

Power Inductors for Automotive Applications

INTRODUCTION

Over the next 10 to 15 years, countries around the world will be working to reduce their CO₂ emissions to levels mandated by their governmental regulatory agencies. The transportation sector has received a great deal of attention due to its overall contribution to CO₂ emissions, its rapid expected growth rate – particularly in emerging markets – and the opportunities for technology to help reduce those emissions. The European Union has set an aggressive CO₂ emission target of 95 g/Km by 2020 while China's 2020 target is 117 g/Km, and the United States has a 2025 target of 97 g/Km.

Although cars powered only by internal combustion engines (ICE) are expected to account for most of the production volume for the next ten years, rapid growth is expected in vehicles with alternative powertrains, primarily:

- **Mild hybrid** – Often referred to as parallel hybrid, the powertrains do not have sufficient electric power to move the vehicle without the gasoline engine. They have two battery systems: a 48V system for powering heavy loads such as air conditioning, and a 12V system for lighter loads such as the entertainment system. They are more fuel efficient than ICE-only vehicles and are expected to grow in popularity more rapidly than vehicles employing other alternative powertrains.
- **Full hybrid** – Often referred to as series hybrids, the powertrains have electric motors and batteries with enough power to move the vehicle for some time without the gasoline engine. They typically have a battery system that operates at 100V and above.
- **Plug-in hybrid (PHEV)** – The powertrain has both an electric motor and ICE, but the electric motor can operate the vehicle for longer distances than that of a full hybrid. The batteries are fully recharged by plugging the vehicle into an electric power outlet.
- **Battery electric vehicle (BEV)** – The powertrain consists of an electric motor only. The batteries are fully recharged by plugging the vehicle into an electric power outlet.

The move towards alternative powertrains is made possible by more sophisticated electronic control systems. These control systems must be capable of operating reliably in harsh environments that experience severe vibrations and wide temperature extremes.

OPERATIONAL DEMANDS

The electronic control units (ECUs) in automobiles perform many functions, with optimizing the comfort, performance, fuel efficiency, and safety of the vehicle as the primary objective. As the technology has evolved, ECUs have moved out of the passenger compartment and closer to the mechanical devices they control. ECUs have been developed for mounting inside the engine compartment, and more recently mounted directly onto devices such as the engine, transmission, oil pump, etc. Recent advances in mechatronic integration have resulted in ECUs built into the actual device, such as the alternator, battery charging system, and transmission control.

Physical Environment

When ECUs move closer to the device they control, their operating environment becomes increasingly harsh (see Figure 1). Those ECUs must be able to withstand higher temperatures and broader temperature ranges. Many devices, such as motors and actuators, also present a high vibration operating environment. ECUs integrated into such devices must also be able to withstand those vibrations.

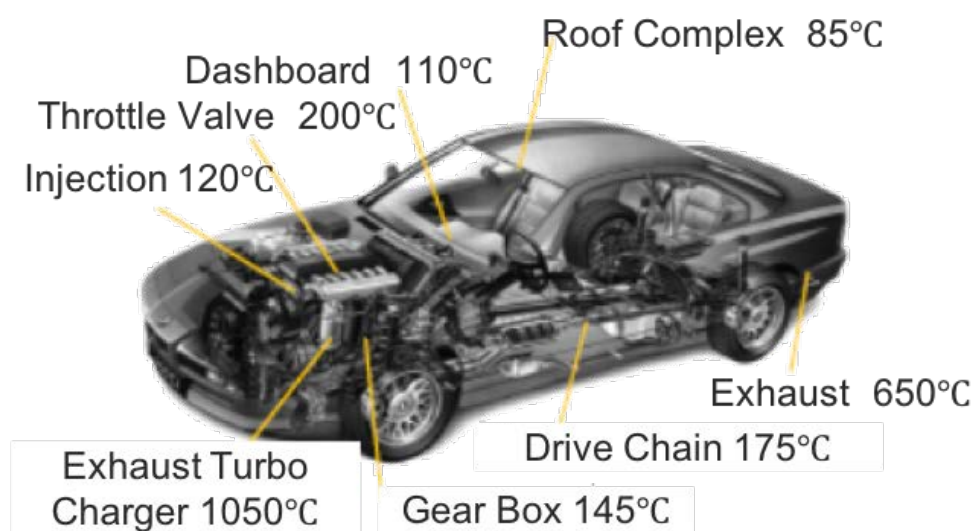


Figure 1. Automotive Temperature Environment

Voltage

As mentioned in the previous section, the growth in mild hybrid technology is expected to be greater than other powertrains because they are more fuel efficient than ICE-only vehicles. Figure 2 shows that many ECU components must be able to operate at 48V instead of 12V. Some components are also needed to handle the bidirectional 12V / 48V DC to DC power interchange. And of course, as the popularity of full hybrid powertrains grows, more components will be needed to operate at 100V and higher.

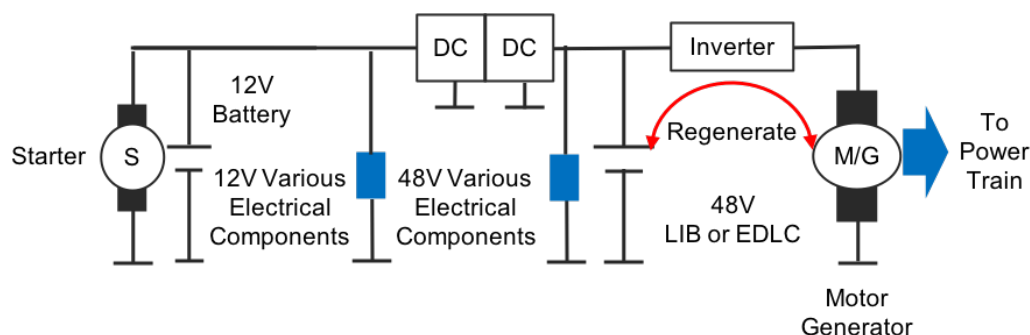


Figure 2. 48V Mild Hybrid Battery System

Miniaturization

To support the advances in hybrid and battery powertrain technologies, an increasing number of ECUs are needed to provide greater control over various aspects of the vehicle's operation. As the numbers increase the average size of an ECU must shrink to fit within the limited space available. This means the numbers and/or size of components used in the ECU must also shrink.

Frequency

Many components in an ECU must operate at lower voltages. Microprocessors and microcontrollers, for example, typically have a supply voltage somewhere between 5V and 1.2V. The power supply switching frequency in those applications must be set above the AM band to avoid interference with AM radio (see Figure 3). Those higher frequencies contribute to the reduction of component size but place additional parametric constraints on the ECU components.

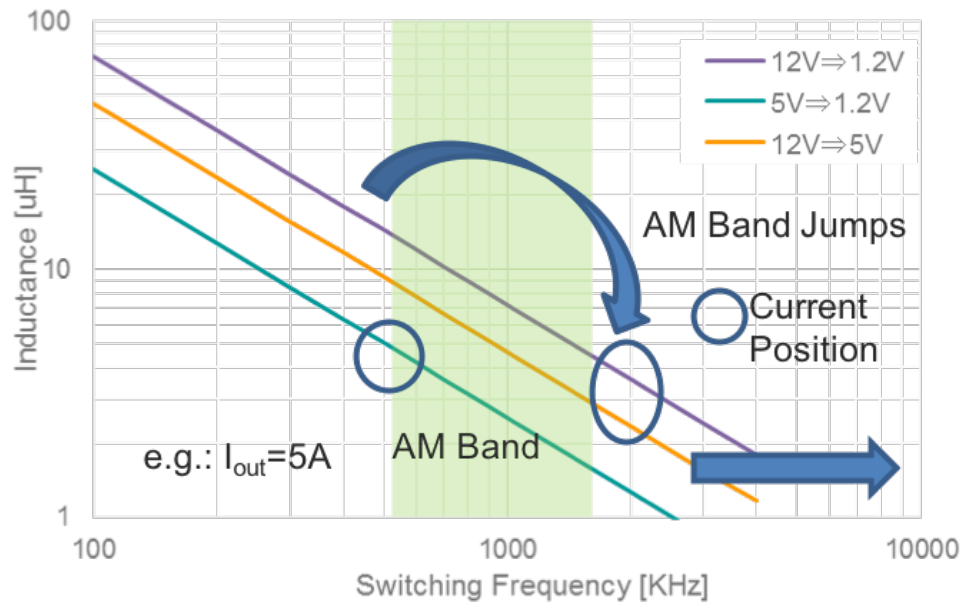


Figure 3. Power Supply Switching Frequency

SURFACE MOUNT POWER INDUCTORS

TAIYO YUDEN offers a robust portfolio of surface mount (SMD) power inductors for automotive ECU applications. The focus of this whitepaper is on TAIYO YUDEN's metal core and ferrite core offerings. These inductors are AEC-Q200 qualified, meeting the global standard for high-temperature and high-humidity tolerance, thermal shock resistance, and durability in automotive applications. Built using state of the art materials technology and manufacturing processes, the inductors have improved saturation current and packaging characteristics ideal for addressing the demanding requirements of advancing powertrain technologies.

MCOIL™ MD SERIES

The MCOIL™ MD series of metal core SMD power inductors are wire-wound products containing a core made with a proprietary magnetic, compacted metal alloy powder that does not use an organic binder. This compacted powder is shown on the left side of Figure 4, with the black areas indicating the absence of an organic binder. Each grain in the powder has an oxidized coating to maintain insulation, as shown on the right side of Figure 4. The performance of the material is superior to ferrite cores and metal magnetic cores bound with an organic material. Magnetic permeability of the core is approximately twice that of traditional composite cores.

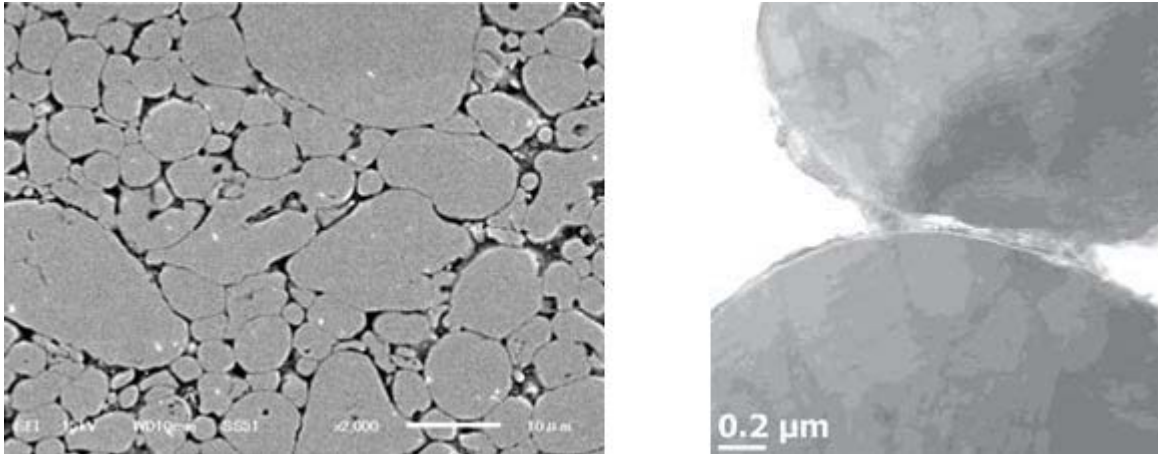


Figure 4. Metal Magnetic Compacted Powder (left) and Thin Oxide Layer on Particle Surface (right)

The wire winding on the proprietary core is done with greater accuracy than what is typical with a traditional composite core. After the wire is wound a high- μ shielded resin is applied to cover the wire winding. This resin also helps improve the inductor's structural strength. Figure 5 shows the MCOIL after the wire is wound around the core but before the resin is applied (left) and after the resin is applied (right).

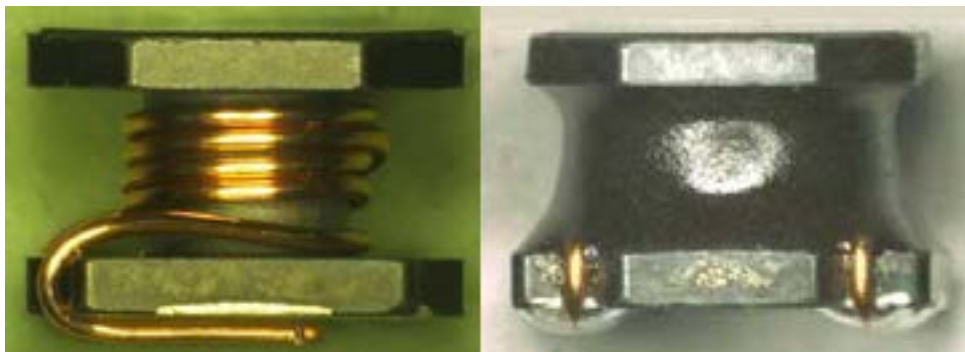


Figure 5. MCOIL Before (left) and After (right) Resin Application

Reliability Advantages

The reliability risks found in an inductor built with a traditional composite core are shown in Figure 6. The proprietary MCOIL core's higher density helps reduce the risk of cracking due to external stresses. Also, it prevents compression of the wire winding during the manufacturing process. The resin provides greater structural integrity and helps prevent the wire from moving or sliding when the inductor is under external stress. This not only lowers the risk of cracking but also the risk of developing a short.

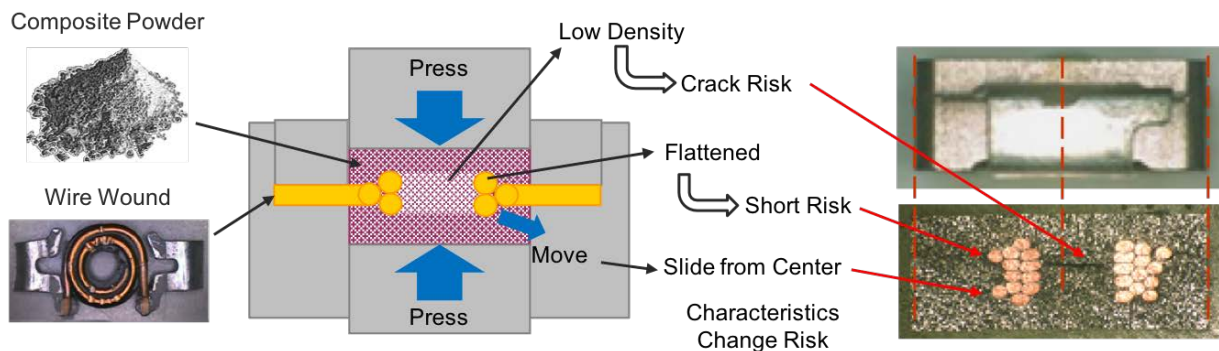


Figure 6. Reliability Risks in a Traditional Composite Core Inductor

Other Advantages

In addition to the reliability advantages, the MCOIL MD series of inductors provide the following advantages over traditional ferrite-based devices:

- Compact package size: 4.0mm x 4.0mm x 1.2mm thick and smaller.
- Inductance values suitable for high-frequency applications, up to 10 μ H.
- Low DC resistance.
- High saturation current characteristics.
- Stable self-temperature rise current characteristics.
- Low magnetic flux and RF emissions.

MCOIL™ ME-V SERIES

MCOIL™ ME-V series inductors are smaller surface mount devices than the MD series inductors. Available sizes measure just 2.5 x 2.0 x 1.2mm and 2.0 x 1.6 x 1.2mm. They are AEC-Q200 grade 2 qualified with an operating temperature range of -40°C to +125°C, including self-temperature rise. Devices are suitable for most automotive applications with the exception of automotive safety and powertrain.

The structure of an ME-V series inductor is illustrated in Figure 7. On the left is the finished product showing the round direction-identification mark on the top of the device. Structural elements of the device are shown on the right.

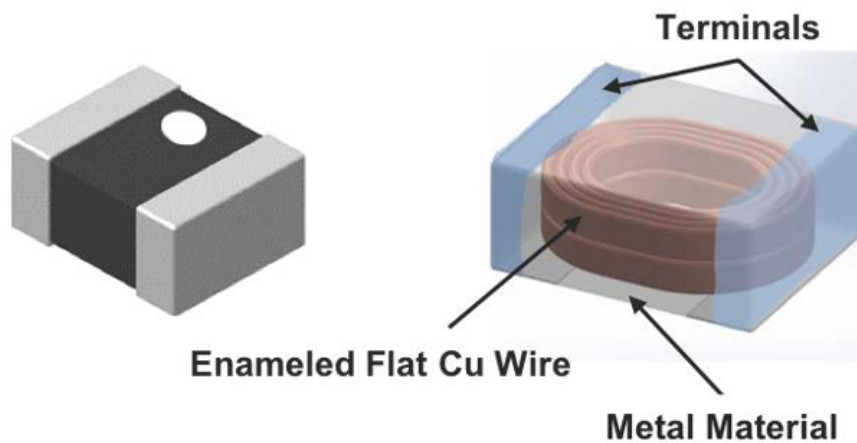


Figure 7. Structure of an ME-V Series Inductor

Referring to Figure 7, ME-V series inductors contain an enameled, flat copper wire winding. This winding is encased in a metal resin composite material. The metal resin reduces AC loss and improves reliability due to its greater thermal resistance compared to traditional materials.

Another unique feature of ME-V inductors is that the silver-nickel-tin terminal is found on five sides of the device instead of just the bottom. The resulting bond is stronger because of the solder fillet attached to the sides of the terminal. This improves mechanical reliability compared to devices with a terminal only on the bottom.

NR SERIES S/V/H TYPE

The NR series of power inductors are constructed using high-quality, proprietary materials developed by TAIYO YUDEN. The sleeveless drum core is constructed using a fine, pelletized iron oxide composite material. The material is manufactured to strict tolerances to keep the individual granules uniform in size (see Figure 8). When the drum core is manufactured using this material the result is a product with a uniform density (see Figure 9), resulting in a more even distribution of magnetic flux during operation.

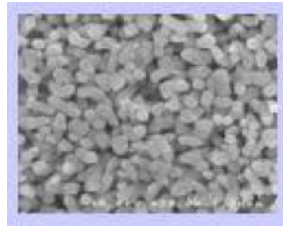


Figure 8. Pelletized Iron Oxide Material used in NR Series Ferrite Core

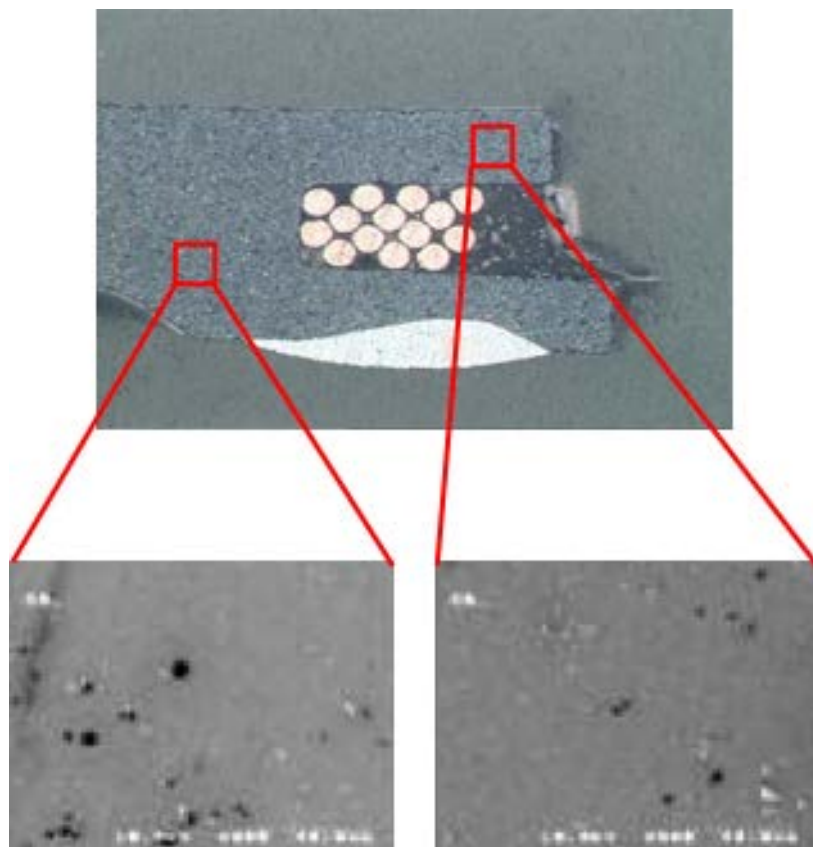


Figure 9. Uniform Drum Core Material Density in NR Series

After the wire is wound around the core, it is filled with a proprietary, ferrite-based magnetic resin. The resin is a hard polymer with ferrite powder evenly distributed throughout its structure. The primary purpose of the resin is to improve the device reliability by increasing the drum core’s strength. The resin hardness reduces the risk of the core cracking due to external stresses. Also, the resin’s linear expansion coefficient is close to that of ferrite, thus improving the device resistance to thermal strain. These two reliability characteristics are illustrated in Figure 10.

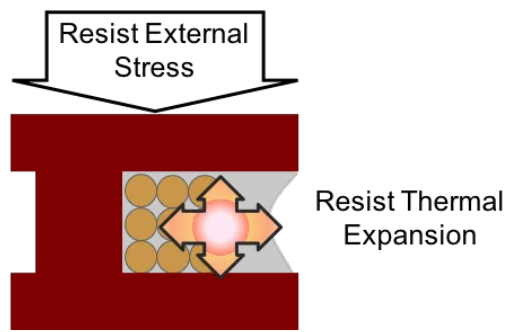


Figure 10. Reliability Improvements from NR Series Proprietary Resin

The resin used in the NR series inductors provides additional operational benefits as described in the following sections.

Thinner Drum Flange

The resin strength enables a thinner drum core flange, thus increasing the wire-wound area (see Figure 11). Increasing the wire-wound area lowers DC resistance, improves the DC bias characteristics, and increases the current rating.

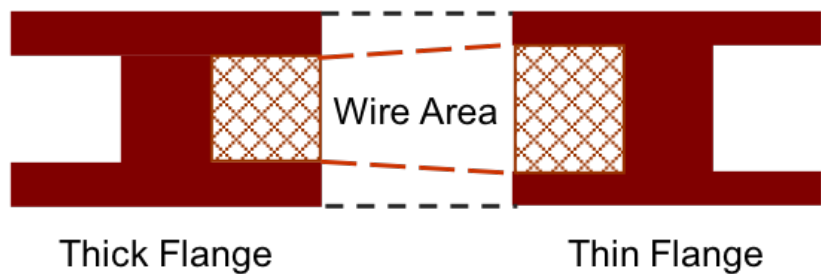


Figure 11. Increased Wiring Area due to Thinner Drum Flange

Sleeveless Drum

In an inductor with a sleeve, the sleeve guides magnetic flux and acts as a shield to prevent electromagnetic interference (EMI) in noise-sensitive applications. Saturation current in this type of inductor drops steeply, as can be seen in the top of Figure 12, because the sleeve limits magnetic flux density. An air gap exists in such devices between the sleeve and the core, bridged on one end by the device electrodes, as can be seen in the top of Figure 12. These electrodes interfere with the magnetic flux, increasing AC resistance.

In the NR series of inductors, the magnetic resin provides a path for the magnetic flux, so no drum sleeve is required (bottom of Figure 12). The combination of oxidized ferrite material in the resin and the resin itself effectively produces the equivalent of many very small barriers and “air gaps” that shield the core and prevent EMI. This results in a gradually decreasing inductance as the core is saturated with current (bottom right of Figure 12). Such a characteristic may be preferable in some applications. Also, electrodes do not interfere with the NR series magnetic because there is no gap on the bottom of inductor, resulting in low AC resistance.

Finally, Figure 12 illustrates that the drum core’s size is unchanged in the sleeveless inductor containing the magnetic resin. This means that eliminating the drum sleeve yields a smaller device without sacrificing electrical characteristics.

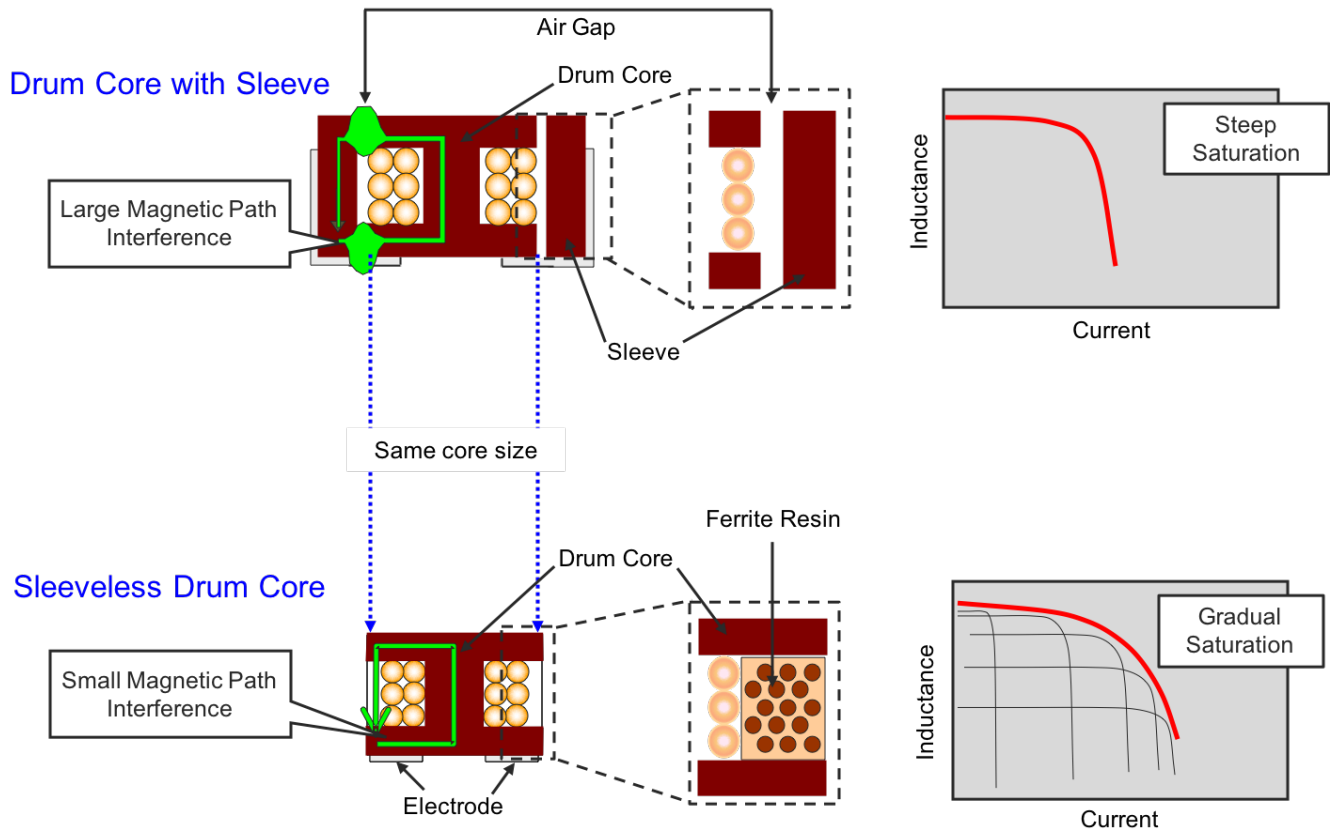


Figure 12. Effect of Ferrite Resin in Sleeveless Drum Core

Coil Directly Mounted to PCB

The wire winding that surrounds the core is mounted directly to the PCB, as is illustrated in Figure 13. The wire is not mechanically connected to a metal terminal as is done in inductors with a sleeve, thus eliminating open-mode defects due to that connection.

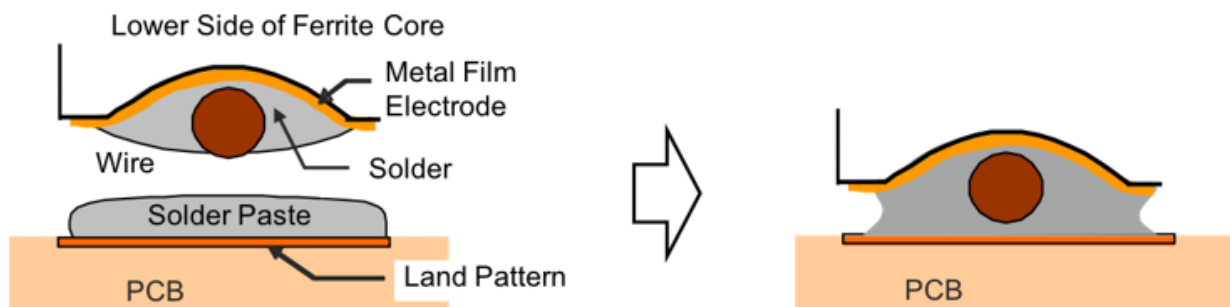


Figure 13. NR Series Inductor Coil Wire Mounted Directly to PCB

EST SERIES

Some automotive applications demand the increased mechanical strength and thermal resistance of an inductor with a drum sleeve. TAIYO YUDEN produces the EST series of ferrite power inductors for such applications. These devices have a simplified yet robust structure that provides improved mechanical strength and a maximum operating temperature of 150°C.

The design innovations of the EST series inductors start with a folded frame terminal that is mechanically fixed in place by the drum core. This helps prevent damage to the core due to temperature cycles as well as mechanical stresses such as vibration and impacts. Figure 14 shows the folded frame terminal of an EST inductor without the drum core in place.

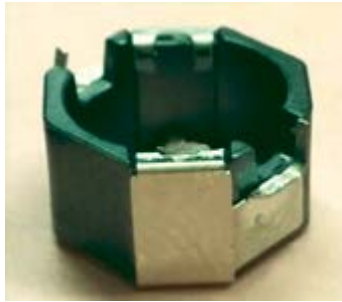


Figure 14. Folded Frame Terminal of an EST Inductor

Another key design feature is the use of laser welding to directly bond the copper coil wire to the terminal. The weld provides significantly improved bonding strength when compared to soldered connections and helps reduce the occurrence of open failures due to thermal stress and vibration. Figure 15 shows a close-up of the coil wire connection to the terminal (center) and a cross-section of the welded interface (right).

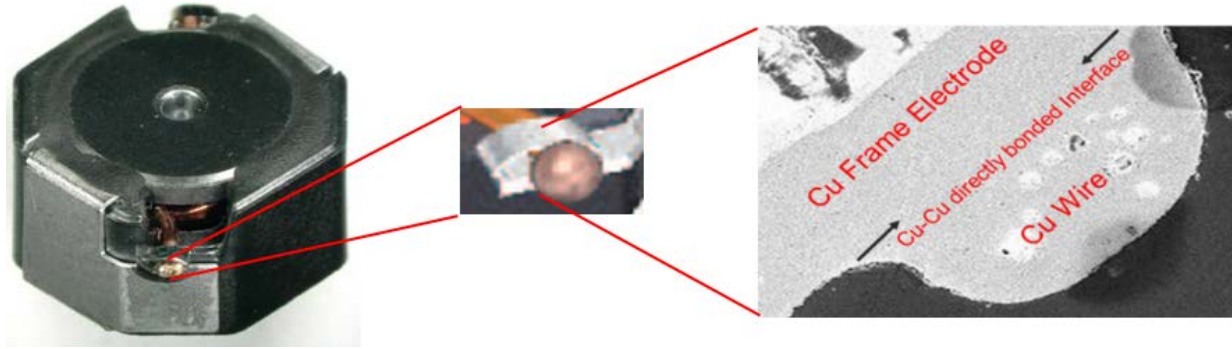


Figure 15. EST Inductor Coil to Terminal Laser Weld

Finally, the drum core is affixed to the sleeve frame using a heat cured epoxy adhesive. This helps further protect the device from mechanical and thermal stresses. Figure 16 shows the top (left) and bottom (right) view of the EST inductor. The top view shows the epoxy adhesive surrounding the edge of the drum core. The bottom view shows the folded frame terminal affixing the drum core in place.

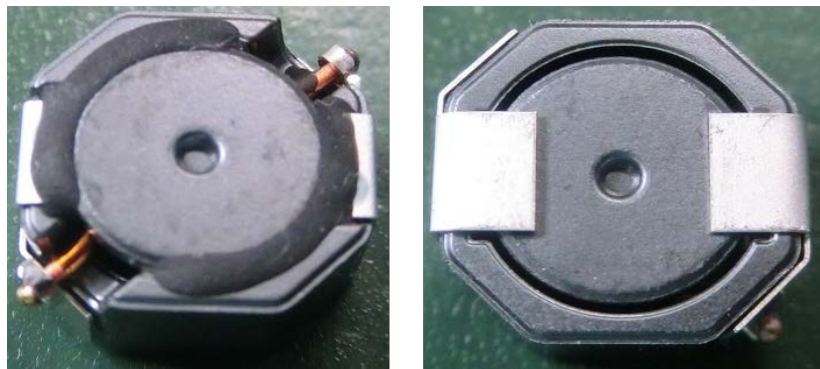


Figure 16. Top (left) and Bottom (right) View of EST Inductor

To better manage and improve product quality, each device is laser engraved with a two-dimension code that records various production parameters. If a customer experiences a problem with a device in the field, a photo of the two-dimension code can be sent to TAIYO YUDEN who can use it to trace the product's production history and determine the extent, if any, of the impact on other products. Figure 17 shows the two-dimension code on the left side of an EST inductor.



Figure 17. EST Inductor with Two-Dimension Code

SUMMARY

TAIYO YUDEN offers a broad portfolio of power inductors for automotive applications. These products have been developed and manufactured using proprietary materials and techniques that deliver improved electrical characteristics, enhance reliability, and shrink the application footprint. Because they are AEC-Q200 qualified they are ideally suited for automotive applications.