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# Microwave Performance Of Ball Grid Array Packages

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## Abstract

*Ball Grid Array (BGA) packages are a preferred solution for many applications. This is due to their ease of use, surface mount compatibility and performance. In recent years, BGA packages have been applied to microwave applications. However, their wide spread use is still limited. The purpose of this paper is to present a few of the design parameters which affect the electrical performance of BGA packages at microwave frequencies. Design details will be presented along with 3D electromagnetic modeling results. Finally, electrical measurements will be presented.*

Key Words: BGA, Microwave, Millimeter-wave, HTCC, Packaging, RF Performance.

## 1.0 Introduction

Ball Grid Array (BGA) interconnects are used for a variety of IC packages such as low I/O count amplifiers and DSPs with hundreds of ball contacts. BGA packages offer a method for compact interconnects between the package and motherboard.

BGA packages are surface-mount package with solder balls that form an array on the underside of the package. The solder balls are the interconnection to the next level, typically a motherboard or another package. BGA packages can achieve finer pitch between I/O pins and are able to accommodate higher pin counts compared to leaded or leadless packages.

BGA balls can be in an area array format which provides great optimization of circuit board real estate compared to a leaded package.

In addition to smaller size, BGA packages can have improved electrical and thermal performance. Also, they are capable of achieving good performance at microwave frequencies.

Microwave packages have used BGA interconnects with success to achieve improved reliability for large IC packages.

## 2.0 Package Description

A package was designed for a GaAs microwave IC. The IC is a Monolithic Microwave Integrated Circuit (MMIC). Its function is a Low Noise Amplifier (LNA) and dissipates less than 1.5W.

Hermeticity was not a concern. The main issues is electrical performance and reliable ball to motherboard attachment. Also, the package had to be surface mount attached to a laminate substrate.

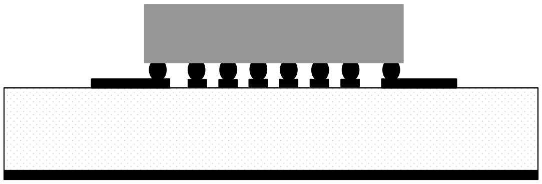


Figure 1. Illustration of the ceramic IC package mounted onto the laminate motherboard.

Figure 1 illustrates a cross section of the package and motherboard. Note that the package is solder attached to the motherboard with the solder balls. It is important to design the transitions in the motherboard and package so that high frequency performance is achieved.

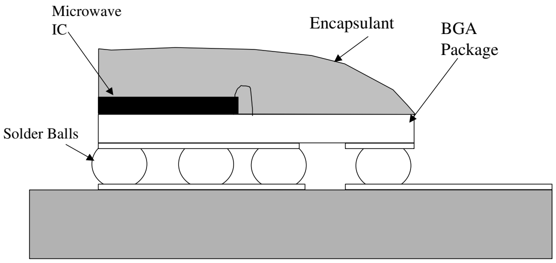


Figure 2. Close up view of the package showing the die and encapsulant.

Figure 2 shows a more detailed view of the package. For the motherboard, metal traces, vias, substrate thickness and substrate material all effect the transition. For the IC package, the solder balls, internal vias and traces effect the transition.

## 3.0 Package Electrical Design

The majority of the electrical design was conducted using the Finite Element Method (FEM) with HFSS from Ansoft Corporation [1].

MPT has developed a design process around the HFSS tool. The process can be used to design and develop commonly used IC packages. For instance, a leaded packages illustrated in Figure 3 was designed using the MPT process. Note that the model image is for that portion of the package that was actually used for high frequency signals. The package was symmetrical so that the high frequency I/O were repeated around the package. The other I/O were for bias lines and other low frequency signals.

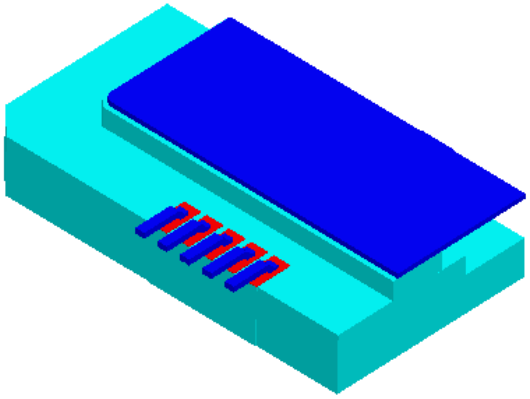


Figure 3. Leaded package designed using the MPT HFSS Design Process.

The simulated performance is shown in Figure 4. Note that the predicted eye performance is nearly perfect.

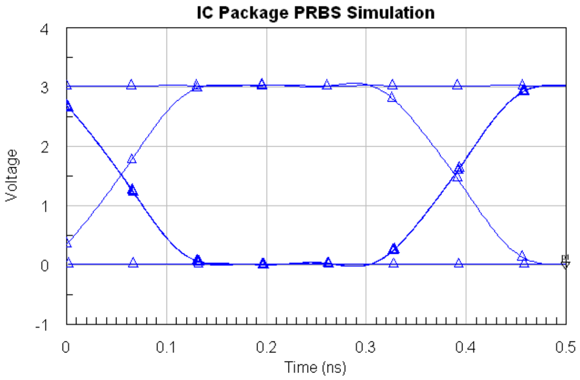


Figure 4. Simulated eye performance of the leaded package.

Another example of the MPT process is the design of a microwave module feedthru. Figure 5 shows the 3D model and the actual fabricated hardware.

The agreement between the modeled return loss performance and measured result for the feedthru showed less than 1.5dB variation from 5 to 15 GHz.

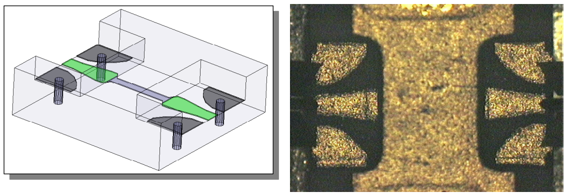


Figure 5. Feedthru transition HFSS 3D model and photo of the completed hardware from a top down view.

The BGA package was designed using the MPT HFSS design process. The goal was to achieve better than 25dB return loss. Figure 6 shows the simulated return loss.

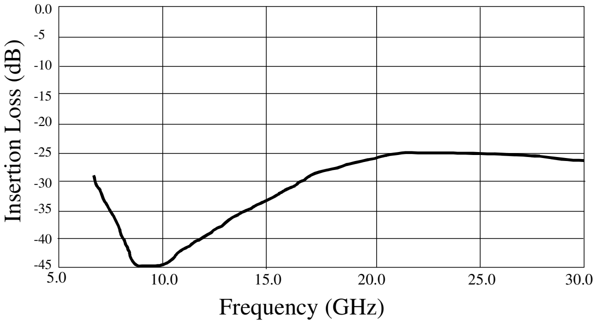
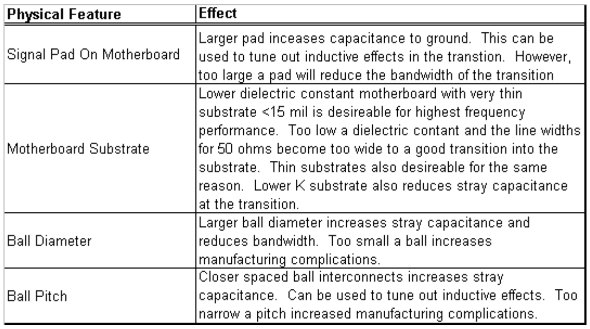


Figure 6. Simulated performance of the BGA transition.



| Physical Feature | Effect |
|---|---|
| Signal Pad On Motherboard | Larger pad inceases capacitance to ground. This can be used to tune out inductive effects in the transtion. However, too large a pad will reduce the bandwidth of the transition |
| Motherboard Substrate | Lower dielectric constant motherboard with very thin substrate <15 mil is desireable for highest frequency performance. Too low a dielectric contant and the line widths for 50 ohms become too wide to a good transition into the substrate. Thin substrates also desireable for the same reason. Lower K substrate also reduces stray capacitance at the transition. |
| Ball Diameter | Larger ball diameter increases stray capacitance and reduces bandwidth. Too small a ball increases manufacturing complications. |
| Ball Pitch | Closer spaced ball interconnects increases stray capacitance. Can be used to tune out inductive effects. Too narrow a pitch increased manufacturing complications. |

Table 1. Parameters affecting BGA performance.

The main parameters affecting the electrical performance are shown in Table 1. The most significant effects on electrical performance are the ball size, pitch, motherboard pad sizes, motherboard material.

## 4.0 Measurement Method

Measurements were conducted using a microwave probe station. A measurement motherboard was fabricated and the packages were mounted to the motherboard. The probes contacted the motherboard top surface.

Figure 7 illustrates the measurement method. Coplanar waveguide probes were used to inject the signal into and out off the test fixture. The tests were conducted using an Agilent 8722E vector network analyzer. A TRL calibration was used to de-embed the launch.

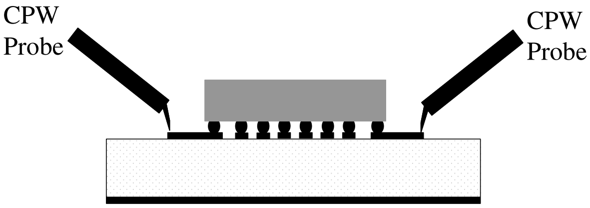


Figure 7. Illustration of measurement method.

The TRL calibration standards were fabricated on the motherboard. Both TRL and SOLT calibrations were possible since matched 50 ohm loads were also fabricated onto the calibration standard.

## 5.0 Results

The package was fabricated. It used 99% alumina thick film. All traces were gold plated inside the package and on the mounting motherboard. The motherboard was Rogers 4003 and used ½ oz copper traces.

The test fixture was assembled. Figure 8 shows an image of the assembled BGA on the motherboard before encapsulation. Note that the GaAs MMIC is 4mil thick. It is epoxy attached to the package substrate and wire bonded.

In addition to the circuit shown, a test circuit was fabricated that has a thru line in place of where the IC sits. It allows for the characterization of the transition. Measured results showed less than 0.8dB total insertion loss for two back to back transitions including the ball transition and short transmission line on the package.

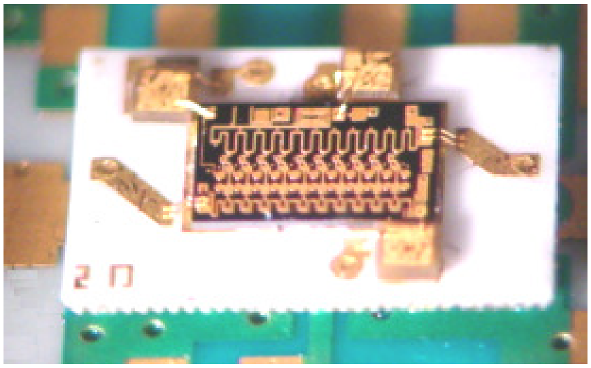


Figure 8. Photo of the BGA thick film ceramic package before encapsulation with MMIC attached.

## 6.0 Conclusions

The main result of this investigation a BGA package that can be used up to 15GHz and a set of loose guidelines on the effects of the physical features of the BGA transition on electrical performance.

## References

[1] Ansoft Corporation.
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[2] Adtech Ceramics.
Contact: Bill Minehan (423) 755-5400.
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