Design and Characterization of a Two-Channel Transmitter SiP Module

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Abstract: This paper presents simulation, design and verification details of a 12mmx12mm two-channel transmitter LGA SiP module. With a simulation aided design approach, the complex SiP module is designed, fabricated and verified in a single design cycle. The SiP module is able to meet all the stringent performance requirements; especially it has achieved high isolation even in this small package. The SiP module is tested with a probe and on a test board. In all cases, the simulated results and measured data are in excellent agreement, which demonstrates Amkor's design, fabrication and verification capability of a complex SiP module.

1. Introduction

Ever increasing demand for high performance, low power, low cost and small size consumer electronics and communication equipment requires innovative architecture and design approach. A growing awareness of higher level integration and complete system configuration has continued to drive SiP (System in Package) solutions.

Much has been published about the SiP products, its typical design flow and its application to modern electronics, but a systematic simulation aided design approach for a complex SiP module from initial design to final test and verification in the lab has been discussed much less often. In this paper, a case study of a two-channel transmitter SiP module is discussed using the above mentioned design approach. Details of the 3D HFSS models will be presented, which includes models for SiP module only, test board only and for SiP on test board. From comparison of simulated results and actual measured data, the accuracy of these 3D models is verified. It will be demonstrated that careful design using appropriate simulation techniques can be very effective in achieving excellent performances within a small package. It improves design efficiency and reduces design cost and time to market.

The purposes of this paper are two folds, one to present technical details of design, simulation and verification of a 2 channel transmitter SiP, and more importantly, to provide a systematic simulation added design approach that we use at Amkor and showcase our design capability of complex SiP module.

2. Two Channel SiP Design Details

At Amkor, we designed a two-channel transmitter SiP module, integrating two complete TX chains into one 12mmx12mm 4 layers LGA package, over molded with embedded RF shield. The module includes

- several bare dice and pre-packaged active components
- passive components, such as SMT discrete units, filters, crystals, baluns, etc.
- embedded metal shield

From function point of view, the two TX channels operate around 2 GHz at RF output ports while the incoming signals to the module have the frequencies between 0 to 300 MHz. The SiP module consists of complete TX analog /RF functions of pre-amplification, up-conversion and gain control for the two RF channels, which transfers low frequency, low power signal to a 2GHz RF signal at a desired power level. The simplified block diagram and layout of the design are shown in Figure 1 and Figure 2.

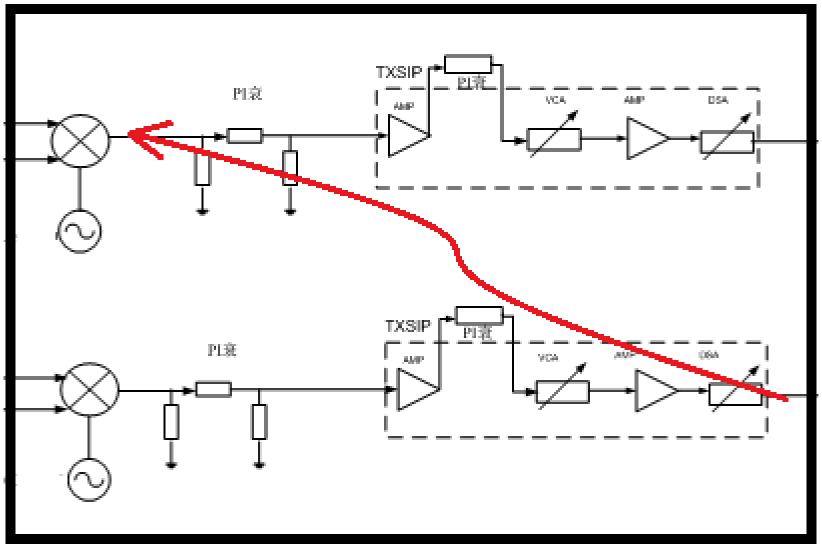

Figure 1 Simplified Block Diagram of the Two-Channel Transmitter SiP Module

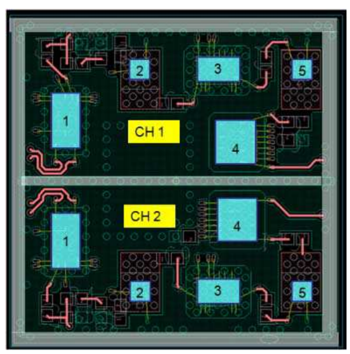

Figure 2 Simplified Layout of the Two-Channel Transmitter SiP Module

While integrating two complete TX chains into one small package using SiP technology helps to improve system performance, reduce power consumption, reduce overall cost and size, it does come with significant challenges, such as design complexity, test and characterization, thermal issues, etc. One of the most significant challenges in the electrical design is cross-talk between channels and among all the components due to their close proximity, especially those as shown in the block diagram, therefore stringent isolations between different ports are required for this design. In order to meet these stringent isolation requirements, an embedded RF shield, as shown in Figure 3, is incorporated into the SiP module. The shield design itself and its integration into the 2TX module is also a significant challenge. Not only the shield has to provide enough isolation for electrical purpose, it has stringent size limitation, especially height, but it needs to let mold flow properly. Extensive electrical and mechanical simulations on the shield have been done to make sure the design work properly both electrically and mechanically.

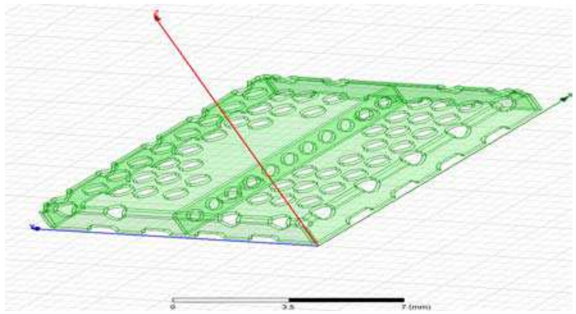

Figure 3 An Embedded RF shield

3. Simulation and Test Verification Set-up

From the beginning of the design process, we employed a rigorous simulation aided design approach. At the beginning of the electrical design, a detailed 3D HFSS model for the SiP module was built and extensive simulations, such as SiP on an ideal FR-4 mother board and SiP probing case, with different type of shields and ground patterns, were performed to guide SiP module and shield design for optimized performance. The full wave 3D HFSS model for the entire shielded package is shown in Figure 4. With this optimized design, a two-channel SiP module was fabricated and a test board was also built for lab verification. A wide range of tests were done with SiP on the test board, as shown in Figure 5, for RF performances, such as RF power, gain, gain control and spectrum. They passed all specs. Extensive isolation measurements with only SiP module using probe station, test board only and SiP on test board were taken to compare with simulated results by HFSS/ADS. In all cases, simulation and measurement are in excellent agreement. It shows that high isolation within a small package can be achieved with proper electrical and shielding design. A block diagram of the isolation test set up is shown in Figure 6.

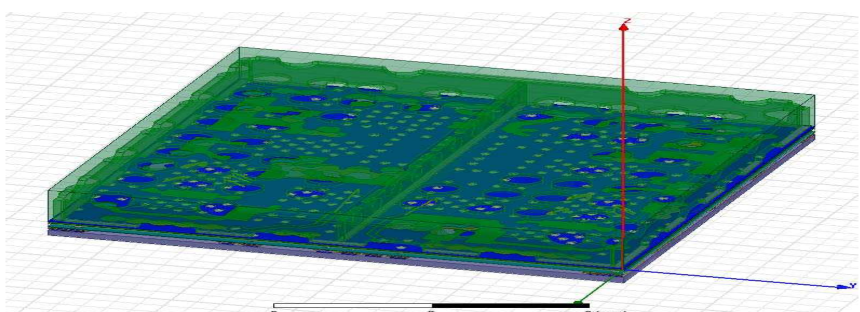

Figure 4 HFSS Model for a Two-Channel Transmitter SiP Design with RF Shield

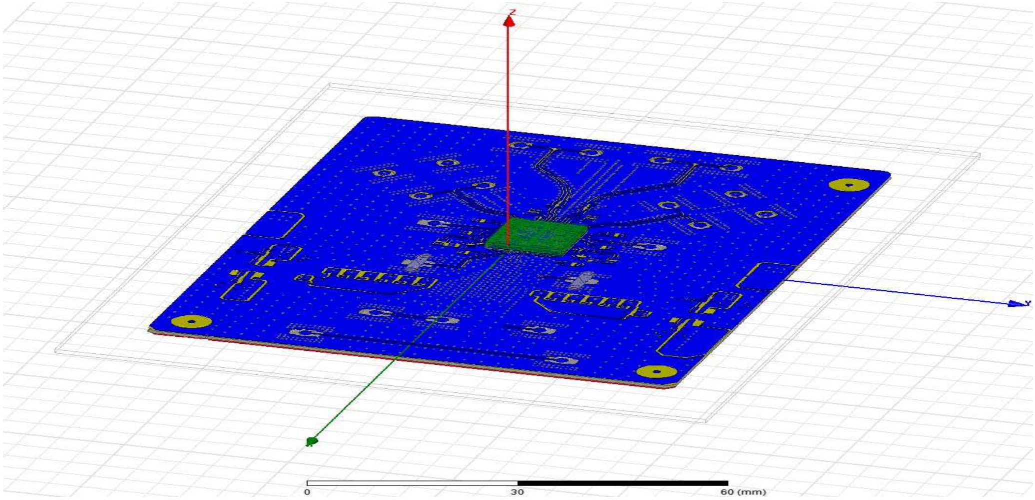

Figure 5 HFSS Model for SiP Module on a Test Board

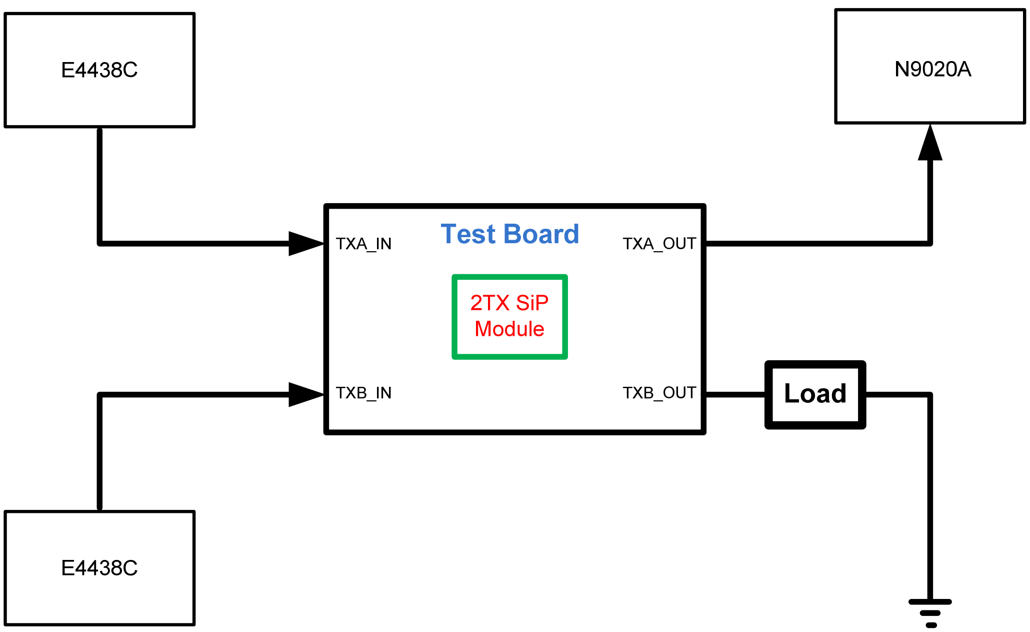

Figure 6 A Block Diagram of Two-Channel Isolation Test Set Up

4. Measurement and Simulation Comparison

Using the design approach described above, a two-channel SiP module was designed and fabricated. Extensive tests have been done on many specs, such as output power, gain, gain control, noises, etc., and they all passed specs with good margin. In this section, we will present comparisons between measured and simulated isolation, one of the most challenging specs to provide some insight on the accuracy of the 3D full wave HFSS model and the effectiveness of this approach.

4.1 SiP Probing Test and Simulation

First we probed the SiP module from the LGA pads as shown in Figure 7 on a probe station and the measured results is shown in Figure 8. Around 2 GHz, the isolation between the two output ports was measured at 75.34 dB. The simulation set up for SiP output port probing is shown in Figure 9 and the simulated results are shown in Figure 10. At 2 GHz, simulated isolation is 75.53 dB at 2 GHz, an excellent match between the measured data and the simulated results.

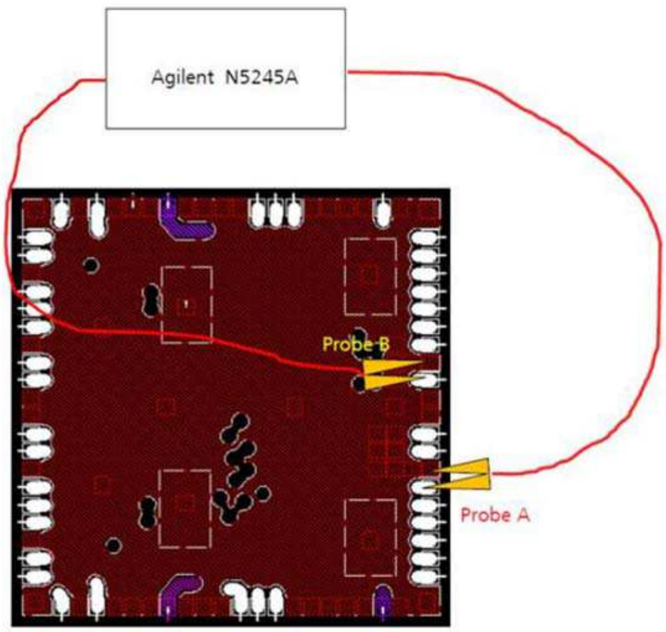

Figure 7 2Tx SiP Isolation Probing Diagram

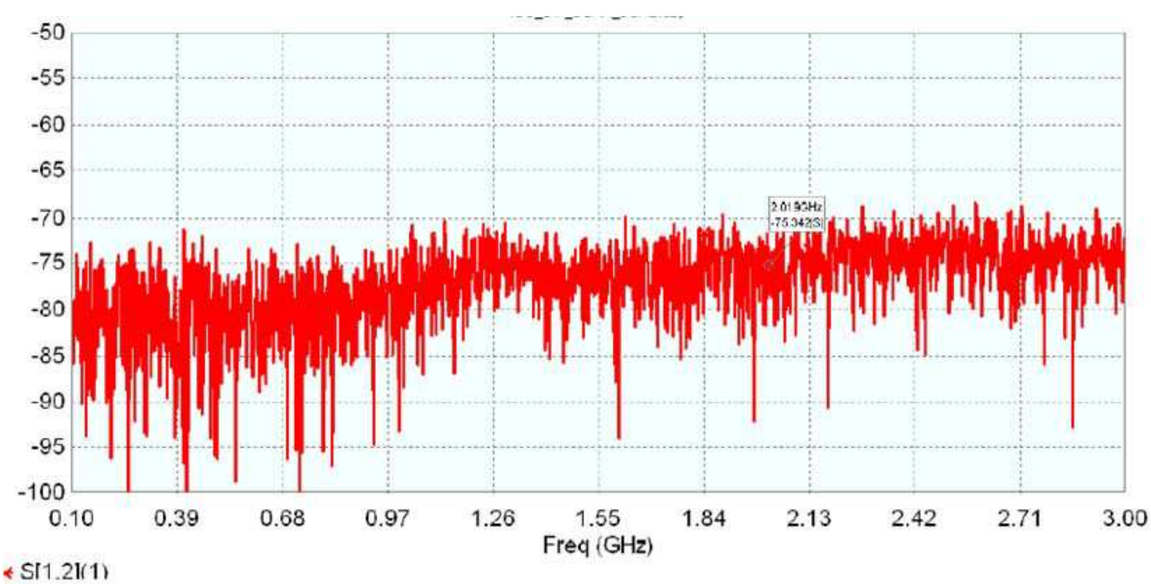

Figure 8 Measured Isolation in a SiP Probing Test

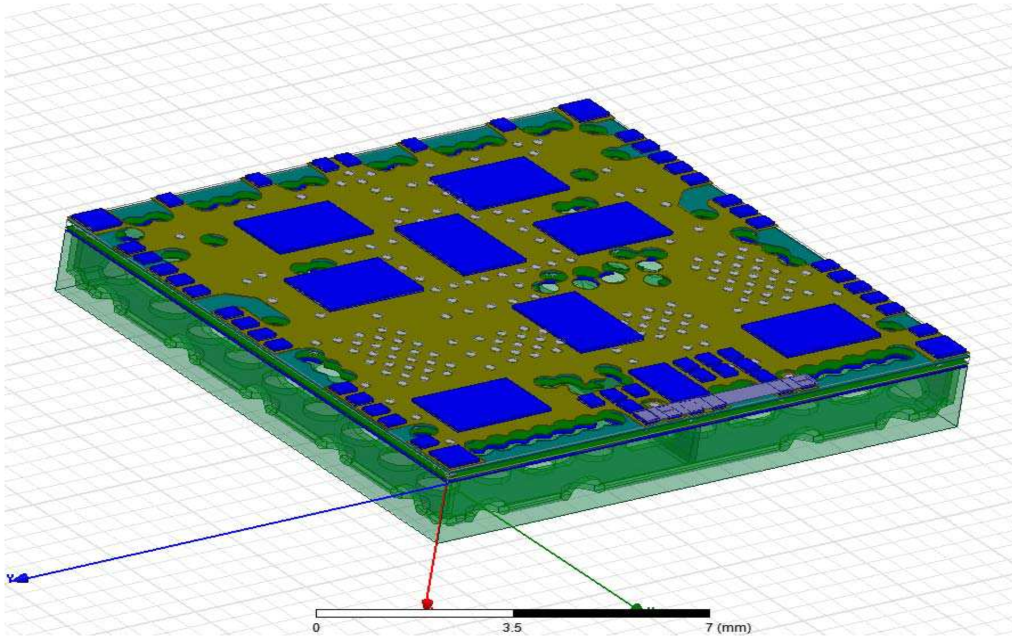

Figure 9 Simulation Set-up for SiP Probing Test

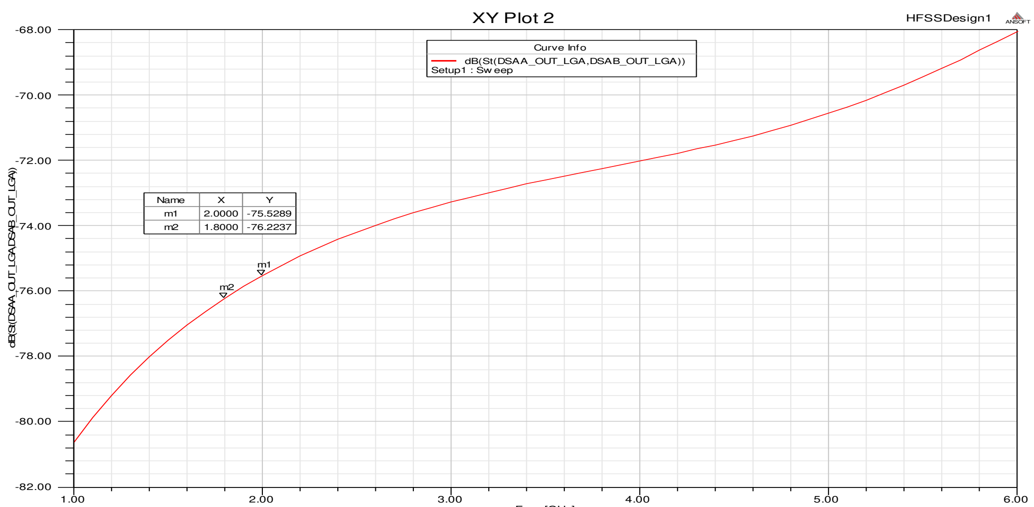

Figure 10 Simulated Results in a SiP Probing Test

4.2 Test Board measurement and Simulation

In order to test the SiP module, a test board is used. Before the SiP module is tested, the test board itself needs to be tested for isolation for the related ports to make sure the ports on the board have high enough isolation in order to have a reliable SiP on test board measurement. Figure 11 is the measured isolation between two output ports on the test board. Figure 12 and 13 show the HFSS model for the isolation simulation between two output ports of the test board and simulated isolation between the two ports. Measured isolation at 2GHz is about 86 dB in Figure 11 and the simulated results show 86.3

dB in Figure 13. It again shows excellent agreement and that test board has high enough isolation for SiP test.

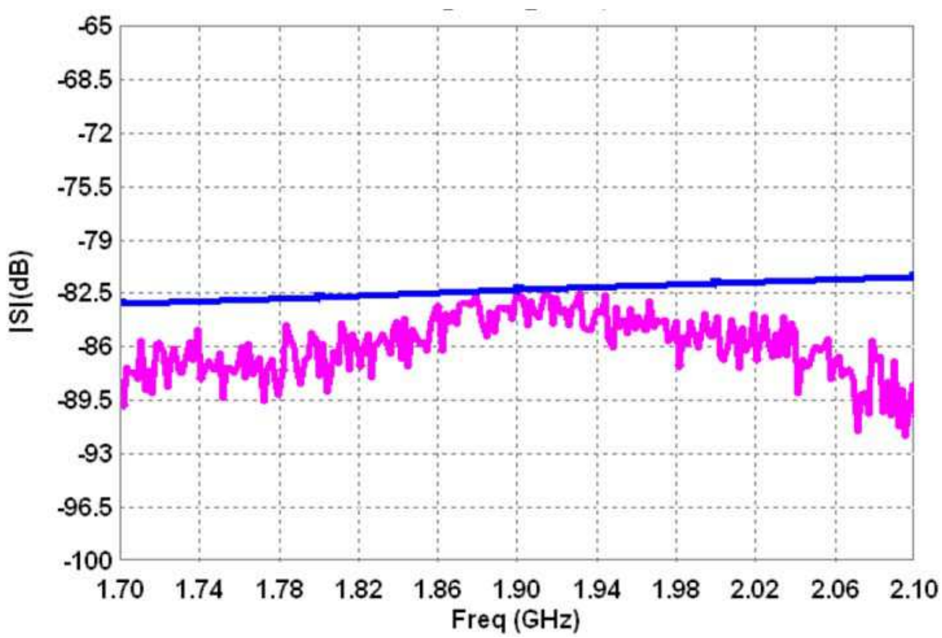

Figure 11 Measured Isolation Between Two Output Ports on the Test Board

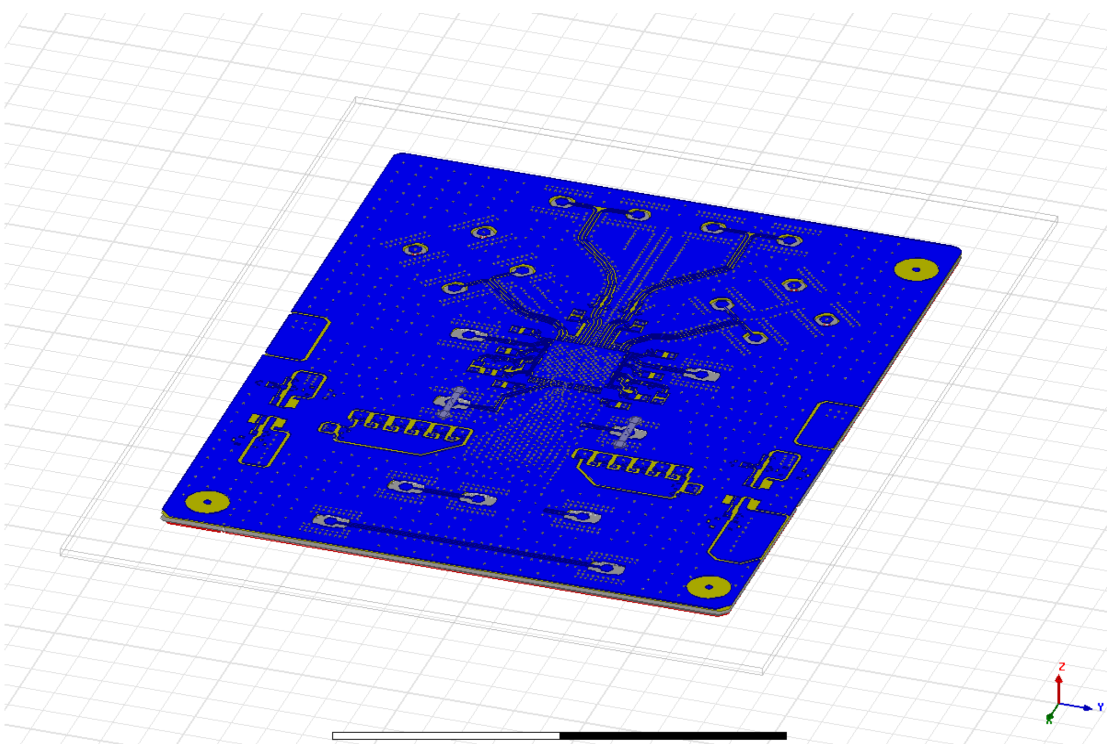

Figure 12 HFSS Model for Isolation Simulation of the Test Board

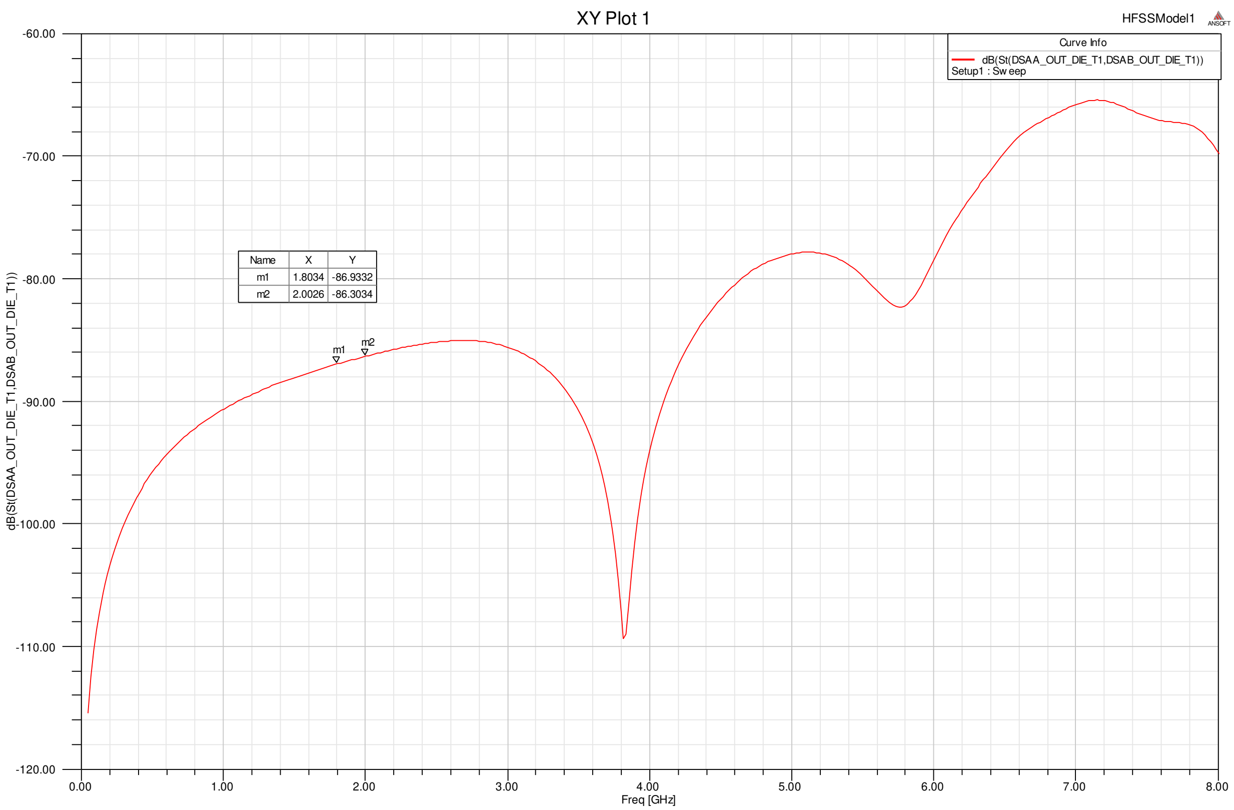

Figure 13 Simulated Isolation Between Output Ports on Test Board

4.3 SiP on Test Board – Measured and Simulation

In order to verify 2Tx module performances, it is placed on a the test board as shown in Figure 14, which is the HFSS model of a SiP on the test board. The lab measurement set up is shown in Figure 6. Many tests have been done with this set up, and more specifically, the isolation between the ports is measured. The measured data are shown in Figure 15 and 16. Both tests show that isolation between the two output ports is around 70 dB when a SiP module is placed on a test board, more specifically 70.17 dB in Figure 16.

Simulation of this configuration gets very tricky and computational intense. Simulation for SiP module on a test board takes a very long time to run, many days in many cases, and especially it takes huge memory to run, and sometimes it runs out of memory so that more stringent meshing techniques can not be used, which affects the accuracy of the simulation. One solution we found is that, by extracting s-parameter of the SiP and the test board separately and combing both Touchstone files in ADS environment as in Figure 17, not only it makes stringent meshing possible, the simulated results matches measured data very well and it is a big time saver. After the extraction of both SiP module and test board, ADS simulation takes less than an hour. The s-parameter extraction itself takes in a few hours, separately. The simulated results are shown in Figure 18. It shows that output port isolation simulated S12 is 69.84 dB at 2 GHz, again in excellent agreement with measured data in Figure 16.

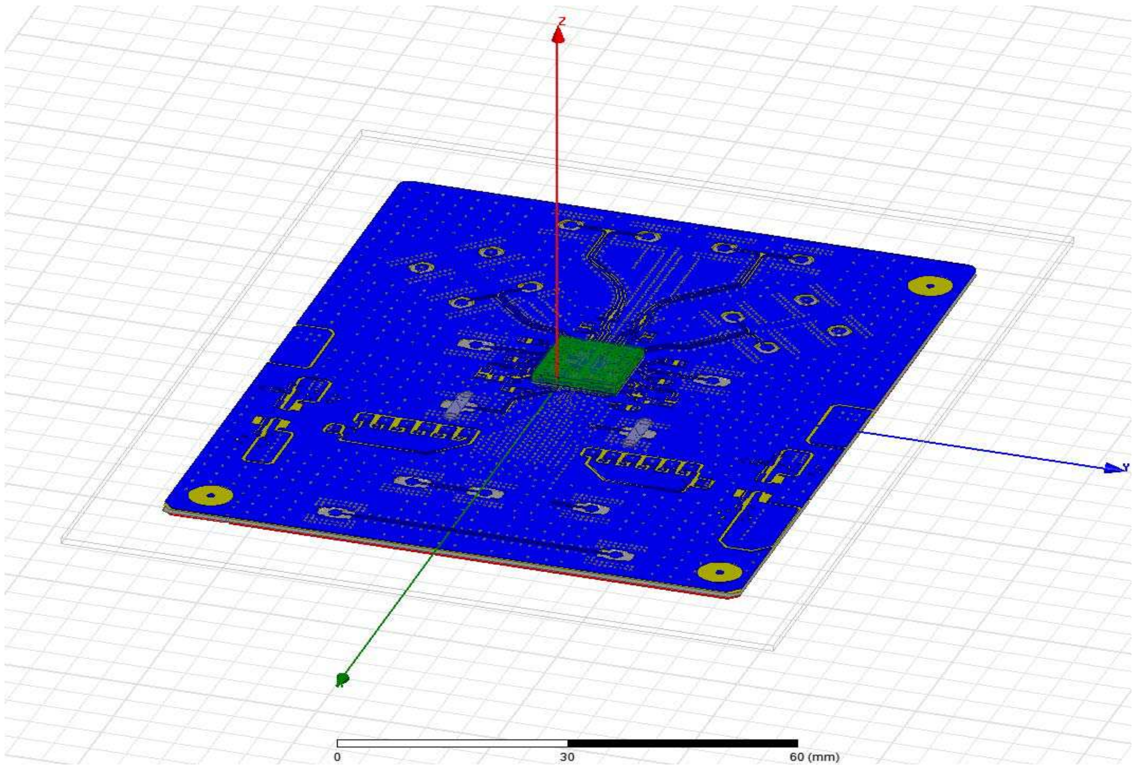

Figure 14 HFSS Model for SiP module on a Test Board

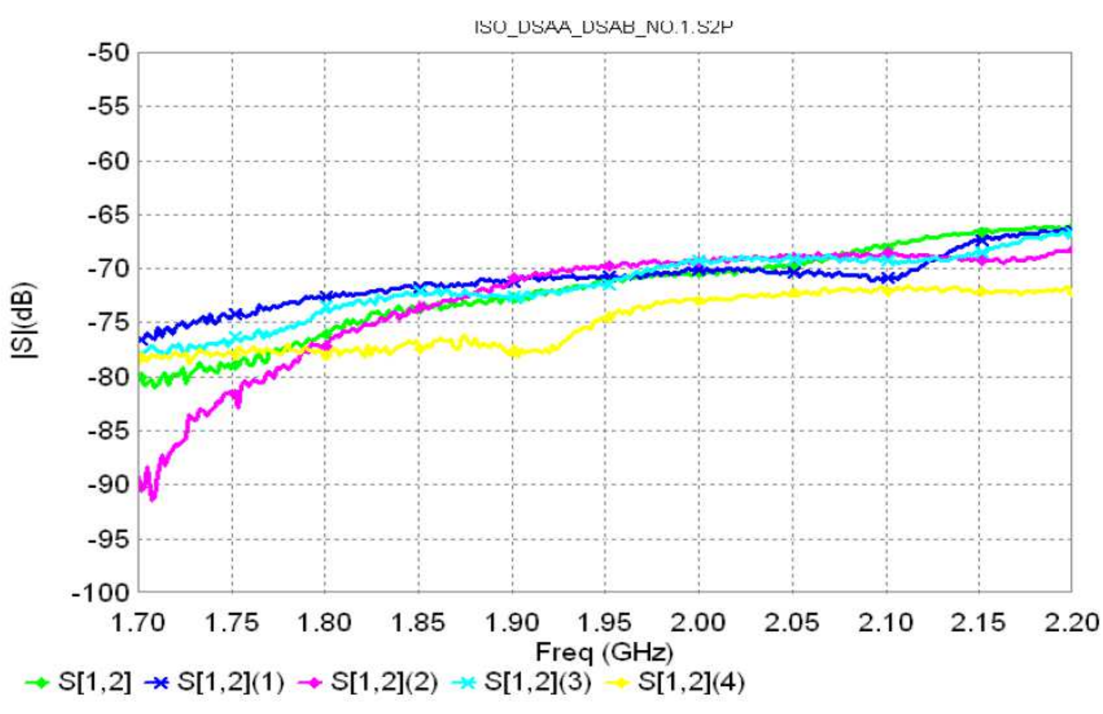

Figure 15 Measured S12 – 5 Modules on a Test Board

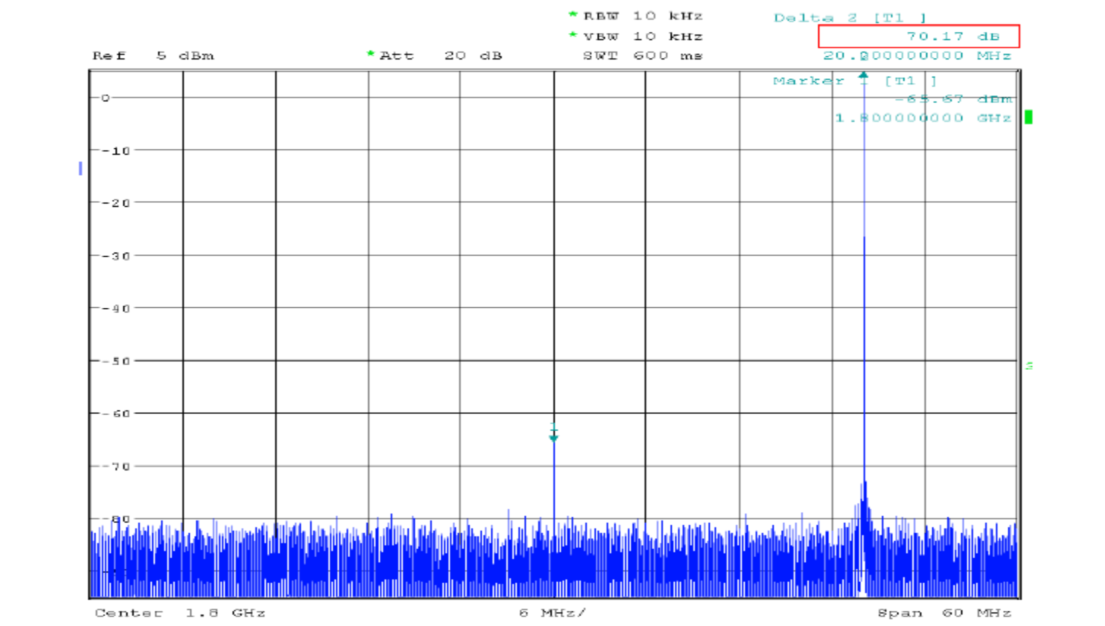

Figure 16 Isolation Test – SiP on a Test Board

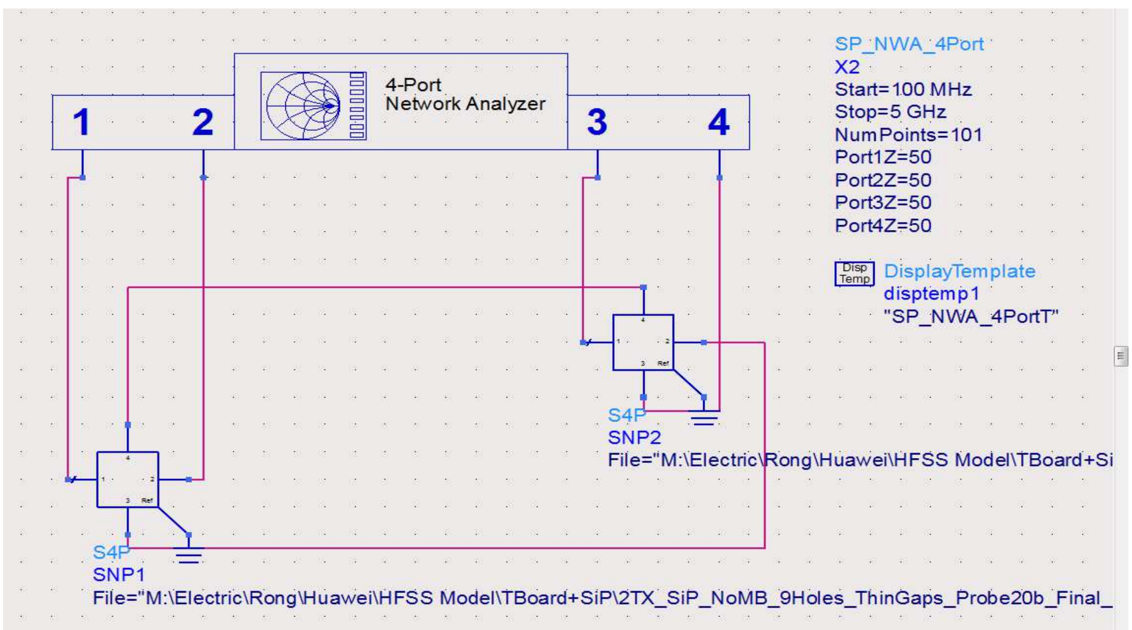

Figure 17 ADS Simulation Set up – SiP + Test Board

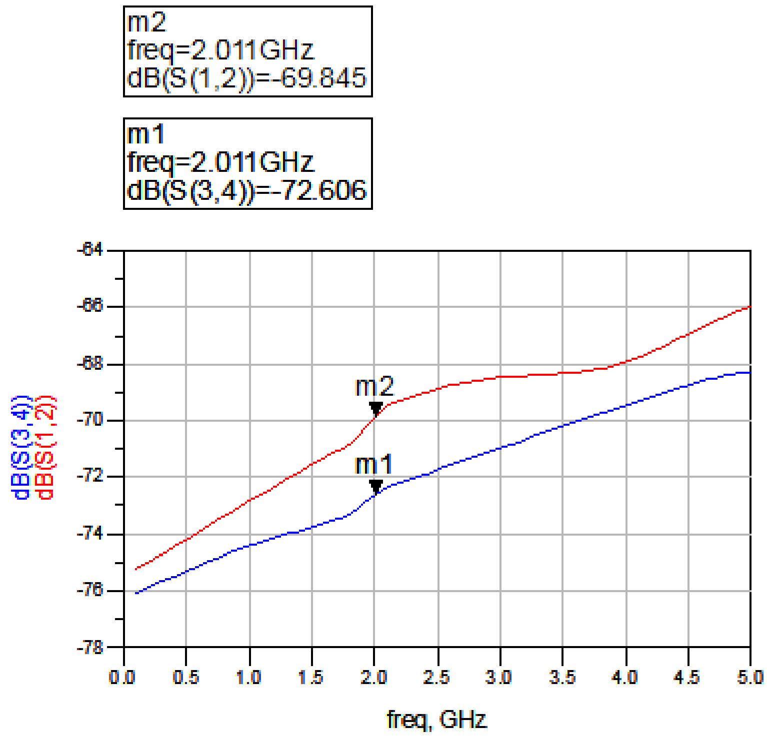

Figure 18 Simulated S12 for SiP on Test Board using HFSS/ADS Simulation

5. Conclusion

As discussed, this paper has presented some of the design aspects, such as design considerations, modeling and simulation process and issues, fabrication issues, test and measurement set up and characterization process, and comparisons between simulated results and measured data. With this simulation aided design approach, we were able to achieve very good performance across the board for a very complex system in a single design. The simulation and measured data are in excellent agreement for all the cases we measured and simulated, such as SiP probing, test board only and SiP on test board, which gives us great confidence moving forward. This approach also provided us with insight for further improvement. Many improvement techniques can be employed using the same approach so that we can be confident with our design even before the SiP module is fabricated. We also discussed some aspects of SiP module test. This paper demonstrates Amkor's capability in designing and testing a complex SiP module with our unique simulation aided approach.