSAT to be informed of product utilization in automotive applications. The automotive sector has developed its own supplier assessment and audit processes. One set of rules for doing process audits comes from the German automotive industry (VDA6.3). It is often used to meet the requirements of another specification, ISO/TS16949, aimed at developing quality management systems and emphasizing defect prevention and the reduction of variation and waste in the supply chain. And although the International Automotive Task Force (IATF) contributed to its preparation, many large Asian manufacturers have their own quality management requirements. Therefore, upstream visibility is important and enables the OSAT to become a partner in support of these criteria. The OSAT will communicate through their supply chain, improving supplier quality by raising awareness, documenting specifications, implementing Best Known Methods (BKM), and aligning with provider expectations which may also include downstream compliance certifications or specialized testing.

Conflict minerals/metals remain an area of great importance to the global automotive supply chain. Each supplier must implement procedures demonstrating that the materials procured and sourced are in compliance with government, corporate and customer policies.

Process Flows

Safety, power train and chassis end-use have the highest reliability requirements. In this case, visibility to end-use requirements may generate material, equipment, or process flow options that are customized to meet these more extreme applications.

Automotive processing may include extra cleaning steps or process control monitors. Modifications to basic assembly process steps, such as the use of security wire bonds, may be incorporated into an automotive flow. The security

bond reduces the opportunity for any lifting that could occur. Another example of a modified process flow for automotive application is the roughening of the surface of the lead frame to enhance EMC adhesion. Additionally, a die attach material that provides 100% coverage may also be required, such as conductive or non-conductive epoxy or die attach films.

Inspection Criteria

Specialized inspection steps and sampling plans are often employed for automotive applications. This drives additional process steps as compared to a typical commercial process flow. Similarly, the ability to inspect assembled packages on the PCB is an important requirement for automotive builds. Although x-ray inspection can be utilized if the board is thin enough, when both sides of a board are densely populated, inspection can become difficult. Amkor developed and introduced a side wettable leaded package to visually enhance PCB inspection and ensure that proper solder joint coverage is made between the package and PCB. Side wettable leads have become more of an automotive standard (see Figure 4).

Quality Planning

Advanced Product Quality Planning (APQP) was developed in the 1980s by the “Big Three” US automobile manufacturers, Ford, GM and Chrysler. It is similar in concept to “Design for Six Sigma” but for the automotive industry. Downstream adoption of APQP assists in compliance with overall automotive control plans and the intent to maintain the highest manufacturing standards for all constituent components used within a vehicle.

Reliability Testing

The Automotive Electronics Council sets qualification standards and AEC-Q100 outlines critical stress test qualification for automotive ICs and packaging. Electronic components must be rugged enough to operate in these environments at the IC, package and board level.

Electrical Testing/Lot Screening

Post assembly test is the final screen confirming device and package performance to specifications and overall integrity. A fundamental difference between

consumer and automotive test is the tie to statistical principles and the handling of “inherent risk”. For example, many consumer electronics are allowed to be retested with subsequent passing components deemed “good” product. This is contrary to automotive standards where advanced statistical screening may reject the entire lot. If the automotive sector, in their goal to achieve Zero Defects, cannot fully explain the reason behind a low yield occurrence, it will reject the entire lot as an anomaly with some inherent risk and remove it from the population.

Designated Lines, Trained Personnel

Designated or dedicated lines and equipment are sometimes sought by the customer. These may include specially trained personnel, error proofing systems, or hands-free processing systems. Specific product identification in the WIP may also be featured.

Change Control

Automotive standards are among the most stringent and change management is often measured in years instead of quarters that are more commonly seen in commercial applications. If a safety or reliability concern instigates the change, the timeline will be accelerated although safeguards and rigorous testing are still required. Change control is often undertaken in concert with the customer (incorporating Change Review Boards) to assess technical risk and downstream implications. A proactive issue management infrastructure compliments continuous improvement practices.



About Amkor

Amkor is a leading provider of semiconductor packaging and test services to semiconductor companies and electronics OEMs. More information on Amkor is available at the company's website: www.amkor.com.