FULL-WAVE ANALYSIS OF AIR-FILLED SUBSTRATE INTEGRATED WAVEGUIDE

AHMAD IKHWAN BIN MOHD ZUBIR

UNIVERSITI SAINS MALAYSIA

2021

FULL-WAVE ANALYSIS OF AIR-FILLED SUBSTRATE INTEGRATED WAVEGUIDE

By:

AHMAD IKHWAN BIN MOHD ZUBIR

(Matrix no: 137794)

Supervisor:

Dr. Nur Hidayah Binti Mansor

This dissertation is submitted to

Universiti Sains Malaysia

As partial fulfillment of the requirement to graduate with honors degree in

BACHELOR OF ENGINEERING (MECHANICAL ENGINEERING)

School of Mechanical Engineering

Engineering Campus

Universiti Sains Malaysia

12 July 2021

DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Signed ....(AHMAD IKHWAN BIN MOHD ZUBIR)

Date 12/7/2021 ....

Statement 1: This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by giving explicit references. Bibliography/references are appended.

Signed ....(AHMAD IKHWAN BIN MOHD ZUBIR)

Date 12/7/2021 ....

Statement 2: I hereby give consent for my thesis, if accepted, to be available for photocopying and for interlibrary loan, and for the title and summary to be made available outside organizations.

Signed ....(AHMAD IKHWAN BIN MOHD ZUBIR)

Date 12/7/2021 ....

ACKNOWLEDGEMENT

All acclaim Allah, the Most Gracious and Merciful, in the name of Allah, the Most Gracious and Merciful, Alhamdulillah, for the strengths and blessings in completing this thesis. First and foremost, I want to express my gratitude to my supervisor, Dr. Nur Hidayah Binti Mansor. Her unwavering support has aided me in completing this task. She always gave her best assistance to help me finish my endeavor, even during the difficult times brought on by the COVID 19 pandemic. I'd also like to express my gratitude to all of the technical personnel who have assisted me over my four years at university in making me a more knowledgeable and skilled individual.

I owe a debt of gratitude to my parents for being the pillar on which I have relied financially and emotionally throughout my life. Last but not least, I'd like to express my gratitude to the rest of my family and friends for supporting me during this experience. They have stood with me through the highs and lows of this undertaking, as well as life in general. Thank you so much for your support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

LIST OF ABBREVIATIONS

RWG	Rectangular Waveguides
SIW	Substrate Integrated Waveguide
PCB	Printed Circuit Board
CBCPW	Conductor Backed Coplanar Waveguide
LTCC	Low-Temperature Co-Fired Ceramics
MSIW	Modified Substrate Integrated Waveguide
BI-RME	Boundary Integral-Resonant Mode Expansion
SW-SIW	Slow-Wave Substrate Integrated Wave-guide
HM-AFSIW	Half-Mode Air-Filled Substrate Integrated Waveguide
SISL	Substrate Integrated Suspended Line
SAFSIW	Slab Air Filled Substrate Integrated Waveguide
CLAF-SIW	Contactless Air-Filled Substrate Integrated Waveguide
AFSIW	Air-Filled Substrate Integrated Waveguide
USM	Universiti Sains Malaysia

LIST OF SYMBOLS

E	Electric field intensity vector
dB	Magnitude or logarithmic based decibels
GHz	Gigahertz
S_{11}	Reflection coefficients
S_{21}	Transmission coefficients

LIST OF APPENDICES

ABSTRAK

Pandu gelombang bersepadu substrat berisi udara adalah jenis saluran penghantaran baru yang telah digunakan sebagai penghubung dengan litar SIW tradisional untuk mengurangkan kehilangan litar. Pelbagai cadangan untuk peralihan antara media yang dipenuhi udara dan dielektrik di SIW telah dibuat untuk mencapai kesambungan yang berkesan. Untuk meningkatkan prestasi peralihan, kehilangan penghantaran dan pantulan gelombang sepanjang peralihan mesti dikurangkan. Walau bagaimanapun, kehilangan gelombang dalam peralihan tidak difahami dengan baik. Ini kerana perambatan gelombang elektromagnetik melalui media tidak homogen dengan geometri berubah-ubah sukar untuk diukur dari segi kehilangan. Tesis ini membentangkan kajian tentang kehilangan gelombang dalam peralihan dengan melakukan analisis gelombang penuh di dalam jalur gelombang frekuensi Ka-band iaitu dari 26 hingga 40 GHz menggunakan perisian ANSYS HFSS. Setelah kajian dijalankan, simulasi menunjukkan kehilangan pantulan gelombang adalah dari 24.17 hingga 36.32 GHz manakala kehilangan penghantaran gelombang adalah dari 14.32 hingga 17.46 GHz dalam frekuensi Ka-band. Hasil kajian ini akan membantu penemuan reka bentuk litar koplanar yang lebih padat untuk mana-mana jalur frekuensi dengan prestasi yang lebih baik.

ABSTRACT

The air-filled substrate integrated waveguide (AFSIW) is a new type of transmission line that has been used as an interconnect with traditional SIW circuits to lower circuit losses. To achieve effective connectivity in SIW, various approaches for the transition between air-filled and dielectric-filled mediums have been made. The insertion and return losses along the transition must be minimized to improve the transition's performance. The transitional losses, on the other hand, are incompletely understood. This is because electromagnetic wave propagation through inhomogeneous media with variable geometry is difficult to quantify in terms of losses. This thesis presents the losses in the transition using full-wave analysis in Ka-band frequency which is from 26 to 40 GHz by using software ANSYS HFSS. After the study has been done, the simulation shows that reflection losses that have been obtained are from 24.17 to 36.32 GHz while the transmission losses are from 14.32 to 17.46 GHz at Ka-band frequency. The findings of this research will aid in the invention of more compact coplanar circuit designs for any frequency band with improved performance.

CHAPTER 1 INTRODUCTION

1.1 RESEARCH BACKGROUND

Affordable and good act integrated circuits are in high demand for today's growing millimeter-wave applications, such as high-resolution imaging, fast wireless data networks, and short-range sensor [1]. Rectangular waveguides (RWG) are commonly used in microwave and millimeter-wave schemes due to their better power management volume, low loss, and quality factor [2]. However, they have their disadvantages which are bulky and expensive to produce. Substrate integrated waveguide (SIW) technology is a branch of the substrate integrated circuit (SIC) family and has received special attention in the past ten years because traditional bulky waveguides and Printed Circuit Board (PCB) transmission lines, such as microstrip or conductor, backed coplanar waveguide (CBCPW), are replaced by SIW, which is a lightweight, compact, and low-cost alternative [3].

The loss of the SIW in millimeter-wave component design, however, is one of the most critical issues. The most major cause of losss in SIW is dielectric loss, which is significantly bigger than ohmic and radiation losses. New SIW designs have been created to reduce dielectric loss by omitting the core dielectric component of a SIW, resulting in a considerable reduction in loss. The transition from the dielectric substrate to the hollow like an air-filled region must be properly defined [4]. From the experiment that has been done by Parment et al, the results demonstrate that the design and length of the transition taper can affect the efficiency of an AFSIW circuit.

This project will do a full-wave analysis of the double-layer of the dielectric-to air-filled substrate integrated waveguide transition.

1.2 PROBLEM STATEMENT

The minimization of losses is one of the most important considerations in the design of SIW components, especially when working in the millimeter-wave frequency range. Losses in SIW structures include conductor losses due to metallic walls' finite conductivity, radiation losses due to gaps in the sidewalls of SIW structures, and dielectric losses due to the loss tangent of the dielectric substrate. No studies have analyzed the study about optimize losses in the double-layer air-filled substrate integrated waveguide (AFSIW) structure as most of the research papers shown only study about single layer AFSIW. Although studies on AFSIW loss minimization have been conducted, there are still losses that cannot be determined during the transition.

1.3 OBJECTIVE

The specific objective of this research are:

1. To do a full-wave analysis of the double-layer of the dielectric-to air-filled substrate integrated waveguide transition.

1.4 SCOPE OF THE PROJECT

This project entails creating a simulation of an AFSIW circuit as well as a double layer of the dielectric to air-filled transition. The transition is designed for the Roger RT/Duroid 6002 substrate in the Ka-band frequencies (26 – 40 GHz). Software ANSYS HFSS is used in this thesis to simulate the full-wave analysis of AFSIW and to obtain the return and transmission losses in AFSIW.

CHAPTER 2 LITERATURE REVIEW

2.1 RECTANGULAR WAVEGUIDE

Switching from two-dimensional to non-two-dimensional circuits is usually needed when combining active and passive components through rectangular waveguides. Several approaches to resolving this issue had always resulted in very complicated mounting systems [5]. A good alteration device is required in mass production to achieve optimal performance. In the millimeter-wave spectrum, it's difficult to cut a microstrip circuit into a precise shape.

Not only that, but the manufacturing of rectangular waveguide components is time-consuming and costly. They complicate and increase the cost of planar/non-planar integration. The concept of a rectangular waveguide with integrated components was proposed [6]. A linear array of metalized through holes was used to produce the waveguide on the same substrate as the planar circuit. Metalized walls can also be combined with the waveguide [7]. Size and cost can be drastically decreased by merging planar and non-planar circuits.

Conductor loss within the waveguide area cannot be ignored with a thin substrate. To reduce it, the thickness of the substrate must be increased which can cause greater radiation loss in the transmission line components, as well as other concerns like impedance range availability, which can complicate the design and integration of the active components. To improve interconnection with integrated waveguides, a new transition should be considered using planar transmission lines compatible with thick dielectric substrates.

2.2 SUBSTRATE INTEGRATED WAVEGUIDE

Waveguide-like structures can be produced flat in multilayer microwaves integrated circuits, such as low-temperature fired ceramics (LTCC) or multilayer printed circuit boards (PCBs), by employing periodic metal channels known as SIW [8]. The advantages of classic rectangular waveguides may be preserved in large part using this SIW geometry.

Even though SIW structures have similar qualities to traditional rectangular waveguides, there are significant distinctions between them. For starters, the SIW is a type of periodic (or discrete) guided-wave structure that could cause an electromagnetic bandstop. Second, because of the periodic openings, these structures are vulnerable to leakage. As a result, the modes or waves that pass via SIW circuits differ from those that go through standard waveguides, and a specific sort of leakage wave exists.

The substrate integrated waveguide also known as SIW is a waveguide structure that differs from regular waveguides in several ways. Its main purpose is to provide a design that conserves the benefits of the RWG in a planar configuration, such as a good Q-factor and durable power-handling proficiencies [8]–[10].

Figure 2.1 indicates the modified substrate integrated waveguide (MSIW) presented in this paper, which eliminates the middle portion of the dielectric substrate between periodic metallic walls of the SIW [11]. As shown in Figure 2.1, the removal of the dielectric substrate needs a three-layer PCB fabrication procedure, with two additional layers sandwiching the middle dielectric layer containing the air-cut to accomplish the top and bottom conducting boundaries. The MSIW attenuation constant is nearly independent by providing an adequately sized air cut-off. Conductor losses and radiation are the main causes of attenuation at MSIW

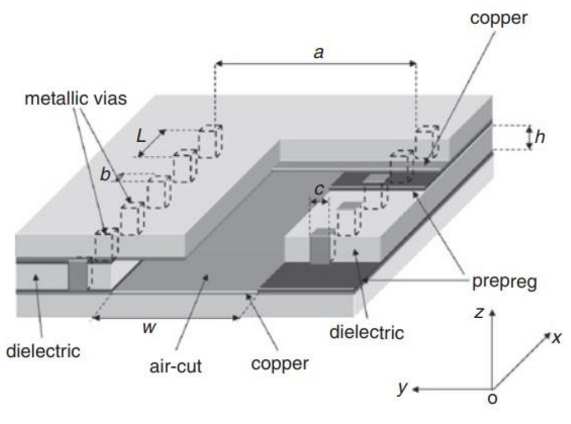

Figure 2.1 Modified structure of SIW with an air-cut region

The full-wave analysis utilized in SIW is based on BI-RME (Boundary Integral-Resonant Mode Expansion) method, which offers the component's generalized admittance medium [12]. This method generates a generalized admittance medium in the frequency domain in the form of a pole expansion, linking modal currents and voltages at terminal waveguide sections. This method can quickly and accurately determine the broadband frequency response of the waveguide circuits integrated into the substrate, and connecting their admittance medium in the frequency domain as a pole expansion. Furthermore, using the BI-RME method, multimodal alike circuit models of substrate integrated waveguide discontinuities can be automatically created [13]. Figure 2.2 shows the BI-RME method used in SIW.

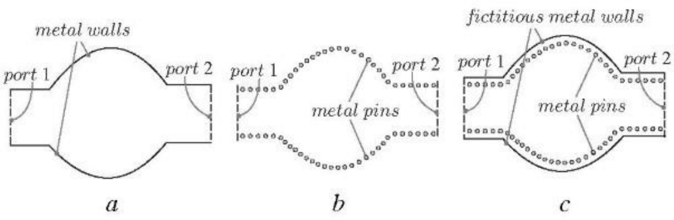

Fig. 1. Examples of two-port waveguide and SIW components: *a*) standard metallic waveguide component; *b*) SIW component; *c*) model of the SIW component, used in the BI–RME analysis.

Figure 2.2 BI-RME method that is used in SIW

The BI-RME method was used to model conductor and dielectric losses, which was presented and validated in [13]. In [14], The BI-RME approach can be used to model leak of radiation, conductor losses, and dielectric losses in the integrated waveguide circuit of the substrate. By defining a fictitious coincident port on the side of the substrate integrated waveguide structure, the theoretical method was reformulated, which explains the leak of radiation. The geometry of the SIW interconnection is shown in Figure 2.3.

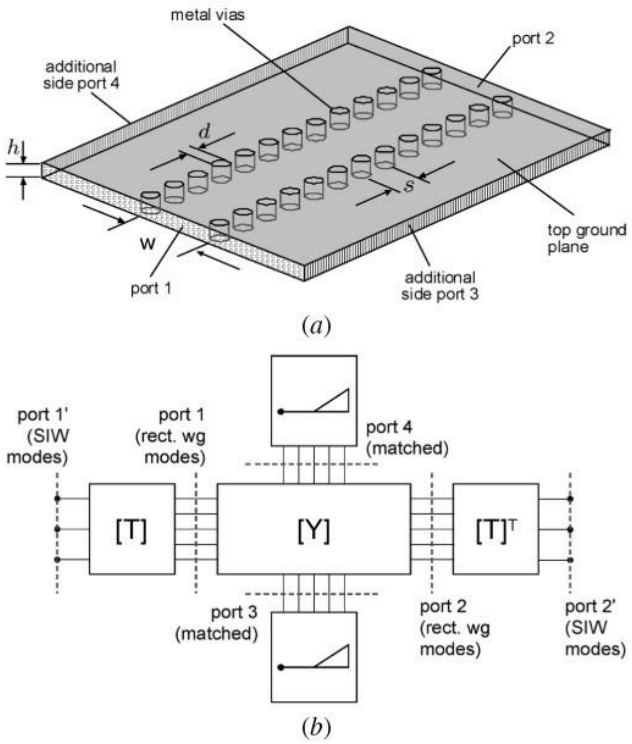

Figure 2.3 Geometry of the SIW interconnect

Similar to [13], the influence of the loss of conductors and dielectrics is directly included in the admittance matrix formula, combined with the perturbation method. Due to its influence on the loss, this approach reveals that raising the substrate thickness reduces the weakening constant of the substrate's integrated waveguide connector and the substrate's integrated waveguide filter insertion loss.

In comparison to a hollow RWG, they lower the SIW's Q-factor [15]. Because the inside of the waveguide in SIW is filled with a dielectric material, dielectric loss is expected to play a significant role in total power dissipation. To reduce dielectric loss in SIW, a redesigned structure known as Modified Substrate Integrated Waveguide (MSIW) is introduced, which removes a portion of the substrate dielectric between the periodic sidewalls, as illustrated in Figure 2.4. The method that is used in this work is proposed in [16], [17]. In [15], the results show that MSIW, which can provide a higher Q factor, can significantly reduce dielectric loss, but has high dissipation due to conductor loss.

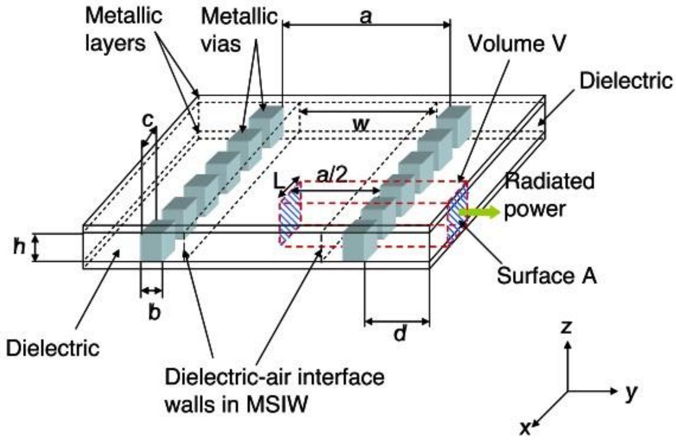

Figure 2.4 Modified Substrate Integrated Waveguide

In [18], a folded substrate integrated waveguide was proposed, which uses a two-fold sheet substrate and a metal septum to decrease the waveguide's size by more than twice that of a traditional SIW. In [19], a half-mode concept SIW was suggested as a way to cut the lateral dimension in half. SIW ridges are introduced by adding the middle row of metalized knockouts [20]. This concept shows the growth in SIW bandwidth: therefore, the horizontal size is reduced by 40%. In [21], a ridge gap waveguide was proposed, with the propagation method set between two parallel metal plates resulting in a waveguide with a lateral dimension better than the wavelength at the cut-off frequency. Despite this, none of the topologies discussed above focused on reducing waveguide longitudinal dimensions.

Slow-wave substrate integrated wave-guide (SW-SIW) is an innovative concept of a slow-wave structure based on the SIW. The concept of numerous rows of metalized blind via-holes was presented in [22] as shown in Figure 2.5. These SW-SIWs, which are based on a two-fold sheet substrate knowledge, have a durable slow-wave consequence, which results in a decrease of mutually crosswise and longitudinal magnitudes, as well as a notable surface miniaturization ratio.

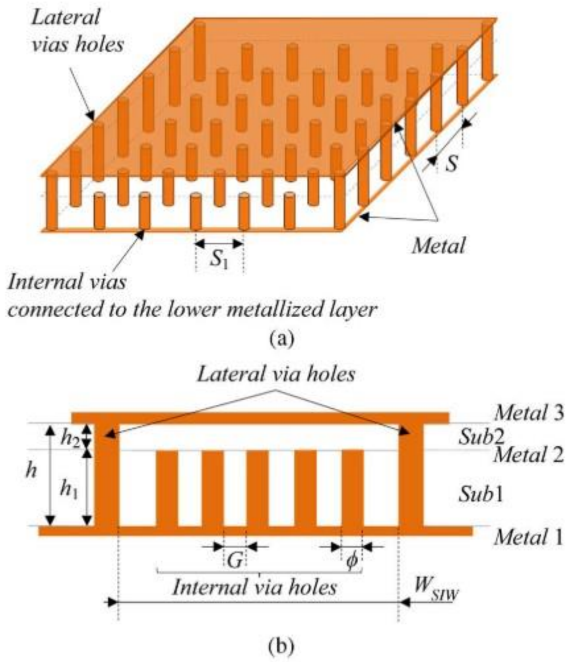

Figure 2.5 Schematic view of the proposed SW-SIW. (a) 3-D view. (b) Transversal cross section of the SW-SIW (example with five internal via-holes)

When compared to a standard SIW at a specified cut-off frequency, the results reveal a 40% drop in crosswise dimensions. Additionally, the phase speed was lowered by 40%, causing smaller longitudinal magnitudes for a specified electrical distance.

2.3 AIR-FILLED SUBSTRATE INTEGRATED WAVEGUIDE

To minimize the dielectric loss, an innovative SIW design has been made to attain lower loss by eliminating the central dielectric area of the SIW [4]. Figure 2.6 shows the suggested AFSIW structure, which is based on a multilayer PCB method. The upper and lower conducting boundaries are realized by substrates 1 and 3. They sit between the air-filled zone and the metallic vias on the intermediate substrate.

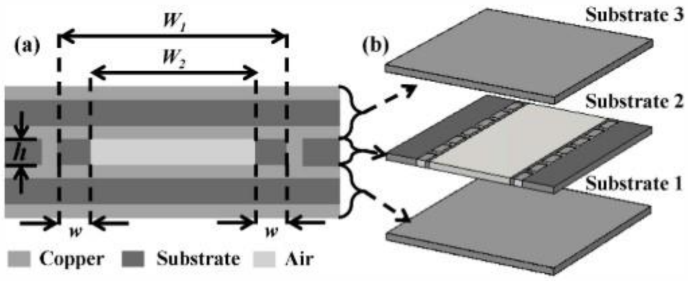

Figure 2.6 AFSIW diagram (a) cross-sectional view (b) structure

The results show that in comparison with the traditional dielectric filling scheme, through the use of the proposed AFSIW, significant improvements in losses and power handling capacity have been obtained.

Using full-wave analysis on the whole SIW structure in which the transition tapers are described, the effect of the transition taper shape on the transmission and return losses is investigated in [3]. In Ka-band and U-band frequency, the structural parameters of air-filled SIWs were designed. As illustrated in Table 2.1, the taper for transition can be designed for a variety of equations.

Shape	$W_2(x)$
Linear	$a + (b - a)(x/L)$
Parabolic	$a(b - a)(x/L)^2$
Exponential	$a + (b - a)\exp[5(x - L)/L]$
Raised cosine	$0.5(a + b) + 0.5(b - a)\cos[(x/L - 1)\pi]$

Table 2.1 Equation for Taper

The results show that the raised cosine taper stays the finest choice to reduce transmission and return losses for Ka-band and U-band frequency. For Ka-band frequency, the raised cosine taper produces the finest return loss of 20 dB to 65 dB and the transmission loss of 0.16±0.02 dB at the frequency range from 28 to 40 GHz while for U-band frequency, return loss of 40 dB to 75 dB and the transmission loss of 0.3±0.01 dB is attained at the frequency range from 44 to 60 GHz as shown in Figure 2.7 and Figure 2.8.

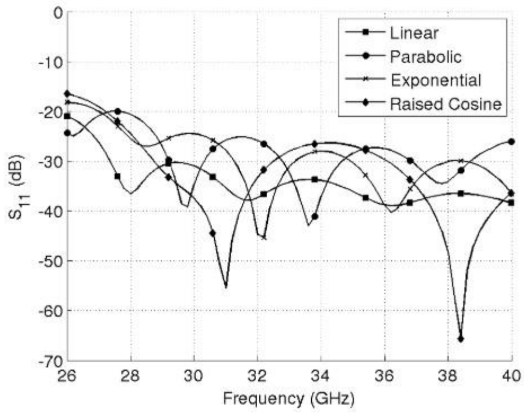

Figure 2.7 Simulated $|S_{11}|$ for a different transition shape of taper in Ka-band frequency at 33 GHz

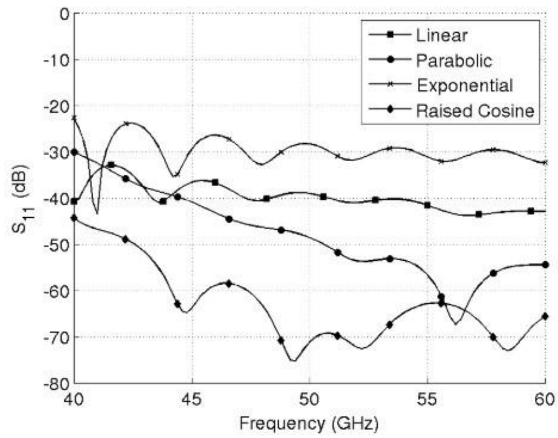

Figure 2.8 Simulated $|S_{11}|$ for a different transition shape of taper in U-band frequency at 50 GHz

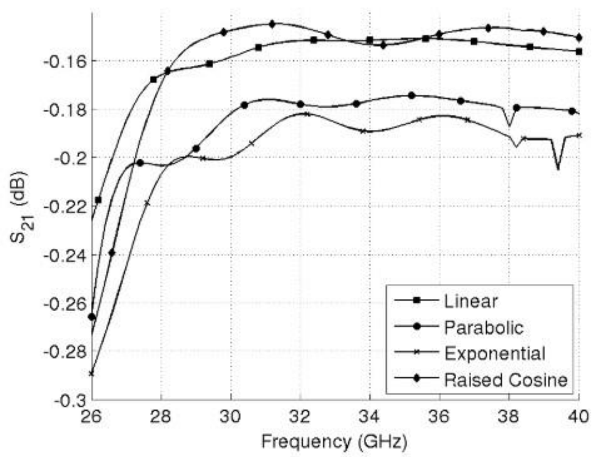

Figure 2.9 Simulated $|S_{21}|$ for a different transition shape of taper in Ka-band frequency at 33 GHz.

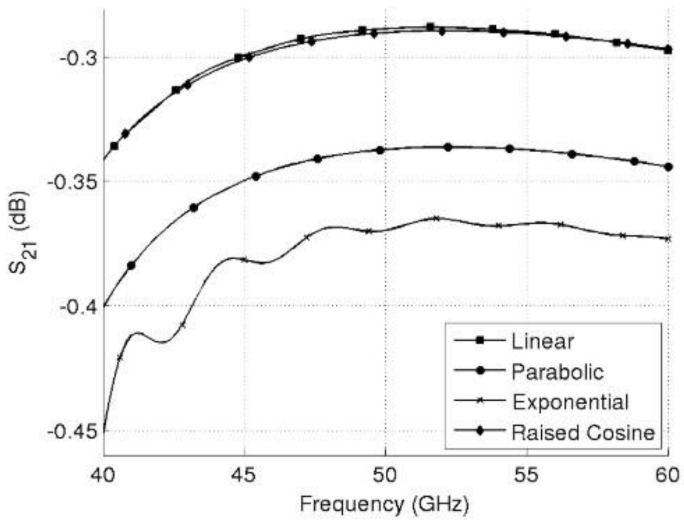

Figure 2.10 Simulated $|S_{21}|$ for a different transition shape of taper in U-band frequency at 50 GHz.

The concept of a half-mode AFSIW (HM-AFSIW) is suggested then tested in this paper [2]. HM-AFSIW is a multilayer design which is a derivation from AFSIW, as shown in Figure 2.9. The observation shows that for HM-AFSIW, radiation loss is the main contributor, which can be attuned by changing Δa. Not only that, when to move away from the cutoff frequency, the radiation loss will decrease with frequency.

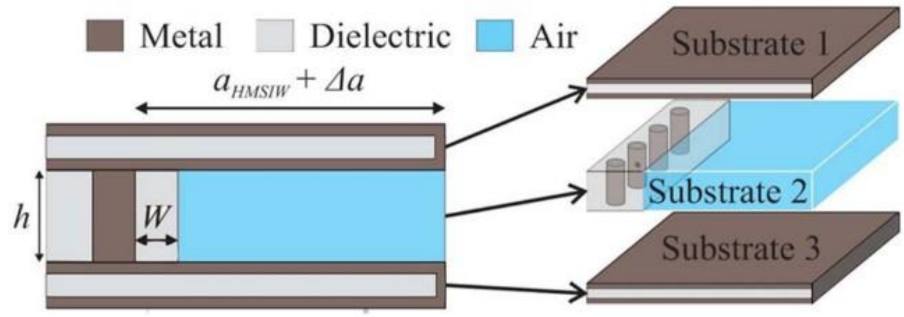

Figure 2.11 HM-AFSIW cross-sectional view with layers representation

The insertion loss of AFSIW and substrate integrated suspended line (SISL) transmission lines is compared to standard planar SIW and CB-CPW in [23]. Figure 2.10 illustrates the structure of AFSIW and SISL.

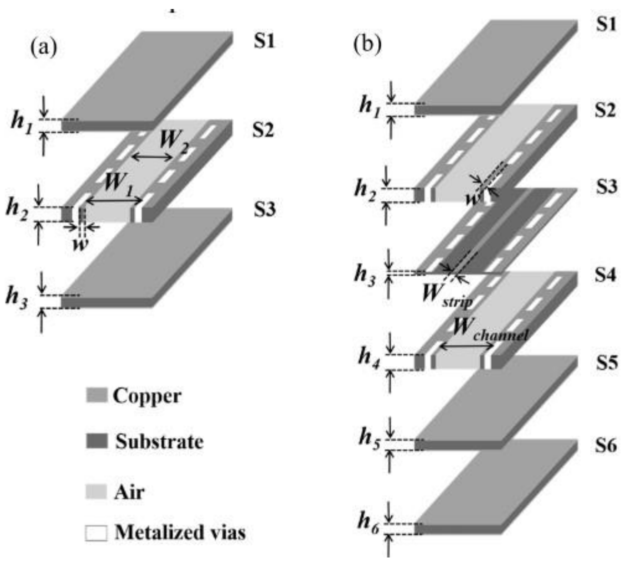

Figure 2.12 (a) AFSIW (b) SISL structures.

It can be seen in Table 2.2 that the losses of AFSIW and SISL are equivalent and exceed the others. Compared to CBCPW and SIW, the loss is decreased by around 2.5 and 3 times, respectively. Therefore, AFSIW and SISL are very promising in the design of low-loss Ka-band systems.

* At 30 GHz.	CB-CPW	SIW	**AFSIW**	**SISL**
Total width (mm)	1.92	4.11	**7.04**	**3.016**
Number of layers	1	1	**3**	**5**
*Transmission loss (dB/cm)	0.116	0.168	**0.049**	**0.045**

Table 2.2 CB-CPW, SIW, AFSIW and SISL comparison

It has been proposed to use the capacitive post for high-performance AFSIW filter post-process adjustment in [24]. Compared to its dielectric-filled SIW (DFSIW) counterpart counterpart[25], [26], the air has a small permittivity and dielectric loss, causing a low-loss and higher power handling structure. This article has demonstrated that it is capable of delivering the high levels of performance necessary aimed at space, aviation, and security applications. This post-processing alteration can be applied to any cavity-based device, such as filters, oscillators, and antennas, as well as various types of substrates incorporated, including standard SIW.

In stacked air-filled substrate integrated waveguide technology, a highly effective IR-UWB connected half-mode cavity-backed slot antenna is presented in [24]. The antenna, which is based on a cavity-backed slot antenna design, is made using the connected half-mode method to produce the requisite antenna characteristics as demonstrated in Figure 2.11 [25].

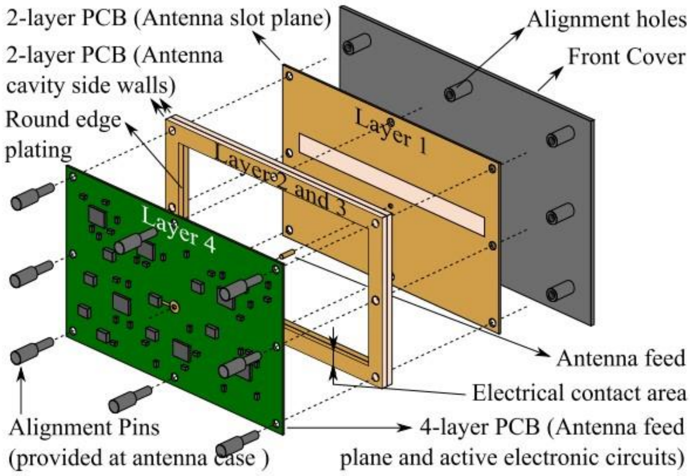

Figure 2.13 Implementation of the cavity-backed slot antenna in standard PCB technology, with integrated IR-UWB circuitry. The copper plated surfaces of the antenna are indicated in dark yellow.

After simulation and measurement in the frequency domain, the results show that stable antenna performance is achieved under the latest conditions, with the lowest antenna efficiency of 89%. This article also looks at the performance comparison between AFSIW and DSIW. AFSIW can bring three effects, namely, the increase in size, the large upsurge in the resistance bandwidth, and the growth in radiation effectiveness. In addition, the AFSIW counterpart is more well-matched for IR-UWB aims than the DFSIW counterpart, and the DFSIW antenna's production cost is substantially greater than the AFSIW counterpart.

The Slab Inflatable Substrate Integrated Waveguide (SAFSIW) has been proposed in [26] as a compromise among the high-performance AFSIW and DFSIW. As demonstrated in Figure 2.12, SAFSIW technology is based on a multilayer PCB construction with a SAFSIW-to-DFSIW transition in the Ka-band frequency.

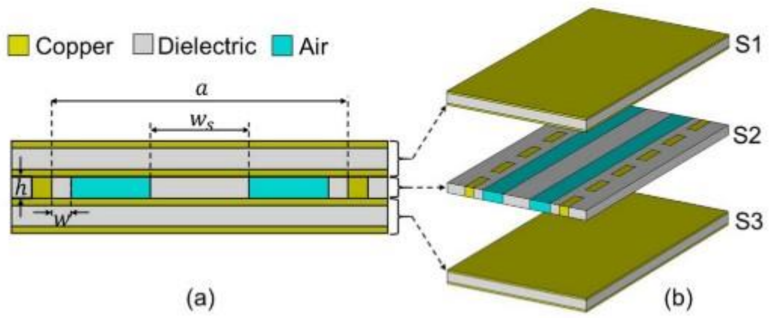

Figure 2.14 SAFSIW structure: (a) cross-sectional view and (b) 3D view.

The main purpose of this slab is to reduce the first mode's cut-off frequency while increasing the second mode's cut-off frequency, letting SAFSIW operate over a larger bandwidth than traditional AFSIW or DFSIW with the same first mode cut-off frequency. SAFSIW provides a good balance between AFSIW and DFSIW in terms of loss and footprint, as well as the flexibility to the AFSIW technological platform, according to the simulation.

At millimeter wavelengths, a modification to the boundary condition around the air-filled integrated guiding medium was implemented, allowing the guiding structure to be self-packaged and isolated in [27] as shown in Figure 2.13. This concept, also known as contactless AFSIW (CLAF-SIW), uses the PEC–AMC parallel cut-off for any gap less than a quarter of a wavelength. As the performance of CLAF-SIW compared to that of a traditional structure, the results show that CLAF-SIW has a smaller loss than AFSIW.

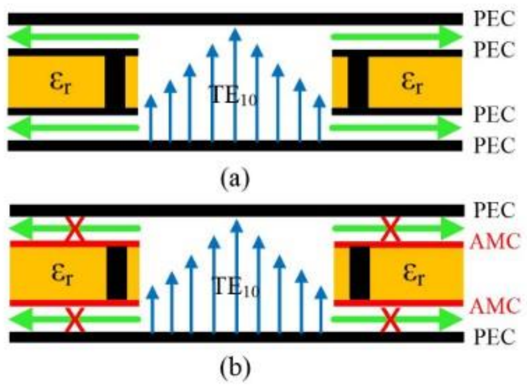

Figure 2.15 (a) Geometry of the conventional AF-SIW. (b) Geometry of CLAF-SIW screws

The study of the transition length effects on AFSIW structure losses was conducted to further minimize AFSIW losses, allowing for the possibility of a more compact printed SIW structure design to achieve miniaturizations while enhancing the wearable microwave device performance [28]. To achieve an effective interconnection between the dielectric and the air fill in the AFSIW circuit, a transition is designed using the characteristic equation in [4] and the raised cosine taper which also from [3]. Figure 2.14 illustrates the transition taper's design. The transition length can be reduced to achieve downsizing while preserving excellent signal transmission quality by using the proper design of the transition structure.

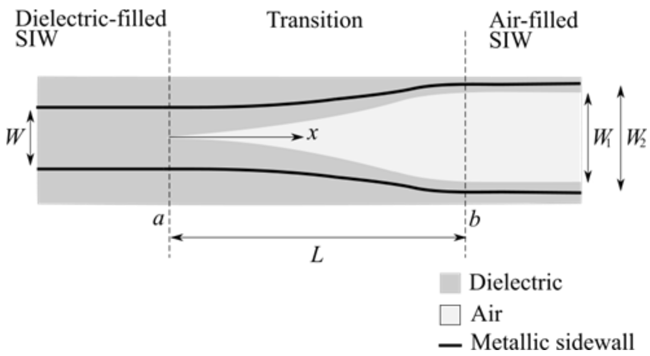

Figure 2.16 Tapered transition with cross-section.

The optimization method combines a multi-objective genetic algorithm (GA) with full-wave analysis to identify the optimal transition profile has been done in [29]. Using full-wave analysis of a complete AFSIW structure, this examines the impact of the transition taper shape in an AFSIW on the return and insertion losses. The taper designs were established in this study by improving the transition losses by stipulating the geometry of the transition taper with the clamped cubic spline function. As demonstrated in Figure 2.15, defining a spline can serve as a finite number of unknowns to be optimized by specifying a fixed number of nodal points, or knots.

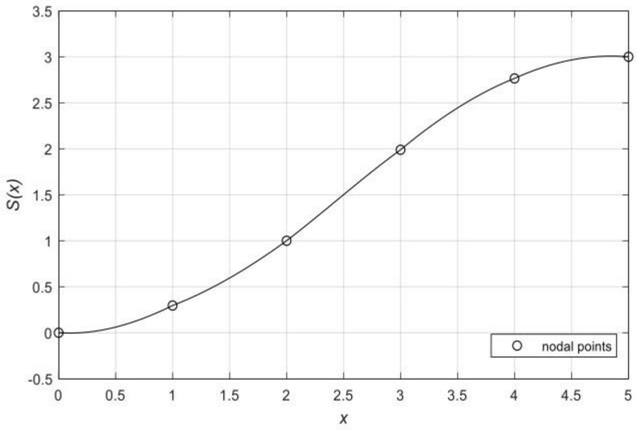

Figure 2.17 Taper profile with clamped cubic splines.

The improved taper transition geometry produced from the clamped cubic spline is shown to further minimize the return and transmission losses in the computational analysis above, indicating that this study is effective in identifying an optimal transition taper [30]. The optimization technique also demonstrates the effectiveness of real-time connection between MATLAB and ANSYS HFSS for full-wave electromagnetic simulations as the optimal transition taper showed a 17% improvement concerning the return loss and the improvement in transmission loss of the optimal taper is 50%.

CHAPTER 3 METHODOLOGY

3.1 SOFTWARE ANSYS HFSS

Ansys HFSS is a 3D electromagnetic (EM) simulation software for designing and simulating high-frequency electronic products such as antennas, antenna arrays, printed circuit boards, etc. Ansys HFSS is used to build high-frequency, high-speed electronics found in communications systems, radar systems, advanced driver assistance systems (ADAS), satellites, internet-of-things (IoT) goods, and other high-speed RF. HFSS (High-Frequency Structure Simulator) uses adaptable solvers and an easy GUI to provide outstanding performance and deep insight into 3D EM challenges. HFSS delivers a powerful and full multiphysics study of electronic goods through integration with Ansys thermal, structural, and fluid dynamics tools, ensuring their thermal and structural durability.

3.2 DESIGNING THE SIW

The dimensions and properties of the SIW are designed for Ka-band frequencies which are from 26 GHz to 40 GHz. The geometry model of SIW is shown in Figure 3.1.

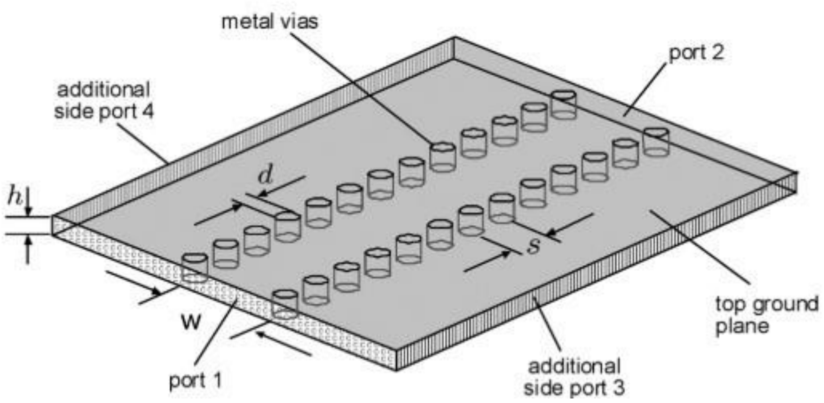

Figure 3.1 Geometry of SIW

The material that is used to design SIW is Rogers RT/Duroid 6002 substrate layers with thickness h = 0.508 mm. For the geometry of SIW, w=8.2mm, d=0.5mm, and s=1mm

The model was designed as a simple substrate integrated waveguide with just with only Rogers RT/Duroid 6002 substrate and via holes as shown in Figure 3.2. This acts as a foundation and also as training for using the first simulation software HFSS to design a waveguide. The width and the length of SIW are 9.2mm and 20mm respectively.

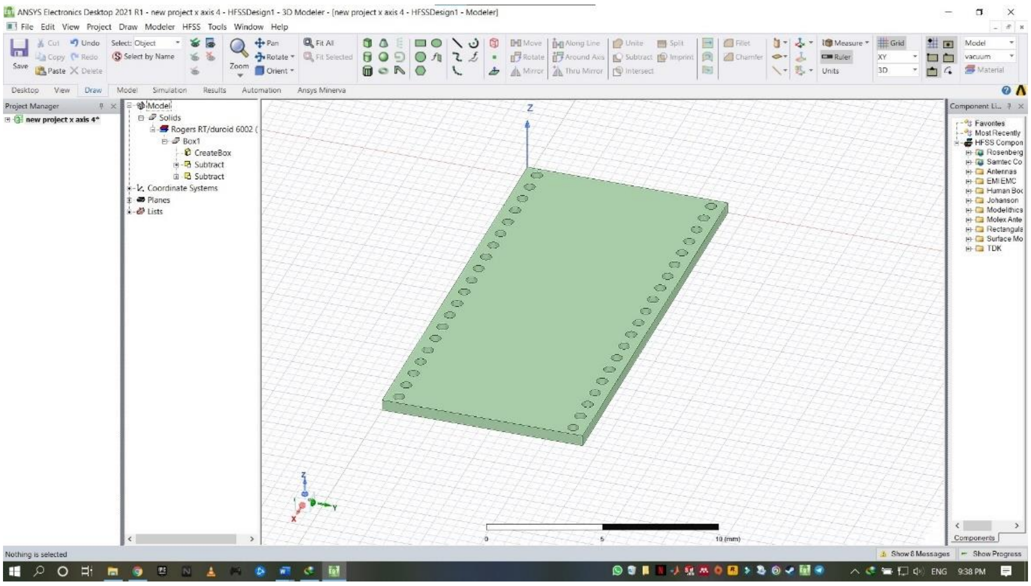

Figure 3.2 Design of SIW

3.3 DESIGNING THE AFSIW

Next, the design is further improved by making an air-filled substrate waveguide. This is done by hollowing the middle part of the substrate into a raised cosine tapered shape. The waveguide uses the same vias and material as the above design. This uses the same concept as the transition proposed in [1]. Figure 3.3 shows the geometry of AFSIW.

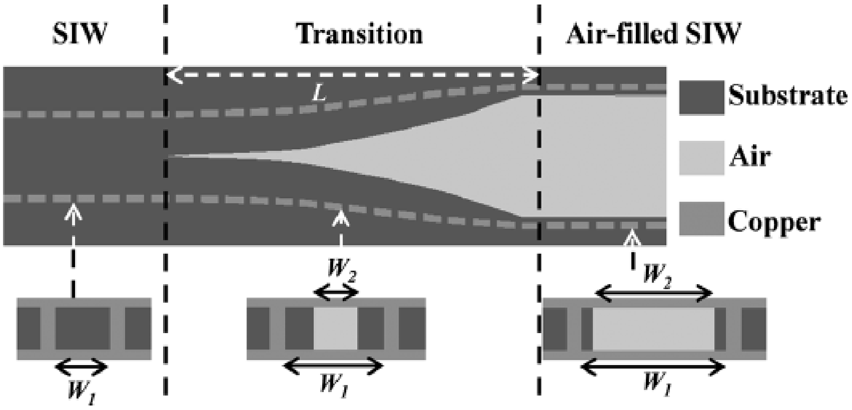

Figure 3.3 Geometry of AFSIW

The design that was made in HFSS is shown in Figure 3.4 below. It has a spline profile taper for the air-filled substrate to further optimize the waveguide.

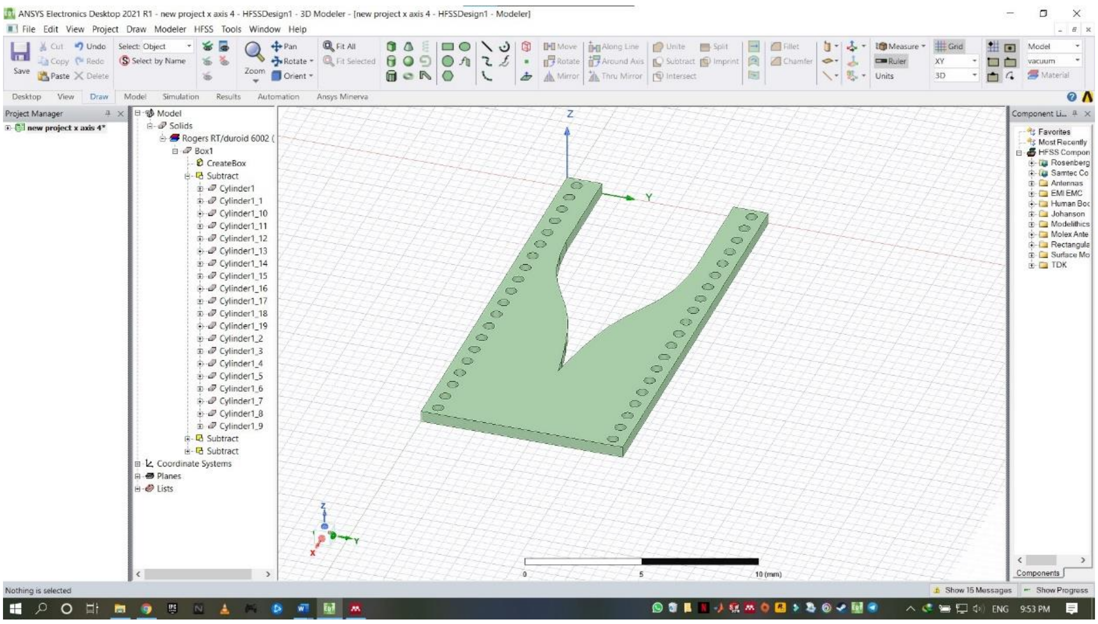

Figure 3.4 AFSIW design in the ANSYS HFSS

The width and the length of the air-filled SIW are 6mm and 5mm respectively. The length for the transition is set at 10mm and the remaining 5mm for the dielectric. After that, the copper layers are added on the top and bottom of the AFSIW as shown in Figure 3.5 with each height is 0.2mm.

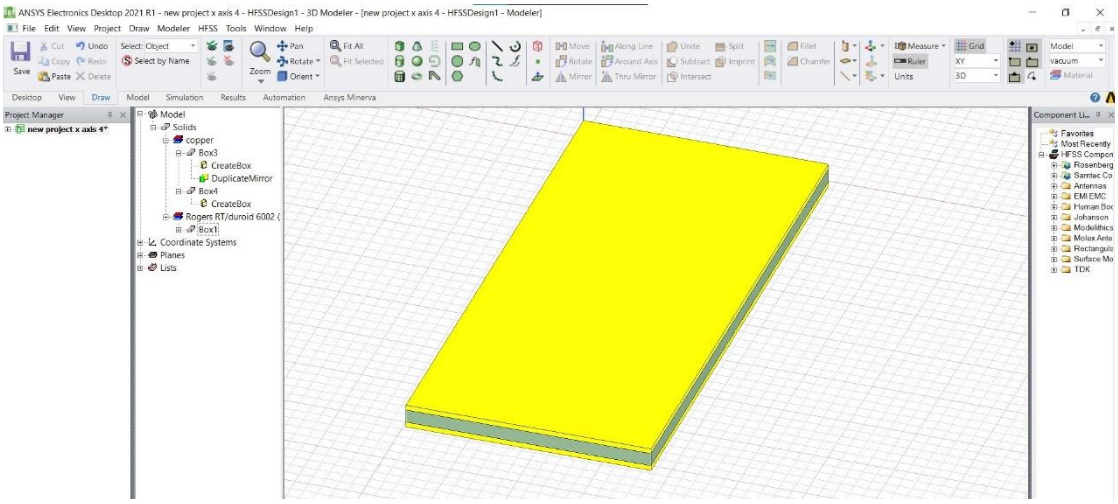

Figure 3.5 Copper layers on top and bottom of AFSIW

3.4 SIMULATION OF FULL-WAVE ANALYSIS AFSIW

Next, the wave port is created in the front and back of the AFSIW. After that, the excitation is applied to the wave ports of AFSIW. Excitations in HFSS are used to specify the sources of electromagnetic fields and charges, currents, or voltages on objects or surfaces in the design. Excitation was applied on both wave ports as shown in Figure 3.6 and Figure 3.7. For the wave port at the back of AFSIW, it is set as input while the wave port at the front of the AFSIW is set as output.

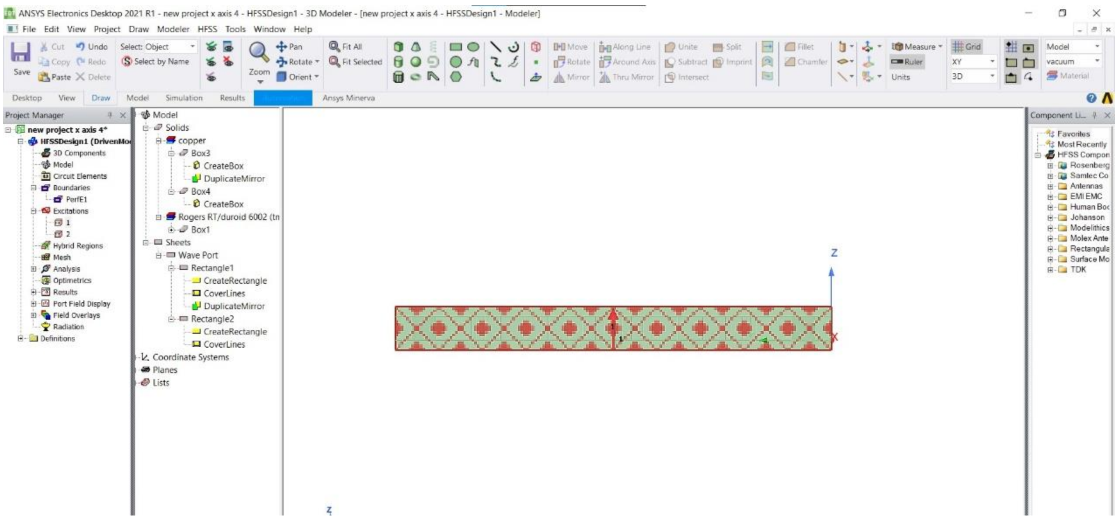

Figure 3.6 Input wave port AFSIW

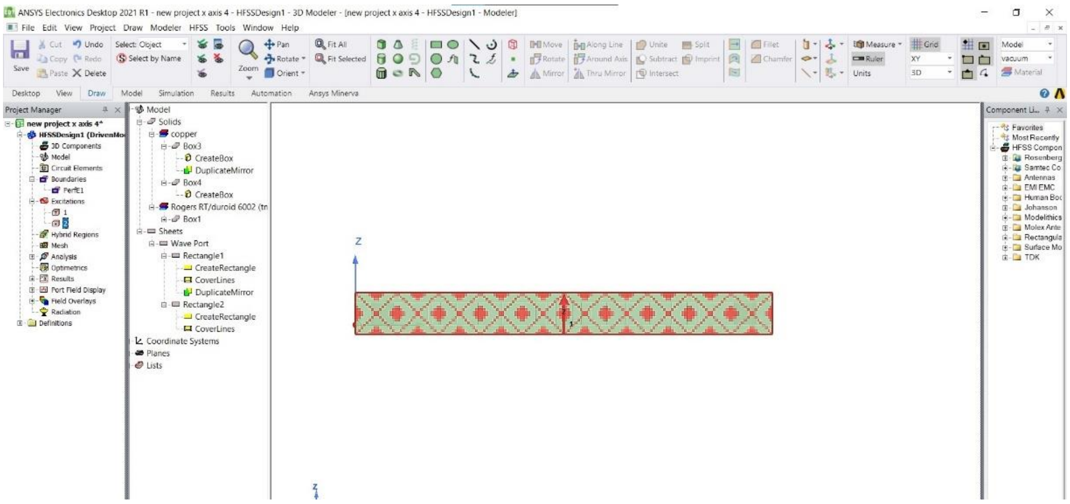

Figure 3.7 Output wave port AFSIW

Then, the boundary is assigned for both copper layers in AFSIW. Boundary conditions define the field behavior at the problem region's and object interfaces' edges. The boundary is set as Perfect E as shown in Figure 3.8. Perfect E boundaries are boundary models that perfectly conduct the surface of a structure, forcing the electric field to be normal to the surface.

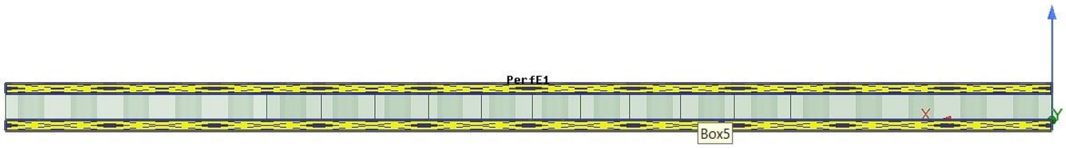

Figure 3.8 Perfect E boundary on both copper layer

The boundary for the AFSIW is also assigned as radiation as shown in Figure 3.9. Radiation is the boundary that simulates an open problem that permits waves to radiate endlessly far into space, such as antenna designs. The radiation boundary is applied by creating a box with the same height and width as AFSIW and both copper layers. Vacuum is applied as the material of the boundary on the AFSIW.

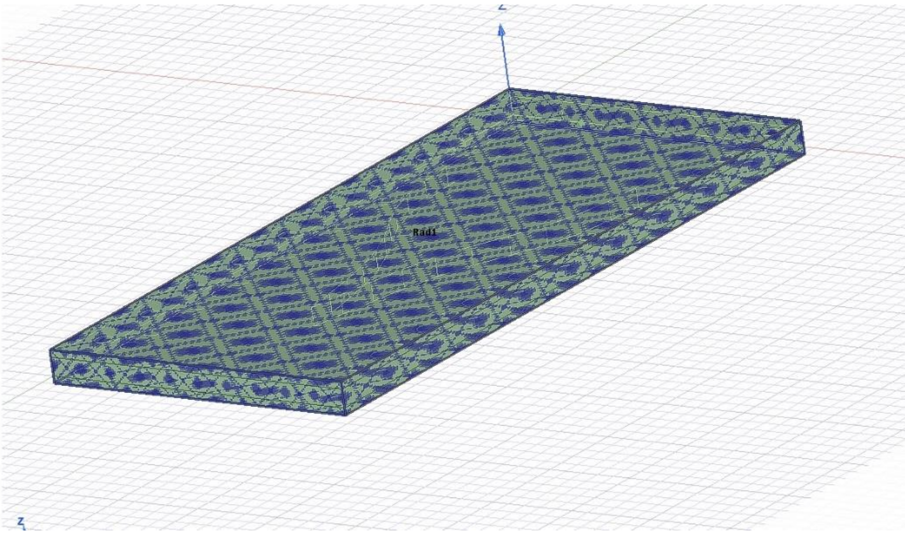

Figure 3.9 Radiation boundary on the AFSIW

The analysis setup is created for the AFSIW. The solution setup is shown in Figure 3.10 and Figure 3.11

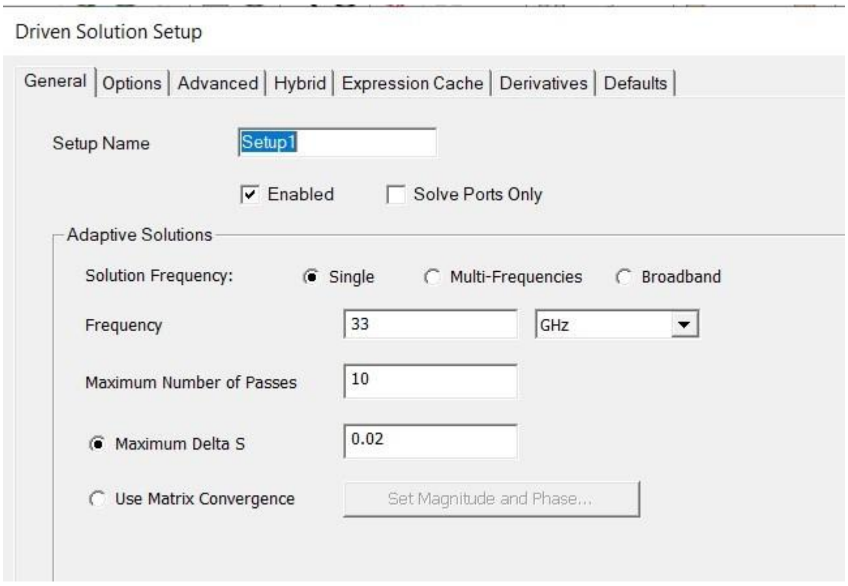

Figure 3.10 Solution Setup AFSIW

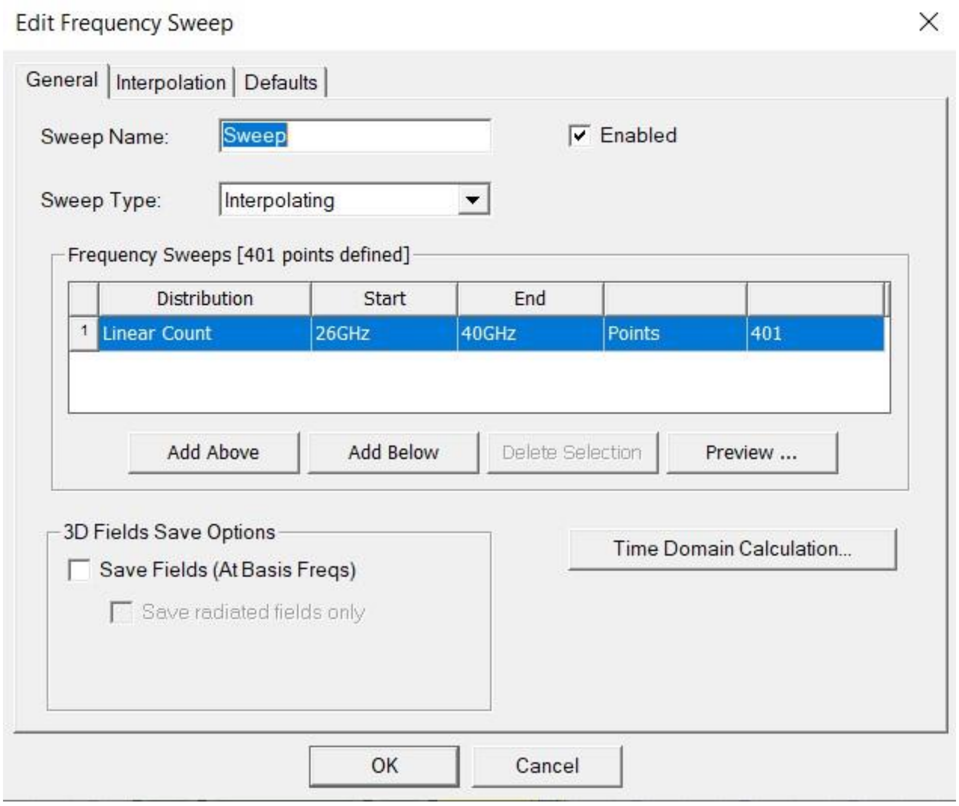

Figure 3.11 Frequency sweep setup

After the design is finished, the simulation needs to be run to get the data of the AFSIW. The simulation is run in the Ka-band frequency which is frequency from 26 to 40 GHz. The obtained result is observed and the frequency against simulated reflection coefficient, $|S_{11}|$ and transmission coefficient, $|S_{21}|$ are then plotted.

CHAPTER 4 RESULT & DISCUSSION

In this chapter, the results from the methodologies given earlier in Chapter 3 are presented and discussed accordingly. This chapter will cover an analysis of the full-wave computations of the dielectric to air-filled SIW transition when length transition is set at 10mm.

4.1 FULL-WAVE ANALYSIS OF DIELECTRIC TO AIR-FILLED SIW TRANSITION

To validate the performance of the transition in a complete air-filled SIW structure, an analysis of wave interaction at the interface between air- and dielectric-filled in AFSIW was performed. Figure 4.1 and Figure 4.2 show the result of the reflection coefficient, S_{11} and transmission coefficient S_{21} when the transition length is set at 10mm.

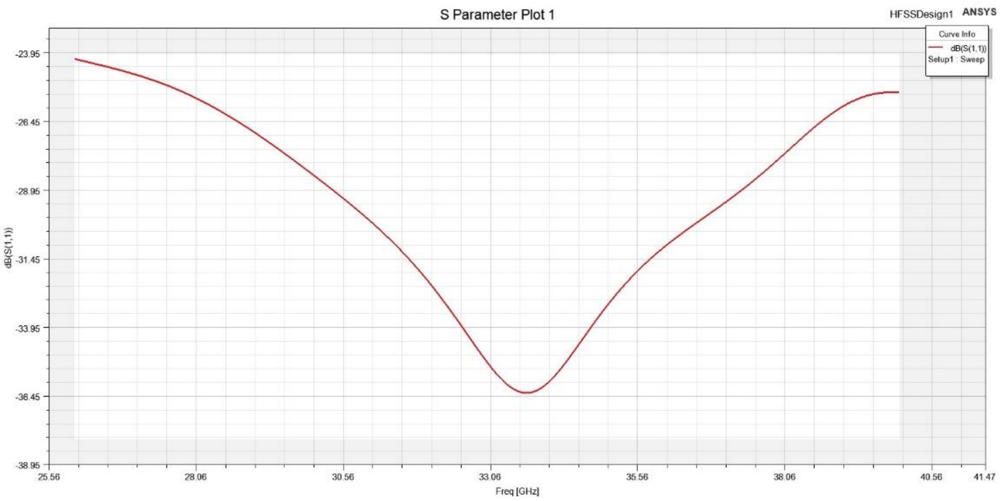

Figure 4.1 The reflection coefficient S_{11} in Ka-band frequency at 33 GHz