

Broadband Leaded Transitions and a Narrow Band Via Structure for Multi-Layer Hermetic Packaging

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Abstract:

Military electronics provide some of the most challenging requirements for high frequency packaging. The frequency options and specifications can span from DC to 95 GHz with the additional need for hermeticity in a majority of the RF applications. These RF applications can be broadband or narrowband in performance requirements. Many times, because of the specific applications, such as an airframe or space craft, small form factors and very limited room are available for making an impedance matching circuit for the package and board interface. Because of these size limitations, for both broadband or narrow band applications, very compact matches are needed for interface transitions. In order for these transitions to meet requirements, an understanding of the manufacturing processes, microwave theory, and specific applications is needed. This paper describes several unique broadband transitions and compact matches which are compatible in any ceramic multi-layer technology such as HTCC or LTCC. The fundamental construction and implementation, along with manufacturing issues will be discussed, from both the microwave and processing point of view. To limit the engineering of other components, such as the circuit boards and testing fixtures, an eye to common interconnects is especially useful. Specifically, in this paper, several construction variations to a leaded surface mount and gull wing packages for broadband performance will be presented along with a unique and compact RF via matching structure used for a specific narrow band application. Whether the package requirement is broadband or narrow band, a firm understanding of the interrelationship between the electrical behavior and manufacturing processes will make for a robust package, both electrically and mechanically.

Introduction:

High frequency and high data rate transmissions require high performance electronic packaging which distort the signal as little as possible. As the frequency increases, new package designs need to take into account not only the electrical and mechanical performance requirements, but also the economical producibility of packaging, especially for any significant volume production. With the additional requirement of limited design space in both air frames and space applications, designing compact manufacturable package impedance matching circuits and controlled impedance electrical links is not only critical but increasingly challenging

A typical strategy in broadband package performance is to implement controlled impedance designs. In a controlled impedance design, the characteristic and input impedance throughout the entire electrical link, from the board, through the package and finally unto the die, is kept as close to the system impedance, typically 50 ohms, as possible. Controlled impedance designs are, of course, a major challenge. Manufacturing design guidelines for structures such as leads, need to maintain the same pitch on both the circuit board, through some section of air, and the package itself. For a controlled impedance design the impedance along each section of the leads must be ideally

constant. For narrow band applications, typical impedance matching circuits require valuable package real estate. It is in these applications that a library of interconnect options coupled with a fundamental understanding of the microwave engineering and manufacturing limitations can yield high performance structures.

Broad band Transitions:

In this section we discuss packages with leaded interconnects to the printed circuit board (PCB). Leaded structures, whether gull wing or bottom leaded are notorious for poor RF performance. This is not necessarily from an inherent limitation of the leads themselves, but from the use of design guidelines developed for legacy slower speed packages. In the following discussion we will cover two different lead structures and illustrate how to achieve broad band performance by applying microwave engineering principles to the board/package interconnect.

Bottom brazed Leads:

Bottom brazed lead packages have been around for many years, mentioned in packaging trade journals such as in [1]. This package style has the advantages of hermeticity, simple construction, and standard packaging materials. There are three main structures in this package style: a kovar seal ring, the ceramic substrate and the kovar lead frame. The

kovar is nickel plated with another layer of gold plated onto the nickel. The general structure can be seen in Figure 1. In addition to these three main structures, a lid (not shown) is attached to the seal ring.

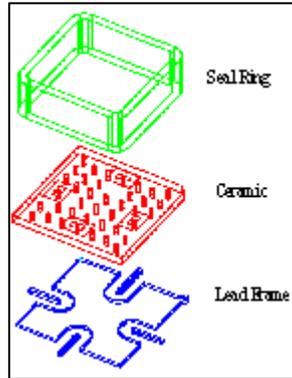


Figure 1: An exploded view of a leaded surface mount package.

An assembled typical SMT package, without the lid, is shown in Figure 2:

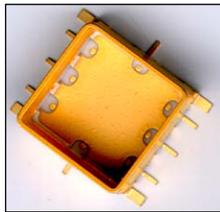


Figure 2: A photo of a typical bottom leaded smt package.

Historically, these packages have been used in applications up to about 6 GHz [3]. New applications, however, are now requiring that leaded packages be designed to perform up to 30 GHz and beyond.

With the development and use of 3-dimensional commercial full-wave electromagnetic modeling tools, such as Ansoft HFSS and CST Microwave Studio, and the increasing computational power of computers, the critical transitions in a package can be improved dramatically. These full-wave tools account for all of the electromagnetic phenomenon associated with a high-frequency package transition. Radiation, mode-loss, and all parasitics are accounted for in the simulation output of S-parameters, a well understood figure of merit for microwave packages. By using microwave engineering concepts, these tools allow key features to be optimized for maximum performance within

the dimensional constraints of the design guidelines of the manufacturing process.

The methodology of using full-wave tools and microwave engineering concepts to design high performance RF packages is illustrated by the following example. For the typical SMT package, the first step is modeling and simulating the original design. As can be seen in Figure 3, this

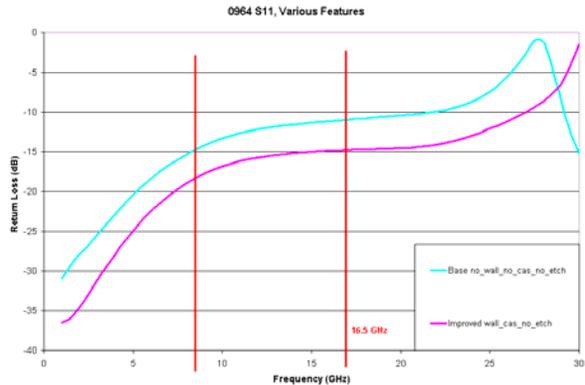


Figure 3: 8 GHz improvement from an additional layer of ceramic.

particular package shows acceptable return loss values (less than -15 dB) up to 8.5 GHz. To improve the package performance, an extra ceramic layer was added to control the impedance near the lead/seal ring region. This region is illustrated in Figure 4. The lower line of the graph in Figure 3 shows the improved return loss resulting from adding an extra ceramic layer to the package. This additional layer keeps the characteristic impedance closer to 50 ohms near the lead/seal ring region. The extra layer improves the -15 dB return loss performance from the original bandwidth of 0 to 8.5 GHz to 0 to 16.5 GHz, almost doubling the bandwidth.

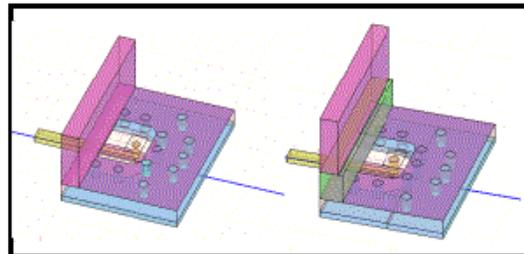


Figure 4: Illustration of additional ceramic layer under the seal ring – in green.

With an additional minor modification to the package lead design, the return loss performance can be further improved. This additional improvement is a half etched lead, also under the ceramic pad area, which again improves the impedance match at this junction. This improvement in input impedance, Z_{in} , is illustrated

by the Smith chart in Figure 5. As can be seen, the first improvement from the addition of the ceramic layer reduced the reactive portion of the input impedance and narrowed the real component variation of Z_{in} closer to 50 ohms for greater bandwidth. With the addition of the half-etch lead, the reactive part of the input impedance was further reduced, while maintaining the real component of Z_{in} near 50 ohms. Figure 6 shows the return loss from 0 to 30 GHz for all three cases: nominal, extra layer, extra layer plus half-etch lead. We should mention that this lead modification is independent of the ceramic production capabilities, but it does illustrate another degree of freedom in improving the bandwidth of this type of SMT package.

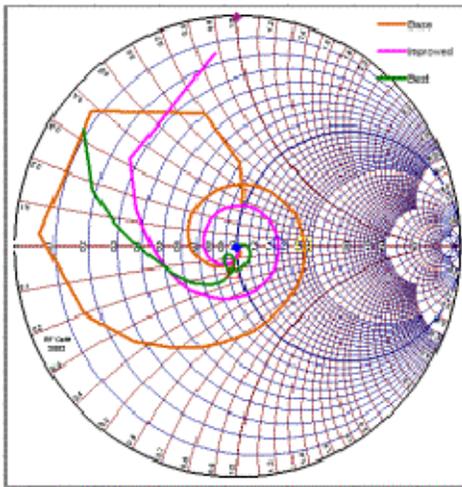


Figure 5: Smith chart of Base, extra ceramic, and modified lead showing improved response.

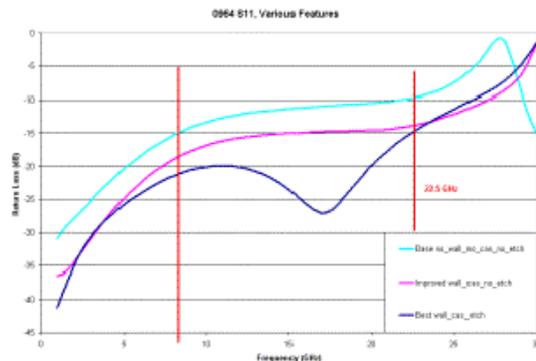


Figure 6: Magnitude S11 plot illustrating the varied improvement.

So, as a final realized improvement, we can see from Figure 6 that the extra layer improved the -15 dB from 8 GHz to 23 GHz. The half-etch lead, while not significantly improving the -15 dB return loss bandwidth, improved the -20dB bandwidth by

almost a factor of four, from 5 GHz to 19 GHz. It is important to realize these improvements in electrical performance did not take up any appreciable extra volume. Although it is true the extra layer of ceramic makes the original package .025" thicker, this additional substrate thickness can be compensated for by a reduction in the seal ring height, thus having a zero net effect on overall package thickness.

Gull Wing Leads:

Gull wing leads are another common and traditional interconnect method in electronic packages. Although gull-wing leads have been used for many years, they have not enjoyed the reputation or applications as a high frequency package interconnect. Again, with a fundamental understanding of the microwave theory and manufacturing capabilities, these relatively easily constructed packages can be engineered to perform extremely well. Shown in Figure 7a is the basic construction of a hermetic gull wing package.

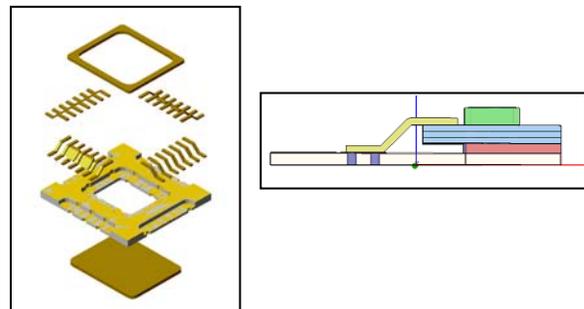


Figure 7a and 7b: a) an exploded view of a hermetic gull wing package b) a side view drawing of a gull wing lead (in yellow) formed as a SMT.

In a gull-wing package, the leads are formed into a bend to provide electrical connection from the surface of a PCB to a level at or near the top of the package as illustrated in Figure 7b. From a conventional point of view, the leads can be seen as large inductive discontinuities while the braze pads, where the leads are attached to the package are capacitive discontinuities in nature.

At high frequencies it is useful to observe the distributed electrical nature of the gull-wing leads. From a microwave engineering perspective, the leads are transmission lines with a certain characteristic impedance. Figure 8 shows a Time Domain Reflectometry (TDR) characterization of a gull wing package. The TDR method to characterized packages is well known in the measurement community[2]. TDR is quite useful in identifying the location and nature of physical

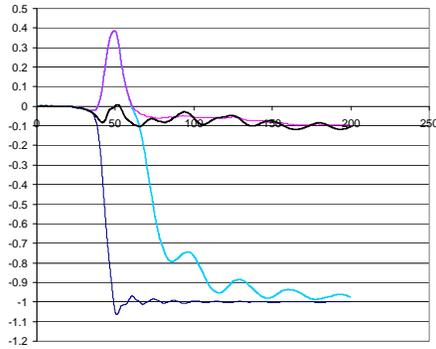


Figure 8: Showing two shorted locations (before and after the leads) and the initial high inductive typical lead design compared to a transmission line behavior of a well designed lead

features that provide discontinuities along a uniform transmission line. From a lumped element point of view, TDR indicates that the leads are inductive, the braze pads capacitive, and the lines on the PCB as having no detectable reactive discontinuities. From a microwave point of view, the leads have a higher impedance than the PCB traces, whereas the pads can still be considered to be small enough, relative to the high frequency wavelengths, to be thought of as capacitive discontinuities along a transmission line. So, in the optimized package design, the gull-wing leads are widened to reduce the high impedance associated with the original lead dimensions, and the addition of small inductive features on the package braze pads compensates the capacitance associated with the lead braze pads. These inductances are achieved with small cutouts on the braze pad. Ground castellations on the outer edge of the package are placed to suppress the loss of energy through non-desired mode coupling which occurs along the ceramic substrate/ceramic wall interface at the higher frequencies. As mentioned before, although these features are key in allowing the gull-wing package to operate at high frequencies, it is critical that the parts remain producible and robust, especially through volume production.

One final key feature which allows the braze pad feature changes to be made while maintaining enough pad area for a mechanical braze fillet for the leads, is the partial removal of the ground plane beneath the lead. This feature, shown in Figure 9, allows two things: it allows the braze pad to widen enough for a braze fillet, which is critical for brazed pull strength, and it allows us to maintain the proper inductive compensation for the capacitive discontinuity associated with the lead braze pad.

So, in a final realization of these features, Figure 10 shows extremely wide bandwidth out to 35-40 GHz while still maintaining producibility within most of the standard design guide lines.

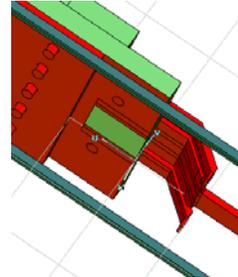


Figure 9: Backside ground pattern under the lead pad, allowing for a wider braze fillet.

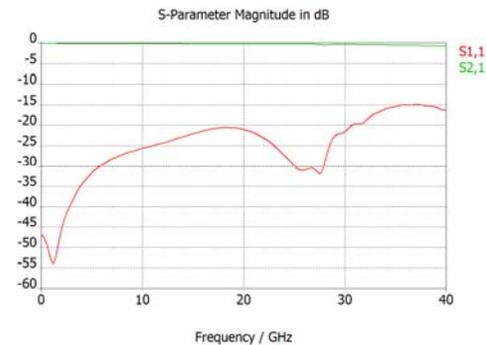


Figure 10: A typical S-parameter plot for gull-wing lead package.

Compact RF Via Matching Structures

In many high frequency RF systems, the electrical performance requirements are narrowband, however the available volume for providing matching circuits between electronic components can be quite small. This is especially true in airplanes, where the much of the RF devices must be placed within the airframe, where the available volume is very limited. Another constraint on the performance of these high frequency RF systems which increases the challenge is very low insertion loss requirements. This means that the signal path from the source to the termination, either another device, or passive element, such as an antenna, must be minimized. So, the electrical link must provide minimum signal loss, be inside a very small volume, and simultaneously providing impedance matching circuits at very high frequencies.

For devices that are placed on the top and bottom of a multilayer package, the shortest path between them is an RF via. This ensures that minimum conductor loss is incurred by the transition. However, depending on the thickness, number of layers and available lateral volume constraints, the reflection loss is required to be minimal between two devices connected by this via. In theory, this can be done along the via with the strategic placement of an iris. However, the placement of an iris will be constrained by the finite and discrete number of locations available for placing the iris arising from the number and thickness of the layers in the package. To circumvent this constraint placed upon the electrical design by the multilayer process limitations, we can introduce another degree of freedom into matching iris as shown in Figure 11.

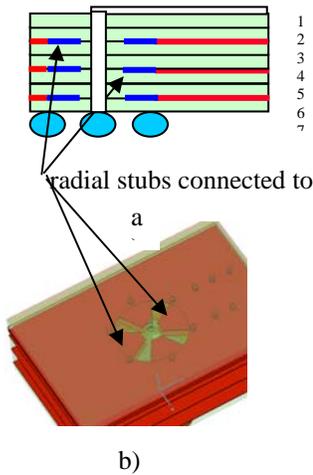


Figure 11a and 11b: Multi-layer via construction with via matching structures

Figure 11 shows a cross-section of a typical ceramic BGA multi-layer package that is connecting a component from the ball-side through a via, ultimately to an active device at the surface of the uppermost layer (layer 1). Figure 11a shows the possible locations for potential matching irises. As can be noted, these are limited to a finite number of positions located in the planes between the ceramic layers. Figure 11b is a perspective view showing the radial slots created in the iris region by extension of the ground plane in a fashion resembling “propeller” stubs. These slots/stubs allow fine tuning of the package input impedance by adjusting not only the number of slots, but the radial width as well. This tuning is illustrated in the Smith chart shown in Figure 12. We start with a nominal via coax with ground openings in the

intervening layers having diameters about equal to the coaxial via structure.

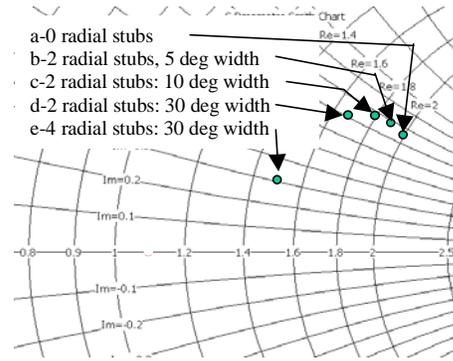


Figure 12a-e: Points on the Smith chart with different via tuning structures

In Figure 12, the nominal coaxial via has a relatively high input impedance as indicated in case a), and can be seen to be approximately $100 + j35$ Ohms. The reference plane for this input impedance is the bottom of the BGA. The characteristic impedance of the coaxial via formed by the balls is close to 50 Ohms. As we add radial stubs and increase the radial width we can see that the reactance and resistance of the input impedance at the reference plane gets closer to our matched case of 50 Ohms; cases b) through e).

Figure 13 illustrates the implementation of this concept for a specific K-band application. Figure 13a shows the return loss for a board connected through an RF via to a 50 ohm coplanar waveguide trace at the surface of the ceramic multilayer package. The desired optimum response is at 21 GHz. By using a set of radial stubs, previously dubbed as propellers, the desired response as shown in Figure 13b is achieved.

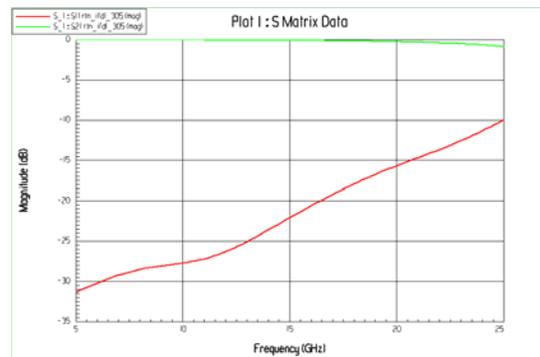


Figure 13a: Nominal return loss without tuning structures

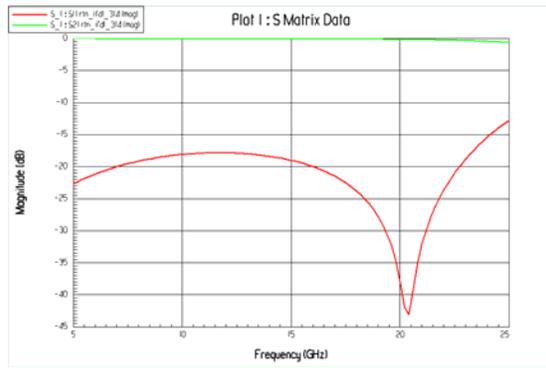


Figure 13b: Result of narrow band tuning via structure

Summary and Conclusions:

It has been shown that designing packages with both a firm knowledge of microwave principles and packaging techniques results in high performance packages. Depending on the requirements, this could be a broad band or narrow band package. In the broad band cases, typical microwave techniques, such as the Smith chart and TDR lead to trouble shooting standard package geometries. In some structures, a novel via matching structure demonstrates an extremely well performing via structure in a compact area. These geometries remain producible and viable microwave packages for a variety of frequencies with the option of narrow band matches or broad band response, whichever the case may be.

Acknowledgements:

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References:

1. "Broad band High Frequency SMT Packages", Microwave Journal, Feb. 1999.
2. "Electronic Packaging Fault Isolation Using TDR". TDA Systems Application Note EPFI-0604