



# Designing with Plastic RF Power Transistors

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*Abstract: This white paper shows the main benefits of RF power plastic packages and provides recommendations on PCB layout, mounting and soldering techniques to create a robust as well as cost-effective design solution using over-molded plastic RF power devices.*

## Introduction

Freescale has a legacy of manufacturing high power RF devices stretching back more than five decades. Over that time, packaging technology has evolved along with the wafer technology packaged inside. In the past decade, the shift to plastic packages has accelerated in the high volume wireless segment. Today, almost all pre-driver and driver stage devices and most output stage RF power devices are available in plastic packages. Other RF power market segments are now moving to take advantage of the benefits of plastic packaging for high power RF applications. Freescale is the leader in high power RF packaging and has been making high power RF LDMOS devices using plastic packages since the mid-1990s. More than 200 million devices using plastic packages have been manufactured in the past 15 years.

## Six Main Advantages of Plastic Packages

For many semiconductor products, plastic long ago emerged as the package technology of choice. Especially for commodity products such as small signal transistors or memories, plastic offered low-cost encapsulation that was easily scaled to high volumes. For RF power amplifiers, plastic packaging was developed primarily to address certain performance limitations inherent in ceramic devices. The main benefits of plastic devices are sixfold.

### Improved Thermal Performance

The biggest advantage of using plastic packaged parts is the improved thermal performance. Plastic packages use a copper heat spreader on which the die is mounted. Copper is one of the best thermal and electrical conductors, with its thermal conductivity close to 350–400 W/m-K depending on the copper alloy used. In comparison, air cavity packages use exotic materials, such as a copper-based laminate heat spreader. The thermal conductivity of the copper-based laminate material is close to 250 W/m-K. When the die is mounted on a copper heat spreader, there is a reduction of ~15–20% in the thermal resistance compared to when the die is mounted on air cavity packages with a copper-based laminate heat spreader.

### Tighter Dimensional Tolerance

Plastic packaged parts have tighter dimensional tolerances than ceramic parts. Key dimensional specifications on a plastic packaged part (e.g., seating plane height) have tolerances on the order of  $\pm 0.003$ " ( $\pm 0.076$  mm) or better. The air cavity packages have tolerances typically in the range of  $\pm 0.005$ " ( $\pm 0.127$  mm) or larger. These tighter dimensional tolerances are a natural feature associated with the manufacturing process used to build plastic packages.

### Second-level Assembly Reliability

Second-level assembly reliability is an inherent advantage of using plastic parts. As previously mentioned, plastic packages use a copper heat spreader while air cavity packages use a copper-based laminate heat spreader. Thus, plastic packages

provide much less CTE mismatch at the solder joint between the leads and the PCB, or between the heat spreader and the coin or pallet in which it is soldered, than air cavity packages. This improves the solder joint reliability significantly. In addition, the absence of gold material eliminates any issues related to gold embrittlement of the solder joint.

## More Power in Lighter Packages

RF plastic power transistors weigh less than the alternative air cavity package options. Additionally, because of the better thermal performance of plastic packages, more power is packed in a plastic package than in an air cavity package of the same size. For comparison, the highest power device with Freescale's Airfast technology in an OM-780 plastic package has a 282 W P1dB power output capability. When the highest power device with the same Airfast die technology is packaged in the same-sized NI-780 air cavity package, it is only capable of a 260 W P1dB power output. The total weight of the NI-780 package is 4.6 g, while the OM-780 package weighs 3.1 g. With this weight differential, plastic packages can be a key factor in support of the military directive of creating replacement platform designs that are lower in size, weight, power and cost (SWaP-C) than existing solutions.

## Multi-stage RFIC Capability

Finally, one of the faster-growing RF power product areas is in the design and development of multi-stage RF integrated circuits on silicon. These RFIC devices not only have much higher gains than single-stage air cavity package devices, they also have added features, such as 50 ohm input and output, DC-blocked input matching, and inter-stage matching and decoupling. Most contain a temperature tracking and compensating feature. These RFIC devices have gains in the 33 to 36 dB range and power levels as high as 275 W. Due to the increased feature set associated with most RFIC power devices, they need the multi-lead package styles that are only available in the over-molded plastic package option. The over-molded plastic packages are more amenable to incorporating multi-lead configuration than air cavity packages.

## Correct Design Techniques for Creating RF Power Amplifiers with Plastic Transistors

In addition to the electrical design of the PA, key consideration should also be placed on how the RF high power device will be mounted in the next assembly. The mounting of the RF power device and the interface used with the device have significant influence on the cost and on the performance of the amplifier. This is not unique to plastic packages, but applies to all high power RF devices. Due to tighter tolerances, plastic parts are more amenable to automated manufacturing processes such as pick-and-place and surface-mount reflow compared to air cavity parts.

## Mounting Options and Heat Removal: Surface-mount or through the PCB?

When designing with Freescale RF power plastic devices, one of the first decisions is whether to use the surface-mount capabilities of the plastic package options and mount the RF device on the top of the PCB over a grounded via pattern, or to choose a through-the-PCB option with the RF power device mounted directly onto the metal coin or pallet.

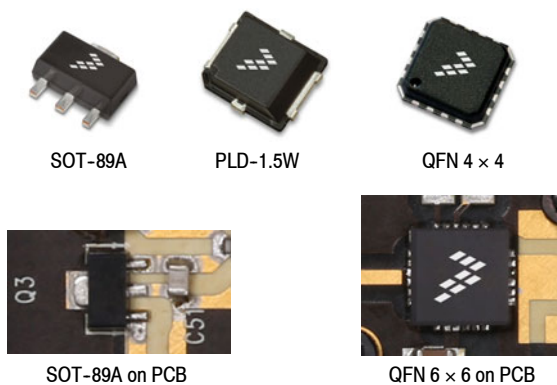
The device source contact is also the metal flange at the bottom of the package in both air cavity and over-molded plastic packages. The source contact functions as both electrical ground and thermal ground. Thus the assembly design needs to provide for a heat-dissipation path through the bottom of the device to the ultimate thermal sink.

There are two options for the heat removal: one is the use of a via farm pattern, and the second is the use of a metal coin or pallet. The via farm has higher thermal resistance than the metal coin or pallet. However, the via farm has an advantage with regard to cost: the RF PCB has many ground vias, so the addition of a few more closely spaced vias in the source pad of the RF PA (power amplifier) device will have almost no cost impact, while the addition of coin or pallet will have a significantly higher cost impact.

The decision to use a via farm or a metal coin or pallet for heat removal comes down to whether the use of a via farm can still keep the device junction temperature within the range where the device reliability still provides significant margin over the lifetime expectations. If the increase in maximum die temperature under worst-case operating conditions still meets the overall design longevity requirements, then a surface-mount option is usually the most cost-effective solution.

**Choosing between Gull Wing and Straight Leaded Packages**

The PQFN, QFN, SOT-89, PLD-1.5 and PLD-1.5W package styles are leadless packages, and they are available only as surface-mount components, as shown in Figure 1. The larger plastic package options, such as the TO and OM, have two mounting options available: a surface-mount option with gull wing bent leads and a through-PCB option with straight leads. Freescale’s RF power devices in TO and OM packages are generally available in both gull wing and straight leaded options, providing customers with appropriate choices.



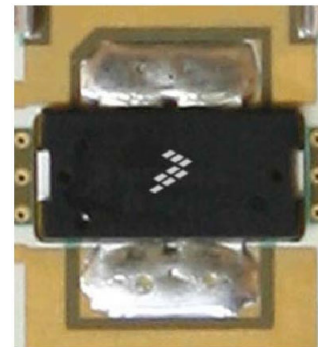
**Figure 1. Examples of Surface-mount Plastic RF Packages**

There are three main factors to consider when choosing between gull wing and straight leaded packages:

- Overall RF power capability of the RF device
- Impact of power capability on junction temperature and cost
- Thickness of the PCB when considering system-level thermal resistance

A rule of thumb is that if the device has a power dissipation of 50 W or below, and the PCB thickness is 2.0 mm and below, then it is possible to mount this device in a surface-mount configuration. If the PCB thickness is greater than 2.0 mm, then the power dissipation capability through a via farm with the device in a surface-mount configuration will be lower.

If the RF PA device cannot be surface mounted using the gull wing packages, an alternative is to use the device with straight leads and to mount it as reflow in cavity, as shown in Figures 2 and 3. The cavity can be incorporated into the PCB in two ways: either as a coin or as a pallet. The choice is primarily driven by cost and size. If the PA board is small and compact, then a pallet may be a good option. If the PA board is large compared to the size of the RF device, then a coin with cavity will most likely be a cost-effective option.

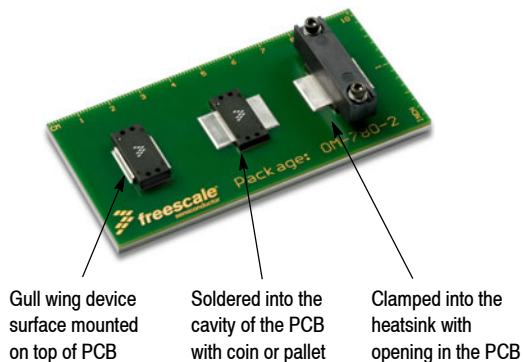


**Figure 2. Example of a Through-PCB, Straight Leaded, Soldered Assembly Mounting**



**Figure 3. Example of a Through-PCB, Straight Leaded, Over-molded Plastic RF Power Device, TO-270-2**

For customers who do not want to perform reflow mounting of RF power devices, the over-molded plastic package is capable of clamping down into the cavity with only the leads soldered to the PCB. The bolt-down or clamp-down methods of assembling an RF power device will negatively affect the performance to some extent. This performance loss is not related to just plastic RF power packages, but is also seen in air cavity packages. This has to do with the lower thermal interface resistance of the soldered device and the improved electrical contact of the soldered interface. Figure 4 shows an example of the same package mounted in all three configurations.



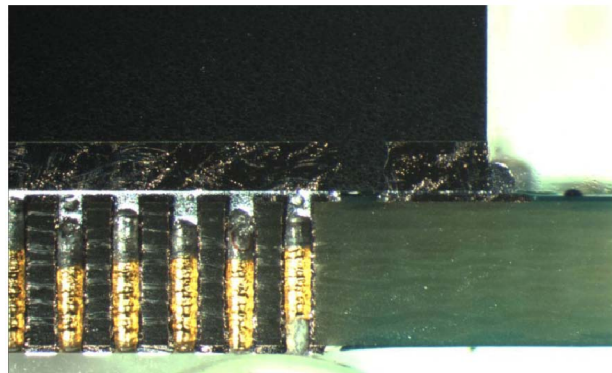
**Figure 4. Three Different Ways to Mount RF Power Packages**

**Via Farm Design**

The use of via holes under a device as a heat dissipation path is one common extension of the via hole technique in the PCB industry, where heat removal from the device through the PCB thickness is important. There are three different versions of via construction that are most common in the industry.

**Unfilled via holes**

The cheapest approach is the use of unfilled via holes in the PCB. Figure 5 shows an example of the unfilled via structure.



**Figure 5. Example of Unfilled Vias under a PQFN Device**

The concern with unfilled vias, as seen in Figure 5, is of molten solder being drawn into the via hole during the reflow process. When the solder is drawn into the via hole, it will amount to a loss of solder volume available for the solder joint of the device, which can result in voids under the device. In Figure 5, the solder is drawn into the via hole, but the solder volume lost is small. If the solder volume drawn into the via hole is larger, there is a possibility that the solder could reach all the way to the bottom via hole and collect on the other side of the PCB. If this happens, it will interfere with the bolting of the PCB onto the heatsink housing.

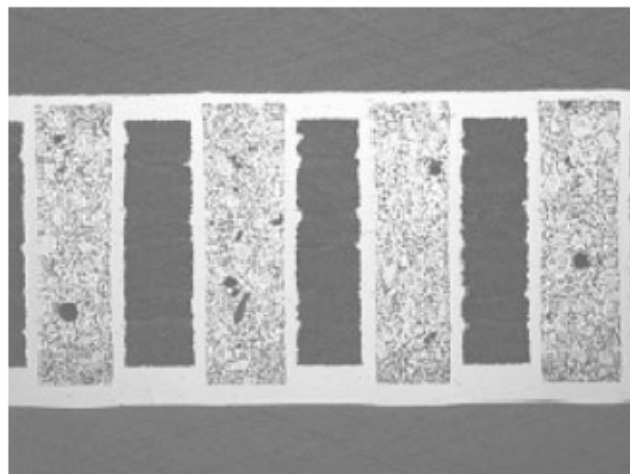
**Plugged via holes**

One way to overcome this issue is to prevent the path of the solder from being drawn into the via holes by plugging them. There are multiple options for what material to use for filling the via holes. One option is to prefill the via holes with solder material. Another option is to fill the via holes with epoxy material, either conductive epoxy or non-conductive epoxy. The most economical approach is to fill the via hole with the

solder mask material. (Contrary to general belief, solder filling of via holes does not improve the thermal performance significantly.)

**Filled, planarized, and plated via holes**

Another approach to fill the via hole is with the use of material such as conductive epoxy that will be planarized and cured and then plated over. This process requires the use of silver-filled epoxy material specifically designed for this application, and then two process steps are added: planarization and plating over again. This adds to the cost, but yields a full metalized pad that is coplanar with the PCB top. A cross section of such a filled via structure is shown in Figure 6.



**Figure 6. Example of a Filled, Planarized and Plated Via Hole**

**A Common Assembly Method for Surface-mount Applications**

The design of the via hole structure is an integral part of a heat dissipation method for high power devices, whether they are in plastic or air cavity packages. The key is to get the most copper area under the device heat spreader as possible. A diamond or staggered pattern is likely to yield a larger number of via holes than a square pattern. In addition, smaller-diameter via holes may be more effective than larger-diameter via holes due to the ability to pack more via holes, and eventually more copper, into the area. The general assembly process steps for the surface mount assembly method are available in Freescale application note AN1949.

If customers are interested in reflow in a cavity style mounting of the RF power devices, the plastic packages are also amenable to this type of mounting. The general instruction to develop a reflow in a cavity style design and assembly can be accomplished by following the details provided in Freescale application note AN1907.

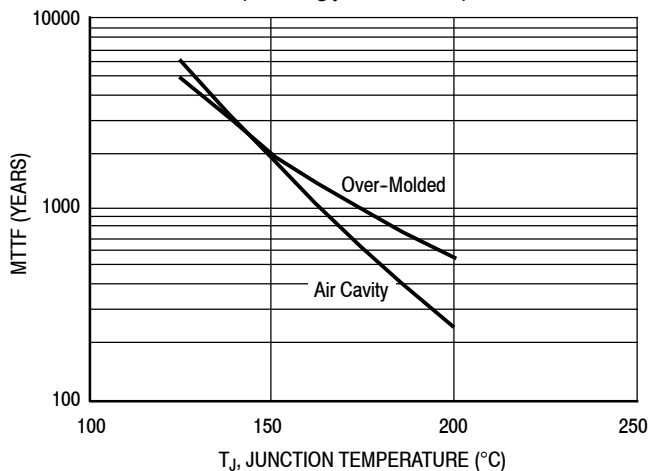
If customers choose to sacrifice RF performance slightly but prefer a bolt-down type assembly mounting, they can still use the leaded over-molded packaged devices in a clamped configuration. The general instructions to develop this type of design are provided in Freescale application note AN3789.

For surface-mount applications utilizing either the leadless PQFN, QFN, SOT-89, PLD-1.5, and PLD-1.5W package options or the gull wing formed RF power transistors, the most common assembly method is to screen print a solder paste pattern, pick and place the RF components along with every

other solder component on the PCB, and then reflow it in a multi-zone convection furnace. The solder mounting has to provide a good consistent thermal and electrical contact between the package source contact and heatsinks. Good solder joints with minimum and distributed voids provide a low electrical and thermal resistance interface between the back side of the device ground and the heat sinking pad on the PCB via pattern. This soldering process does not have to be perfect; the defectivity is measured by performing either sonoscan inspections or X-ray inspections. Solder imperfections will show up as voids on the solder interface, where either the flux was not completely boiled off, or the solder paste failed to fully wet both surfaces. The maximum voiding that is acceptable to the customer is based on the customer's design limit and process capability. Overall IPC (Association Connecting Electronics Industries) workmanship guidelines recommend a 25% total voiding in the solder joint at heatsink. Whether an individual design is capable of conforming to this criterion depends on the customer's design.

### Reliability of Plastic and Air Cavity Transistors

Over the years, as part of Freescale's reliability tests and qualification efforts for various devices, 3.5 million device hours have been accumulated at various temperatures in test conditions for over-molded plastic packages. Over the same time frame, 3.0 million test hours have been accumulated at various temperatures in different test conditions for air cavity metal-ceramic packages. Based on the accumulated test hours, and using the same statistical assumptions, failure in time (FIT) rate and mean time to failure (MTTF) were calculated for both package platforms at various maximum junction temperatures in field use conditions. The MTTF values at different temperatures in the operating regions are plotted as shown in Figure 7. From the data presented, both air cavity and over-molded plastic packages have close to 1,900 years of MTTF at a maximum operating junction temperature of 150°C.



**Figure 7. Comparison of MTTF Values versus Maximum Junction Temperature**

### Summary

RF PAs designed with Freescale's RF power plastic devices offer many advantages over amplifiers made with air cavity

package options. Also, solder mounting of RF high power devices tends to reduce the junction temperature, which results in better device performance as well as increased MTTF. By following a few simple design guidelines that have been outlined in this paper and in various Freescale packaging application notes, one can create a simple, robust, repeatable, reliable, and cost-effective amplifier design.

### Terminology Definitions

- FIT — Failure in time (failures in trillion hours).
- Flange or heat spreader — The exposed metal, primarily copper, part of the plastic package. The die is attached to the top of the heat spreader and the exposed plated bottom is soldered to the carrier.
- Heatsink — The carrier that is typically bolted to a finned heatsink. The heatsink forms the part of the thermal path that carries heat away from the device and to the cooling air.
- Mil — Equal to 0.001 inches.
- MTTF — Mean time to failure.
- Over-molded plastic packages (OM) — A package encapsulates the die and consists of a mold compound, wire bonds, leads, and the heat spreader.
- OM packages — Freescale RF over-molded package designation.
- PLD packages — Freescale RF over-molded package designation.
- Power amplifier (PA) — An electronic assembly module that takes in the input signal, amplifies the signal, and feeds it to the antenna.
- Power device — An RF power device, usually a silicon-based LDMOS discrete device, a multi-stage IC device, or a GaAs or GaN device.
- Printed circuit board (PCB) — The electrical interconnection between the RF power devices and other electrical devices that are part of a PA.
- RFIC — Radio frequency integrated circuit device.
- Size, weight, power and cost (SWaP-C) — A military directive.
- Transistor outline (TO) packages — Freescale RF over-molded package designation.

### References

1. Freescale Application Note AN1949, *Mounting Method for the MHVIC910HR2 (PFP-16) and Similar Surface Mount Packages*.
2. Freescale Application Note AN1907, *Solder Reflow Attach Method for High Power RF Devices in Over-Molded Plastic Packages*.
3. Freescale Application Note AN3789, *Clamping of High Power RF Transistors and RFICs in Over-Molded Plastic Packages*.

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