

The development of a broadband smart skin antenna structure

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ABSTRACT

This paper introduced the research work on the development of a Broadband Smart Skin Antenna Structure (BSSAS). This structure possessed the load-bearing, shape maintaining and communication capabilities at the same time. A frequency-insensitive planar log-spiral antenna suitable for EM communication from 0.8GHz to 8GHz was embedded in a composites sandwich panel. Numerical models have been generated to design and evaluate the EM and mechanical properties of this BSSAS. Specimens have been manufactured and tested in an anechoic chamber. The test data showed a good correlation to the numerical results.

1. INTRODUCTION

Smart Skin Antenna Structure (SSAS) was a multifunctional composite structure with the integration of airborne antenna into a composite aircraft structure. This kind of multifunctional structure possessed load-bearing, shape maintaining and EM communication capabilities at the same time and could greatly reduce weight, drag and radar signature of an aerospace vehicle.

In the 1990s', the Northrop Grumman Corporation and Wright Laboratory developed a high pay-off technology called Conformal Load-Bearing Antenna Structure (CLAS), and successfully installed one in the vertical tail of F/A-18 for air-to-air and air-to-surface communication.

Researchers from Pohang University of Science and Technology (Kim 2009, You 2005, You 2010), Mechanical Engineering R&D Lab (Kim 2011), Communication R&D Center (Yeo 2011) in Korea have also made some efforts and progress in developing some prototypes of composite smart structures.

This paper introduced the work on developing a Broadband Smart Skin Antenna Structure (BSSAS). A frequency-insensitive planar log-spiral antenna suitable to work from 0.8GHz to 8GHz was embedded in a composites sandwich structure. The antenna originally protruding from the aircraft structure now became an internal part of the structure, which significantly reduced the RCS and drag of the aircraft.

2. THE DESIGN PROCESS

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The design process was divided into two stages: the design of a frequency-insensitive planar log-spiral antenna and the design of the BSSAS.

2.1 The design of a planar log-spiral antenna

As the embedded antenna of BSSAS, the planar log-spiral antenna had broadband electromagnetic characteristics: the input impedance and voltage standing wave ratio (VSWR) remained essentially constant over a wide frequency range (Kraus 2003) from 0.8GHz to 8GHz. A logarithmic (or log) spiral curve and a typical planar log-spiral antenna were illustrated in Fig. 1. The equation for a log spiral curve of the planar log-spiral antenna was given by Eq. (1).

$$r(\varphi) = r_0 e^{a\varphi} \quad (1)$$

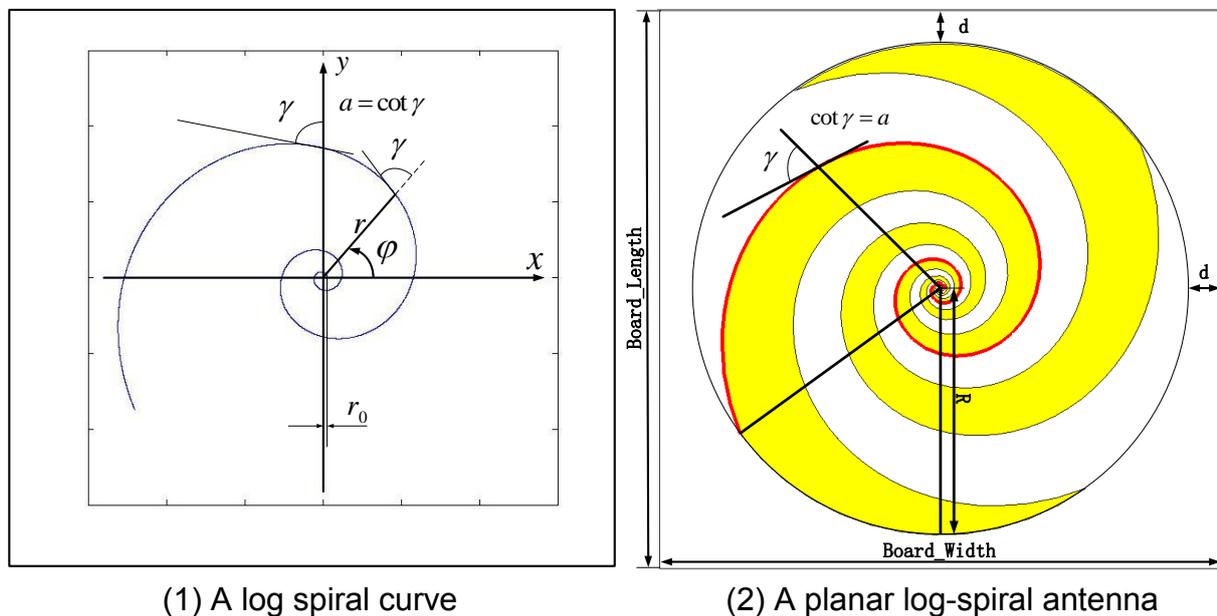


Fig. 1 Logarithmic spiral curve and planar log-spiral antenna

In Eq. (1), r represented the radial distance to a certain point on the log spiral curve; φ represented the angle with respect to x axis; r_0 represented the radial distance to the point on the log spiral curve when the value of φ was zero; and a was a constant which was related to the angle γ between the tangent of spiral curve and a radial line from the origin as given by Eq. (2).

$$a = \cot \gamma \quad (2)$$

The final design of the planar log-spiral antenna was shown in Fig. 2.

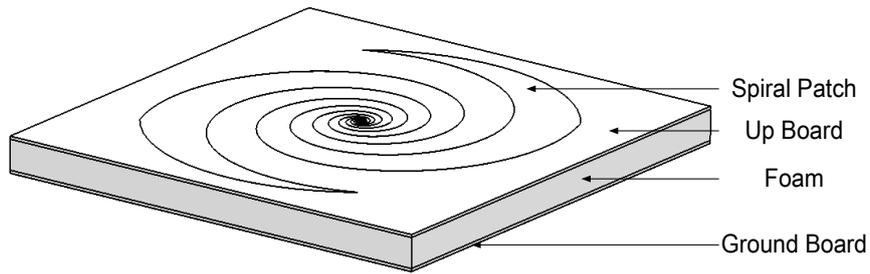


Fig. 2 The configuration scheme of planar log-spiral antenna

2.2 The design of BSSAS

The configuration of BSSAS was shown in Fig. 3 and its cross section was illustrated in Fig. 4. The box and box cover were made by glass fiber reinforced epoxy resin composite. The core material was polymethacrylimide (PMI) foam.

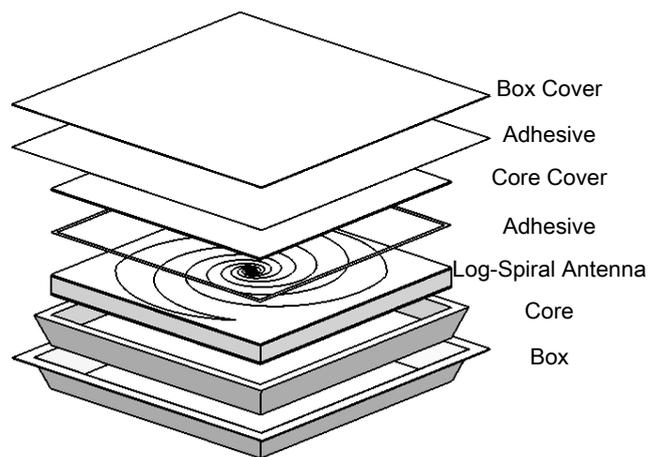


Fig. 3 The configuration scheme of BSSAS

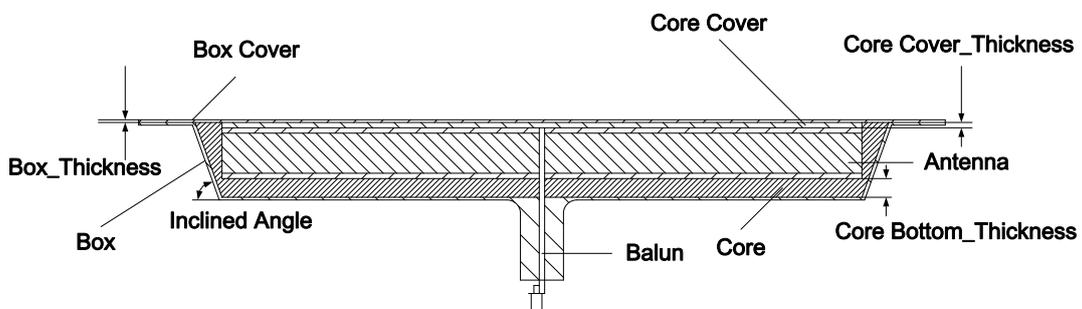


Fig. 4 The cross section of BSSAS

3. NUMERICAL SIMULATION

CST MICROWAVE STUDIO and Abaqus were used to conduct numerical evaluation of the electromagnetic and mechanical properties of BSSAS respectively.

3.1 Electromagnetic performance

In order to evaluate the electromagnetic performance of the embedded planar log-spiral antenna and the BSSAS, electromagnetic simulations of planar log-spiral antenna and BSSAS have been carried out. The models used for analysis were illustrated in Fig. 5. The numerical results were illustrated in Fig. 6 and Fig. 7.

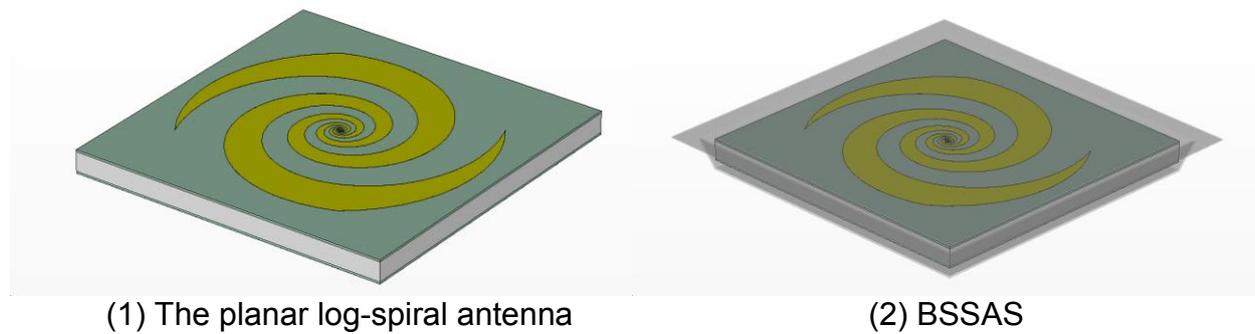


Fig. 5 Numerical models for electromagnetic evaluation

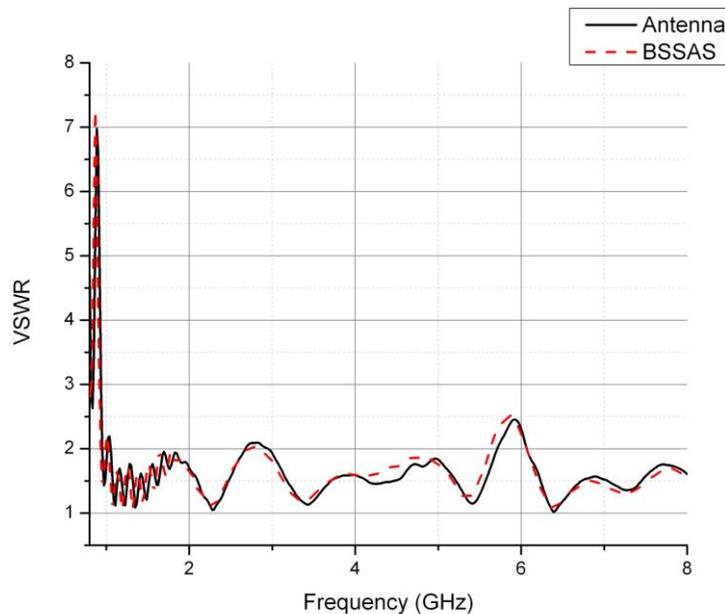


Fig. 6 Numerical results of VSWR

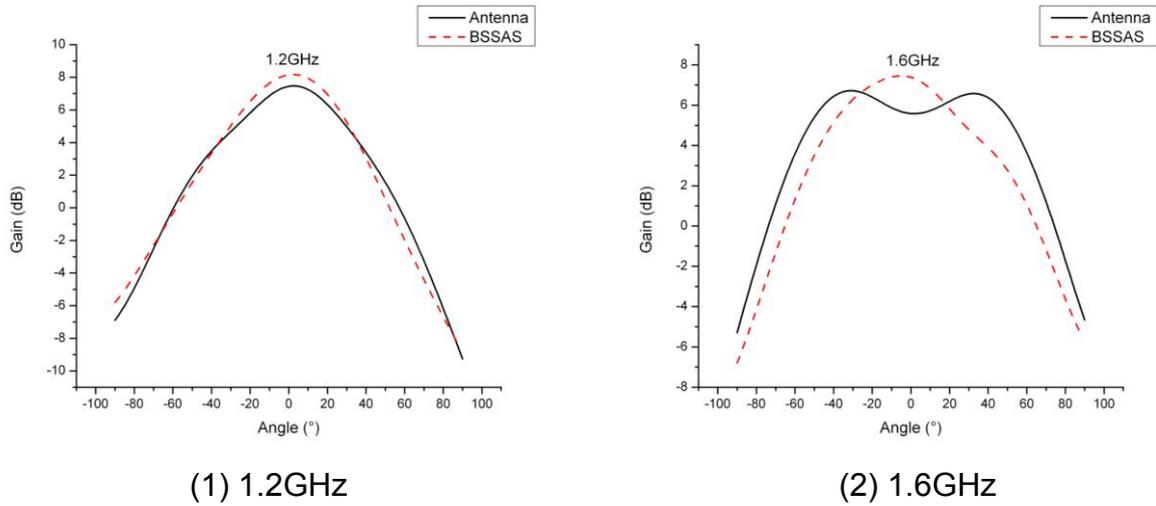


Fig. 7 Numerical results of radiation patterns

According to the results of electromagnetic analysis, one could see that there was little difference between the embedded planar log-spiral antenna and BSSAS in terms of VSWR and radiation patterns at chosen working frequencies of 1.2GHz and 1.6GHz.

The effects of the geometric parameters as well as material properties on the electromagnetic performance of BSSAS were also studied through numerical analysis as illustrated from Fig. 8 to Fig. 13.

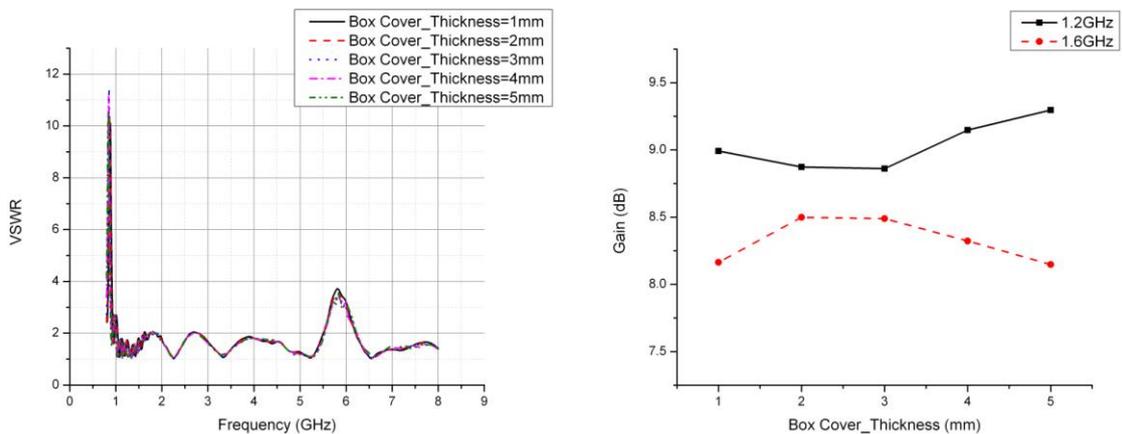


Fig. 8 Effects of box cover thickness on VSWR and maximum gain of BSSAS

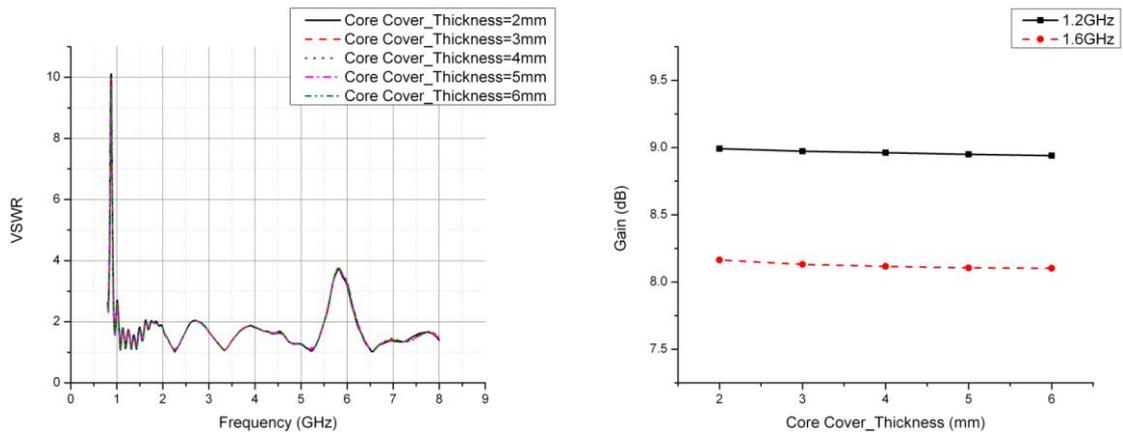


Fig. 9 Effects of core cover thickness on VSWR and maximum gain of BSSAS

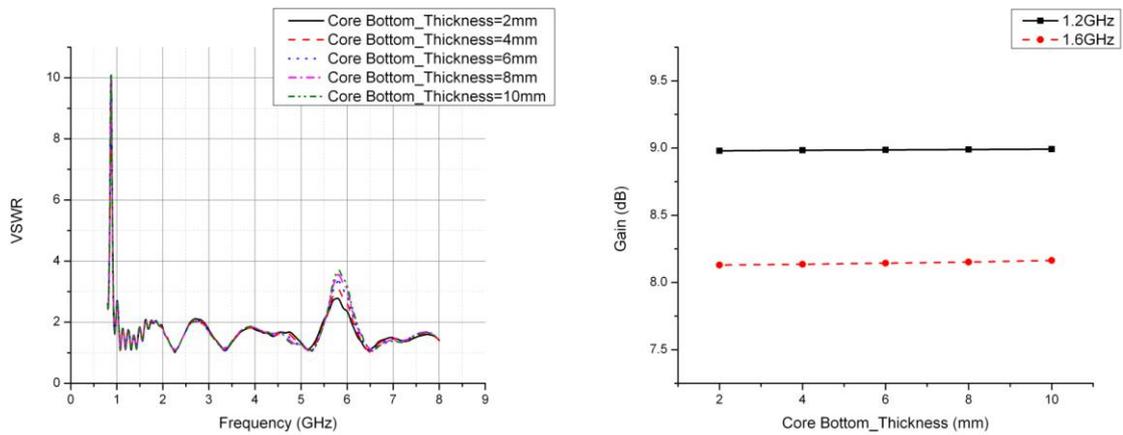


Fig. 10 Effects of core bottom thickness on VSWR and maximum gain of BSSAS

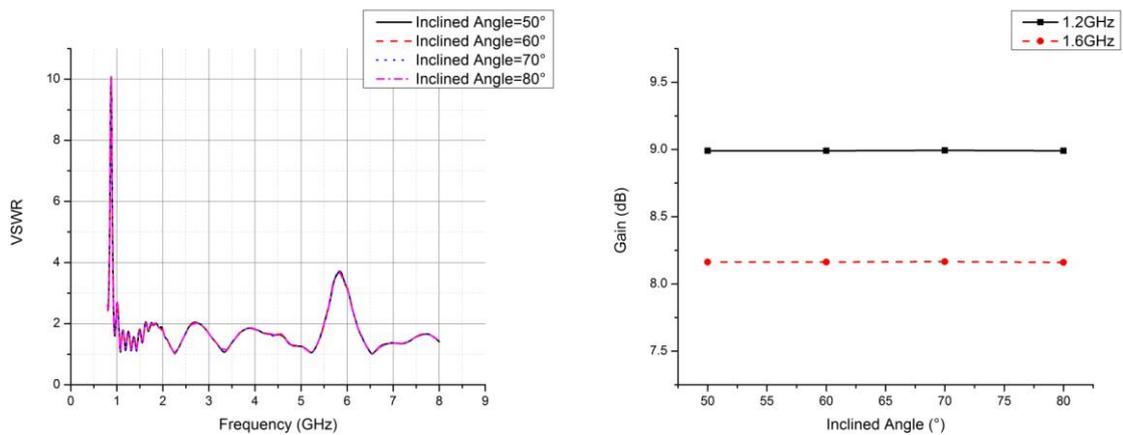


Fig. 11 Effects of inclined angle on VSWR and maximum gain of BSSAS

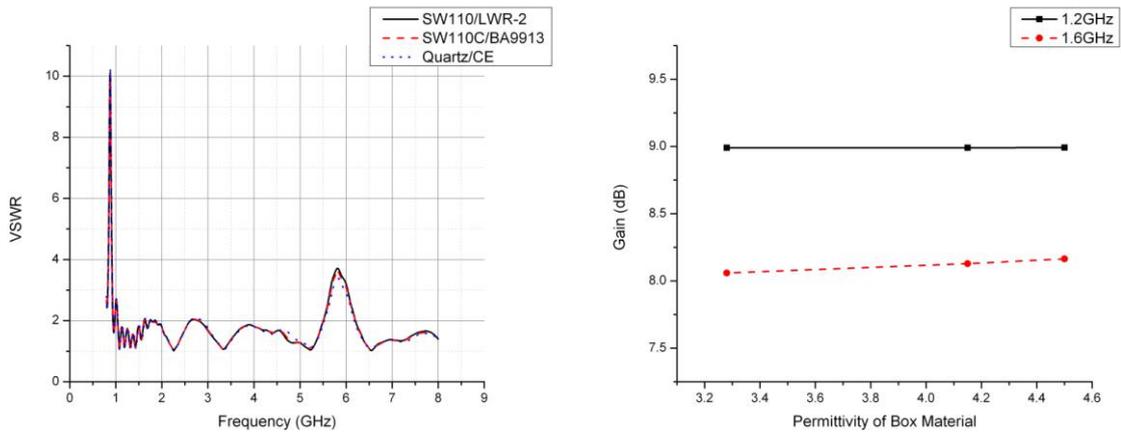


Fig. 12 Effects of box material on VSWR and maximum gain of BSSAS

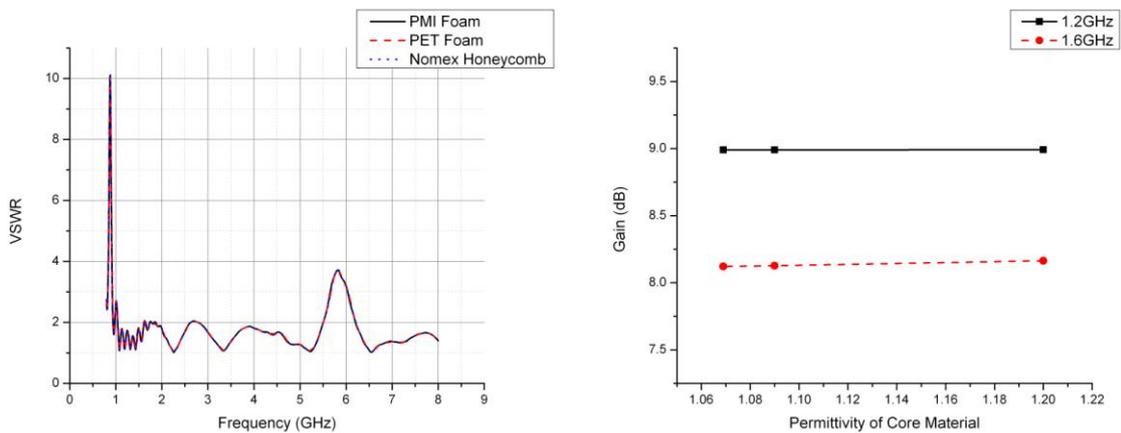


Fig. 13 Effects of core material on VSWR and maximum gain of BSSAS

According to the electromagnetic simulation results, one could see that both VSWR and the maximum gain of BSSAS at 1.2GHz and 1.6GHz were not sensitive to the geometric parameters and material properties.

3.2 Mechanical performance

Abaqus was used to conduct the mechanical performance evaluation of BSSAS under in-plane compressive and shear load. The FEA model of BSSAS was illustrated in Fig. 14. The loading conditions of BSSAS and the analysis results under in-plane compressive and in-plane shear load were illustrated in Fig. 15 and Fig. 16 respectively. FEA results under in-plane compressive and shear load were shown in Table 1 and Table 2 respectively. According to the data in Table 1 and Table 2, the maximum/minimum normal and shear stresses in the parts of BSSAS did not exceed the critical value.



Fig. 14 The FEA model of BSSAS

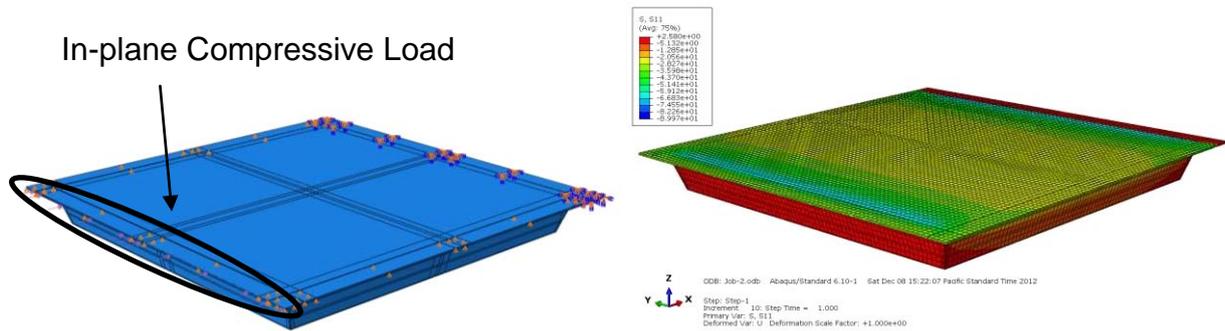


Fig. 15 The normal stress distribution under the in-plane compressive load

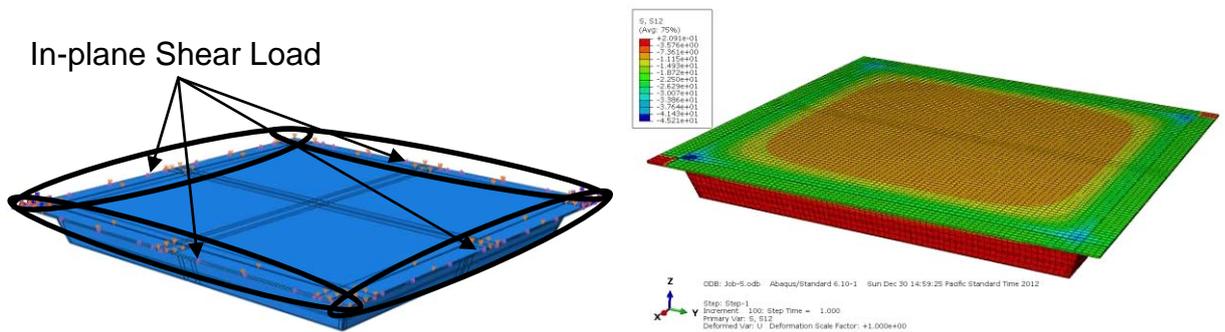


Fig. 16 The shear stress distribution under the in-plane shear load

Table. 1 BSSAS FEA results under the in-plane compressive load

Part	σ_x^{\min} /MPa	σ_x^{\max} /MPa	$[\sigma]$ /MPa
Box Cover	-65.97	0	510
Box	-89.97	+2.58	510
Core Cover	-0.4562	+0.01779	2.8
Core	-1.43	+0.1364	2.8

Table. 2 FEA results of BSSAS under the in-plane shear load

Part	τ_{xy}^{\min} /MPa	τ_{xy}^{\max} /MPa	$[\tau]$ /MPa
Core Cover	-0.3545	-0.01256	1.3
Core	-0.9124	-0.02878	1.3

4. TESTS ON ELECTROMAGNETIC PERFORMANCE

Several planar log-spiral antenna specimens were manufactured. Their electromagnetic performance has been tested, including testing VSWR using vector network analyzer and testing radiation pattern in anechoic chamber. A planar log-spiral antenna specimen was showed in Fig. 17. The test environment and equipments were showed in Fig. 18. Testing results were illustrated in Fig. 19 and Fig. 20. Based on Fig. 19 and Fig. 20, one could find that the test data on planar log-spiral antenna specimens showed relative good correlation to the simulation results.

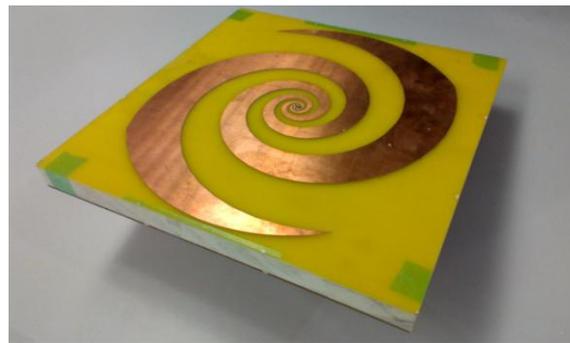


Fig. 17 The planar log-spiral antenna specimen

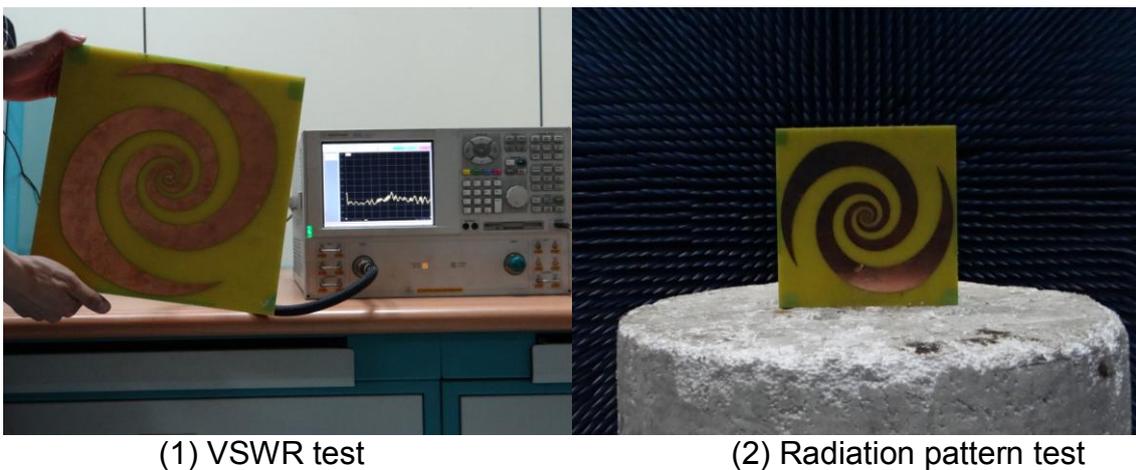


Fig. 18 VSWR test and radiation pattern test in anechoic chamber

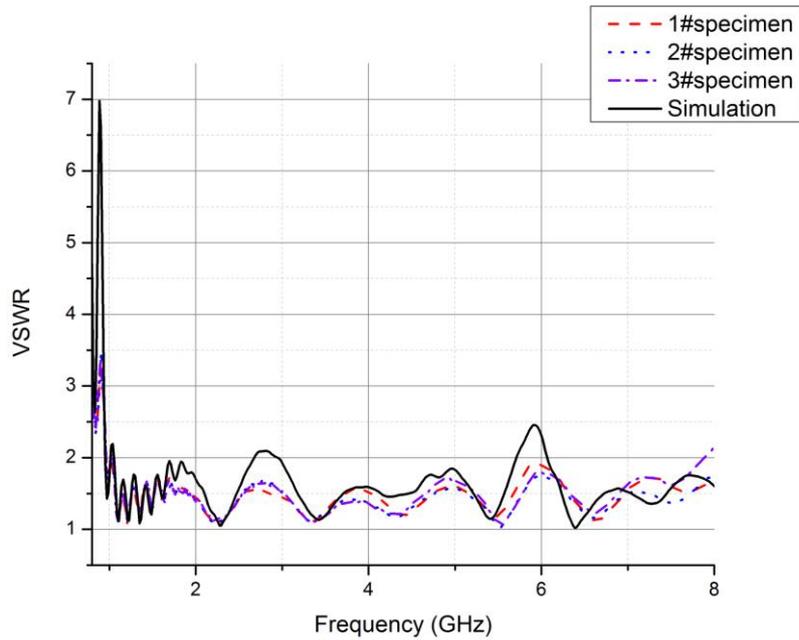


Fig. 19 Comparison between VSWR test data and simulation results of planar log-spiral antenna

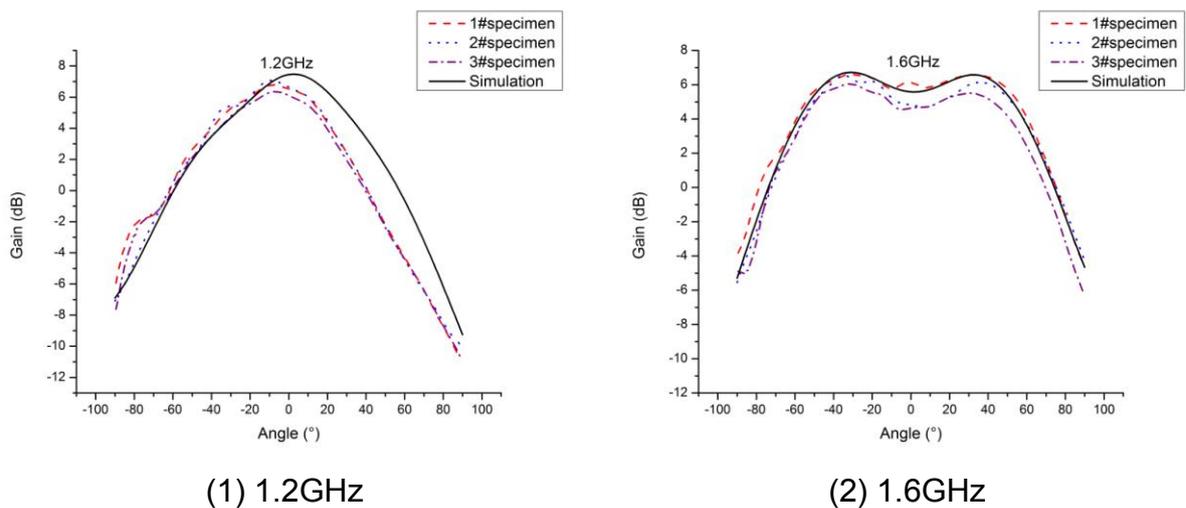


Fig. 20 Comparison between radiation pattern test data and simulation results of planar log-spiral antenna

5. CONCLUSIONS

This paper introduced the design and simulation of BSSAS and its embedded planar

log-spiral antenna. Several antenna specimens have been manufactured and tested. A good correlation between the numerical data and the test data has been obtained. Due to the broadband characteristics, electromagnetic performance of BSSAS was insensitive to the geometric parameters and material properties of the packaging structure.

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