Design of Microstrip Patch Antenna Fed by Substrate Integrated Waveguide for WLAN

Rashmi
Department of Electronics & Communication Engineering
National Institute of Technology, Jamshedpur, India
***E-mail:-** 2018rsec008@nitjsr.ac.in*
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Abstract

In this work, an aperture coupled microstrip patch antenna fed by substrate integrated waveguide (SIW) has been designed for wireless local area network (WLAN) application. The designed antenna shows an increase in gain, radiation efficiency. The overall performance of the antenna increases when fed by SIW compared with conventional aperture coupled microstrip patch antenna. The radiation efficiency increases by an approx 46%.

Keywords— *Substrate Integrated Waveguide (SIW), Aperture Coupled Microstrip Patch Antenna (MPA), Feeding methods*

INTRODUCTION

At the beginning of the century, wireless Communication began a long road full of prosperous progress. Since Marconi's proposals until today, the technologies used for wireless communications have progressed very fast. These advances have always had as its purpose the low power consumption, miniaturization of components, maximum efficiency [1].

With the advent of transistors, circuits have achieved high performance, and current receivers have widely reduced their size. The transistors have enabled many applications such as amplifiers, oscillators, mixers, among others. Without a doubt, this nonlinear device allows a wide range of important applications to the development of wireless communications [2].

Now a day, in microwave communications, receivers have achieved a great reduction of their size, maintaining its efficiency. This is due to the use of the transistor and other technologies that complement each other [2]. One of them is the use of microstrip technology to design passive circuits. Microstrip is widely used due to its compact size and easy integration. But with frequency increasing as an open structure, a microstrip circuit shows undesirable radiation. To solve this problem, we can use SIW technology [3]. The SIW technology is important because any non-planar waveguide like structure (including classical rectangular waveguide) can be synthesized into planar form, which can be seamlessly integrated with conventional printed planar circuits. This is one of the major advantages of SIW technology because it allows us to fabricate a complete circuit in planar form. Moreover, it is possible to mount one or more chips on the same substrate, reducing losses and parasitic. Using the SIW technology, one can optimize an antenna structure and integrate it with different components [4].

With the use of SIW technology, we can propose a better antenna structure. These kinds of antennas have better performance because it suppresses the surface waves; increase the applicable frequency range [5].

Here SIW structure is presented as a low-loss/cost feeding scheme to MPA to alleviate the radiation efficiency degradation caused by traditional planar.

SIW DESIGN EQUATIONS

Substrate integrated waveguide (SIW) is a new form of the transmission line. In high-frequency applications, microstrip devices are not efficient, and because wavelength at high frequencies is small, microstrip device manufacturing requires very tight tolerances [26].

At high frequencies, waveguide devices are preferred; however, their manufacturing process is difficult. Therefore a new concept emerged: substrate integrated waveguide. It consists of a substrate with metal walls at the top and bottom and two rows of via holes embedded at the two sides of the substrate.SIW is a transition between microstrip and dielectric-filled waveguide (DFW). Dielectric filled waveguide is converted to substrate integrated waveguide (SIW) with the help of vias for the sidewalls of the waveguide.

SIW devices can be thought of as a form of dielectric-filled waveguide (DFW); therefore, the starting point can be DFW. For TE_{10} mode, the dimension "b" is not important as it does not affect the cut off frequency of the waveguide. Therefore the substrate can be at any thickness; it only affects the dielectric loss (thicker = lower loss).

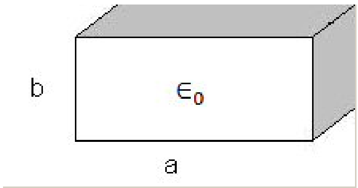

Fig. 1: Dimension definition of rectangular Waveguide

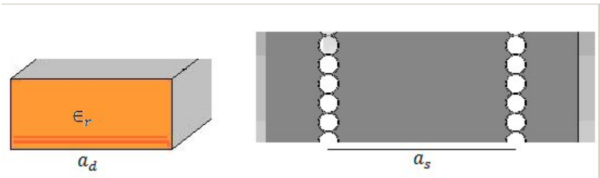

Fig. 2: Dimension for DFW and SIW

For a rectangular waveguide, the cut off frequency of arbitrary mode is found by the following formula:

$$f_{c_{mn}} = \frac{k_c}{2\pi\sqrt{\mu\varepsilon}} = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m\pi}{a}\right)^2+\left(\frac{n\pi}{b}\right)^2} \rightarrow$$

$$f_{c_{110}} = \frac{1}{2a\sqrt{\mu\varepsilon}}$$

(1)

Where:

c: speed of light
m, n: mode numbers
a, b: dimensions of the waveguide

For DFW with the same cut off frequency, dimension "a_d" is found by:

$$a_d = \frac{a}{\sqrt{\varepsilon_r}}$$

(2)

Having determined the dimension "a" for the DFW, we can now pass to the design equations for SIW.

$$a_s = a_d + \frac{d^2}{0.95p} \qquad (3)$$

d: diameter of the via, p: pitch (distance between the vias)

In the design of SIW components, one must ensure that the SIW operates in the frequency band of interest where there is no bandgap effect and leakage loss is negligible over the entire bandwidth of interest.

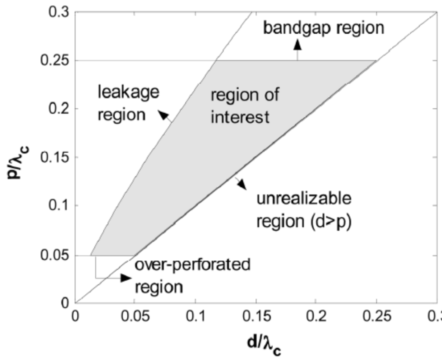

Fig. 3: Region of interest for Substrate Integrated Waveguide

This region of interest is defined by

$$p > d$$

(4) $$\frac{p}{\lambda_c} < 0.25 \qquad (5)$$

$$\frac{\alpha_1}{k_0} > 10^{-4} \qquad (6)$$

$$\frac{p}{\lambda_c} > 0.05 \qquad (7)$$

Equation 4 states that the period length of vias must be larger than the cylinder diameter so that the circuit is physically realizable. The condition given in equation 5 is required to avoid any bandgap in the operating bandwidth. To be negligible, the leakage losses must respect condition 6. Finally, a nonessential but desirable condition for the manufacturing process is to minimize the number of cylinders. These cylinders are usually mechanically drilled and chemically electroplated, and the production time is proportional to their number. Moreover, if the length of the period is very small, the mechanical rigidity is adversely affected. The number of cylinders should therefore not exceed 20 per wavelength, as stated in equation 7.

APERTURE COUPLED MICROSTRIP PATCH ANTENNA DESIGN

Aperture Coupled Microstrip Patch Antenna

The structure of aperture coupled MPA is shown in figure 4. It consists of two substrates. The height of both substrates is 1.5mm. The lower substrate has a microstrip line feed and a rectangular slot in the top metal plane. This top metal plane acts as a ground plane for the upper substrate, which has a metal patch at the top. The rectangular slot is such that the centre of the patch and that of the slot coincide for maximum power transfer. The radius of the outer conductor probe is 1.3mm, and the radius of the inner conductor probe is 0.4mm.

Table I: Dimension of ACMPA

Patch length	10.99mm
Patch width	15.7mm
Substrate length	54.8mm
Substrate width	37.47mm
substrate height	1.5mm
Slot length	12mm
Slot width	1.8mm
Microstrip line width	2.7mm

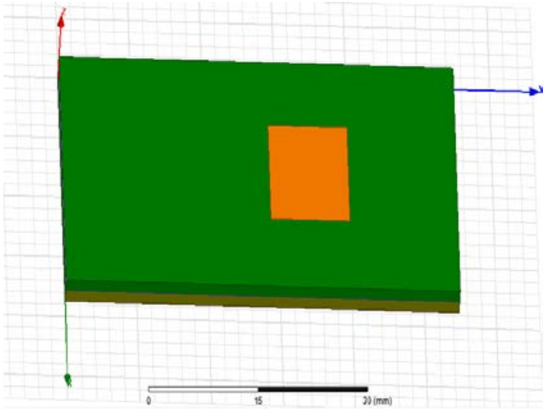

Fig. 4: (a) Structure of ACMPA (Top View)

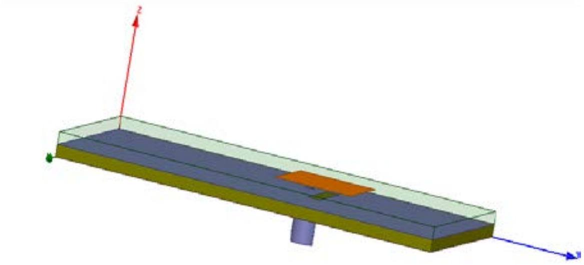

Fig. 4: (b) Aperture coupled MPA (Side view)

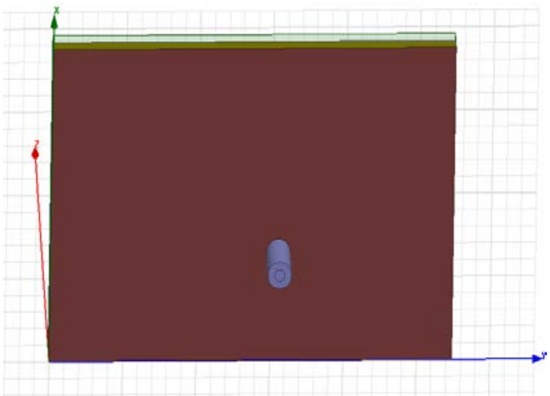

Fig. 4: (c) Bottom View

Aperture Coupled Microstrip Patch Antenna Fed by SIW

The structure of Aperture coupled Microstrip Patch Antenna fed by Substrate integrated waveguide is shown in figure 5. The lower layer is SIW having a ground plane at the bottom and a top metal layer that has an I shape slot in it. The upper layer has a metal patch on its top. The top metal plane of lower substrate acts as a ground plane for the upper substrate.

Table II: Dimension of Aperture coupled Microstrip Patch Antenna fed by SIW

Patch length	12mm
Patch width	15.7mm
Substrate length	54.8mm
Substrate width	37.47mm
Substrate height	1.5mm
Radius of via(r)	1mm
Centre to centre distance between vias (p)	3.6mm
Position of probe feed from origin(x, y)	9mm,31mm
Length of vertical slot	7mm
Width of vertical slot	1.5mm
Length of horizontal slot	5mm
Width of horizontal slot	1.5mm

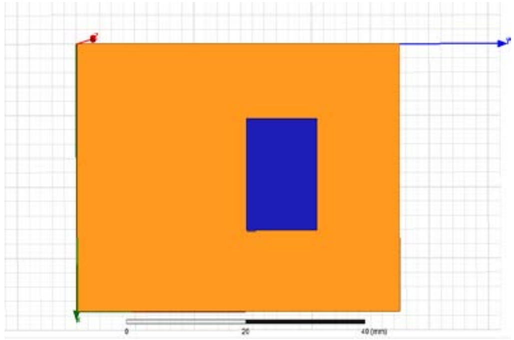

Fig. 5: (a) Aperture coupled Microstrip Patch Antenna fed by SIW (top view)

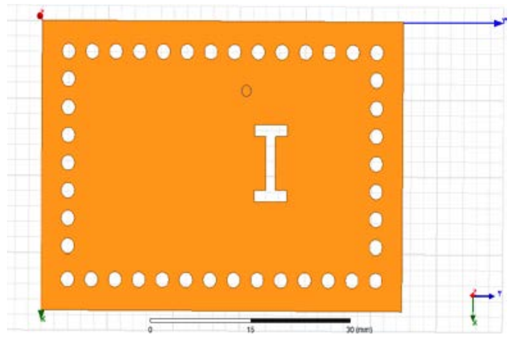

Fig. 5: (b) Aperture coupled Microstrip Patch Antenna fed by SIW (SIW top view)

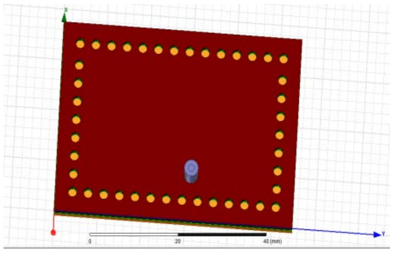

Fig. 5: (c) Aperture coupled Microstrip Patch Antenna fed by SIW (bottom view)

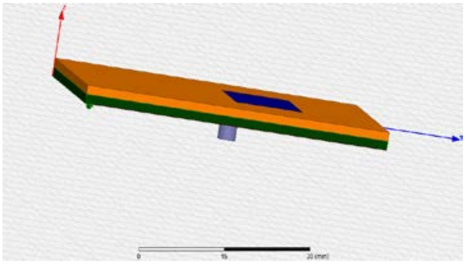

Fig. 5: (d) Aperture coupled Microstrip Patch Antenna fed by SIW (side view)

ANTENNA PERFORMANCE: SIMULATION AND RESULTS

The antenna is designed and simulated with the help of ANSYS High-Frequency Structure Simulator (HFSS) at 5.8GHz. Here FR4 (Fire resistant) material has been used as a substrate for designing antennas having a dielectric constant of 4.4 and loss tangent 0.02. FR-4 or (FR4) is a grade designation assigned to glass-reinforced epoxy laminate sheets, tubes, rods and printed circuit boards (PCB).

FR-4 is a composite material composed of woven fiberglass cloth with an epoxy resin binder that is flame resistant (self-extinguishing). FR-4 glass epoxy is a popular and versatile high-pressure thermoset plastic laminate grade with good strength to weight ratios. With near-zero water absorption, FR-4 is most commonly used as an electrical insulator possessing considerable mechanical strength. The simulation results of both antennas are shown below.

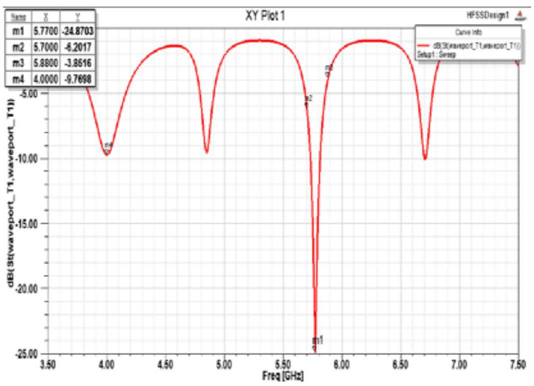

Fig. 6: (a) S_{11} v/s frequency graph of Aperture coupled MPA

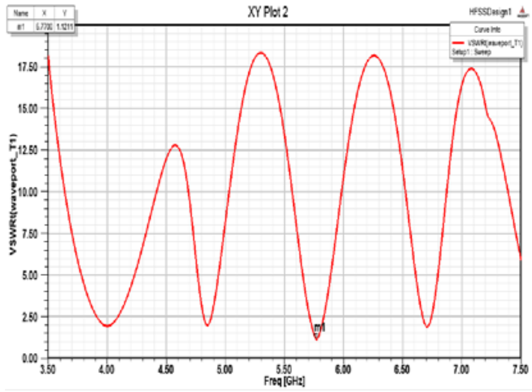

Fig. 6: (b) VSWR v/s frequency graph of Aperture coupled MPA

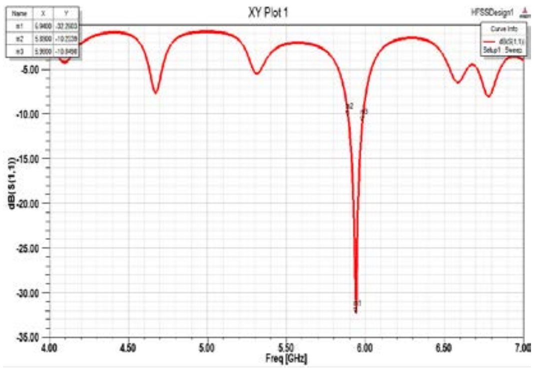

Fig. 7: (a) S_{11} v/s frequency graph for dual layer Microstrip Patch Antenna fed by SIW

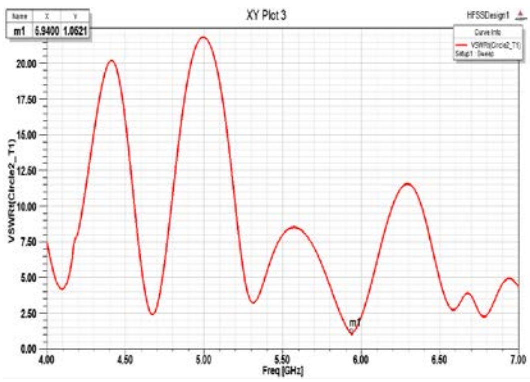

Fig. 7: (b) VSWR v/s frequency graph for Aperture coupled Microstrip Patch Antenna fed by SIW

In table III below, antenna parameters of the antennas designed have been compared.

Table III: Comparison of designed and simulated antenna parameters

Antenna Type	ACMPA	ACMPA Fed by SIW
Frequency	5.8Ghz	
S11	-29.82db	-32.26db
VSWR	1.06	1.05
Bandwidth	180MHz	90MHz
Gain	6.28db	7.1db
Directivity	10.76	9.07
Radiation Efficiency	39%	57%

CONCLUSION

In this paper, a novel aperture coupled microstrip patch antenna using substrate integrated waveguide has been proposed for WLAN application. The simulation results have been presented. The designed antenna shows an increase in radiation efficiency by almost 20% compared to conventional aperture coupled microstrip patch antenna. The central frequency is 5.94GHz with -10dB bandwidth is from 5.89GHz to 5.99GHz, which is suitable for the WLAN application.

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