Miniaturization of 2.4 GHz SIW Antenna using Complementary Split Ring Resonator

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***Abstract*— This paper had been miniaturization the SIW antenna with Complementary Split Ring Resonator (CSRR). The operating frequency of this antenna is 2.4 GHz for Wireless Local Area Network (WLAN) application. This simulation works had been done in Ansfot HFSS 13.0 simulation software. The antenna is fed by use of microstrip line feeding technique and deployed on FR-4 Epoxy substrate with the relative permittivity of 4.2 and the thickness of 1.6mm. To demonstrate the miniaturization, the metamaterials- based antenna will be compared with 2 microstrip antennas 1. Basic SIW antena 2. SIW antenna with CSRR that resonate at the same resonant frequency. . These 5 kind antennas are then compared each other in terms of physical size, return loss, VSWR, gain, and radiation pattern. From the result, it is shown that the incorporation of CSRR can reduce the size of antenna by more than 59%.**

Keywords-Complementary Split Ring Resonator (CSRR), Substrate Integrated Waveguide (SIW), Microstrip Antenna

I. INTRODUCTION

Rapid progress in wireless communication technology has sparked the need for developments in antenna designs. Some applications of the wireless communication system such as cellular phones, laptops, PC wireless cards, and various remote-sensing devices require miniaturized antennas [1]. WLAN or Wireless Local Area Network has become more popular. For examples, the portable devices like laptop, notebook, PDA, and mobile phones are incorporated with WiFi and Bluetooth technologies to connect. This IEEE 802.11b/g is operating at 2.40 GHz. Since 1999, researchers have proposed many structure designs to form metamaterials structure.

In addition,these antennas are expected to be low-profile, efficient, and electrically small to be integrated into modern wireless terminals. As is well known, conventional microstrip antennas are low-profile and efficient but inherently narrow band. In modern wireless communication systems, the microstrip antennas are commonly used in the wireless devices. Therefore, the miniaturization of the microstrip antenna has become an important issue in reducing the volume of entire communication system.

The common method for reducing the microstrip patch antenna size is to utilize a high permittivity dielectric substrate. But, the antennas are more expensive, less radiation efficiency, and have narrow bandwidth. To overcome the above drawbacks, many design techniques of the patch antenna have already been proposed. These antennas have the inserted slot [2], the corrugation structure [3], the iris structure [4], and the shorting pin [5]. However, all of these design strategies have limitation in their design, which are a complex structure and low performance for miniaturization. So, the design methods of the miniaturized patch antenna with metamaterial technology have been reported on some authors, recently [6] [7].

These would include the SRR or CSRR on the microstrip patch, although those antennas have been restrictively researched in single patch antenna. In other words, achievement of size reduction of antenna with the SRR or CSRR has a special meaning in the field of microstrip antenna. The SRR was originally proposed by Pendry in 1999, and is the metamaterial resonator having the negative permeability. The SRR structure is formed by two concentric metallic rings with a split on opposite sides. This behaves as an LC resonator with distributed inductance and capacitance that can be excited by a time-varying external magnetic field component of normal direction of resonator. This resonator is electrically small LC resonator with a high quality factor.

Based onthe Babinet principle and the duality concept, the CSRR is the negative images of SRR, and the basic mechanism is the same to both resonators except for excited the axial electric field. With adjustment of the size and geometric parameters of the CSRR, the resonant frequency can be easily tuned to the desired value [8]. An electrically small complementary split-ring resonator (CSRR) is used to cover the 2.4-GHz bandwidth. The two slot rings in the CSRR are coupled and thereby allow negative permittivity and permeability and exhibit composite right/left-handed (CRLH) characteristics . Further, they possess a narrow bandwidth and a high-Q factor and have been widely used as filters . In particular, many of the existing CSRRs are also combined with the SIW [9].

Recently, substrate-integrated waveguide (SIW) technologies have been used to implement compact, low-cost, planar antennas and filter applications, with performance comparable to that of a bulky waveguide . By using a half-mode substrate-integrated waveguide (HMSIW), substrate integrated folded waveguide (SIFW), and quarter-substrate integrated waveguide, the total size of an SIW is largely reduced, but comparable performance is maintained . A compact and high-efficiency antenna can be designed by taking advantage of SIW technology and CRLH antennas. Previously, CRLH-based substrate-integrated waveguide (SIW) antennas have been proposed to minimize the antenna size [10]. In this paper, a more compact SIW antenna is proposed by loading the CSRR.

II. ANTENNA DESIGN

A. Basic SIW Antenna Design

The SIW antenna is the antennas that constructed on the dielectric substrates like FR4, Taconic or Duroid. Microstrip patch is the basic antennas that can be applied in various applications like Wireless Local Area Network (WLAN), Worldwide Interoperability for Microwave Access (WiMAX), and others. The advantages of SIW antenna are its low profile, easy to fabricate, low cost, and omnidirectional radiation patterns [11]. The SIW antennas were fed either by microstrip line or a coaxial probe through the ground plane in a variety of methods. Here, the design had been fed by the microstrip line at the front of the patch antenna.

TABLE I. DIMENSION OF NORMAL MICROSTRIP PATCH SIW ANTENNA DESIGN

Part	Symbol	Dimension (mm)
Patch width	W_p	32.5
Patch length	L_p	32.5
Feed width	W_t	1.95
Feed length	L_t	18.0
Via Diameter	d_v	1.0
Substrate/ground width	W_s	37.0
Substrate/ground length	L_s	52.5

Table I shows the dimension of the normal siw microstrip patch antenna. The antenna has four major parts – patch, feed,substarte and groundplane. Feed line is located at the bottom of the antenna, connected the patch and the source signal (waveguide port). The four most popular feed techniques used are the microstrip line, coaxial probe, aperture coupling and proximity coupling [31]. In this antenna design, the line feeding is etched on the same substrate.

Figure 1 shows the schematic diagram of the basic microstrip patch SIW antenna design. This design is simulated in Ansoft HFSS 13.0 simulation software. The targeting frequency of this antenna is 2.4 GHz. This structure prints on the FR4 epoxy substrate with dielectric constant εr= 4.2 as well as the groundplane on the bottom side is 0.035mm..

The dimension of the board is 37 mm width x 52.5 mm length. The ground plane is printed on the back side of the substrate with dimension of 37 mm width, Wg x 52.5 mm length, and dimension of patch is 32.5 mm width x 32.5 mm length .. A 50 Ω waveguide port is used to feed power into the radiator.

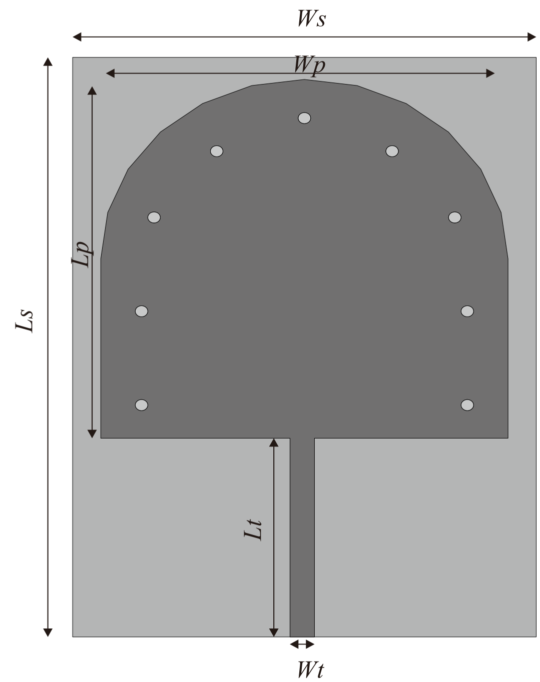


Fig. 1. SIW antenna design in Ansoft HFSS 13.0 simulation software

B. SIW Antenna with CSRR Design

There are many split ring resonator parameters that effect the performance of the microstrip patch antenna design. The example parameters are the split ring resonator shape, the gap between the split ring, the width of the rings, the number of split rings, and the size of the split ring resonator. The dimension of the split ring resonator had been stated as - gap between split ring, Gr = 1.0 mm ,diameter of circular shape split ring resonator, Ds1 = 4.15 mm and Ds2 = 1.15 mm.

TABLE II. DIMENSION OF SIW ANTENNA WITH COMPLEMENTARY SPLIT RING RESONATOR DESIGN

Part	Symbol	Dimension (mm)
Patch width	W_p	18
Patch length	L_p	18
Feed width	W_t	1.95
Feed length	L_t	16.0
Split ring resonator diameter	D_{s1}	4.15
Split ring resonator diameter	D_{s2}	1.15
Split ring resonator gap	G_r	1.0
Via Diameter	d_v	1.0
Substrate/ground width	W_s	22.0

Substrate/ground length	L_s	36.0

Figure 2 shows the schematic diagram of the microstrip patch SIW antenna with complementary split ring resonator design. This design is simulated in Ansoft HFSS 13.0 simulation software. The targeting frequency of this antenna is 2.4 GHz. This structure prints on the FR4 epoxy substrate with dielectric constant εr= 4.2 as well as the groundplane on the bottom side is 0.035mm.. The dimension of the board is 22 mm width x 36 mm length. The ground plane is printed on the back side of the substrate with dimension of 22 mm width, Wg x 36 mm length, and dimension of patch is 18 mm width x 18 mm length . A 50 Ω waveguide port is used to feed power into the radiator.

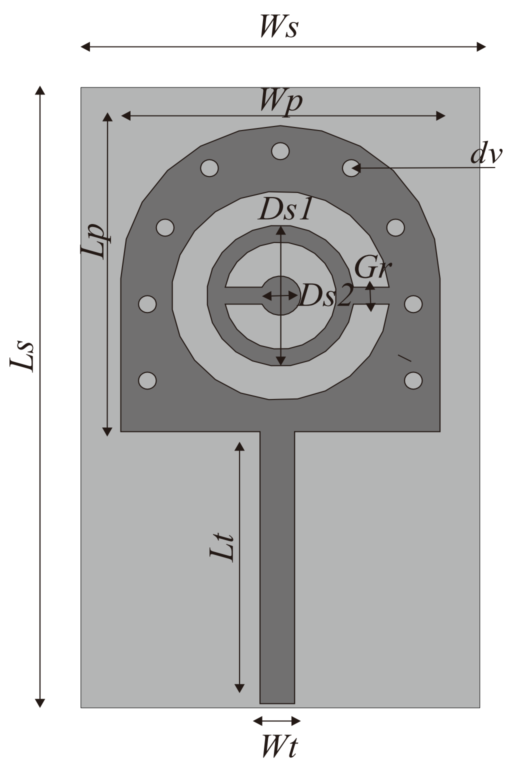


Fig. 2. SIW antenna with complementary split ring resonator design in Ansoft HFSS 13.0 simulation software

III. RESULT AND DISCUSSION

The main parameters that consider in this study are return loss, gain,VSWR and radiation pattern of the antenna. By using values from Table 1 and Table 2, it is calculated that the dimension of the SIW antenna with CSRR is 792mm2, whilst the dimension of the basic SIW antenna is 1942.5mm2. It can be concluded that by using the CSRR the dimension of antenna is miniaturized by 59.2%.

Figure 3 represents the return loss and resonant frequency of SIW antenna and SIW antenna with CSRR in Ansoft HFSS 13.0 simulation software. The resonant frequency, fr for this antenna is 2.40 GHz with - 17.491 dB of return loss performance on SIW antenna and -44.413 dB.

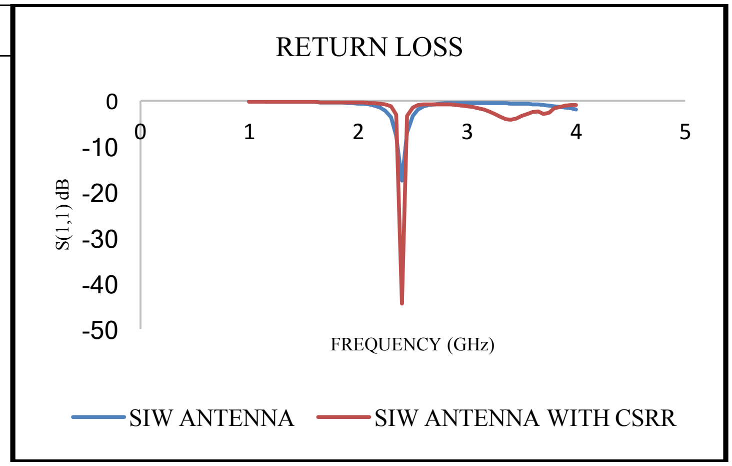


Fig. 3. Return Loss of SIW Antenna and SIW Antenna with CSRR result

The simulated Voltage Standing Wave Ratio (VSWR) for the SIW antenna and SIW antenna with CSRR is illustrated in Fig. 4. The picture shows that VSWR value of SIW antenna is 1.308 and SIW antenna with CSRR is 1.012 on frequency 2.4 GHz. It can also be observed that the design results in a narrow bandwidth with VSWR values only slightly below 2. As stated before, it is because an optimum impedance matching process is not included in the scope of this paper, as this experiment mainly focuses on the frequency shifting characteristics and miniaturization of the antenna.

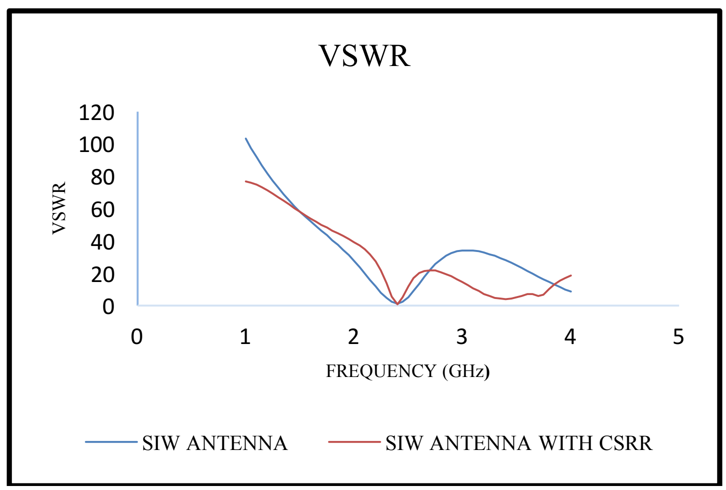


Fig. 4. VSWR of SIW Antenna and SIW Antenna with CSRR result

The simulated gain of the proposed antenna is illustrated in Fig. 5. At resonant frequency 2.4GHz the SIW antenna gain is 9.366 dB and the SW antenna wtih CSRR gain is 1.706 dB. This result shows that the SIW antenna with CSRR still shares a known characteristic of common microstrip antenna which is having low gain.

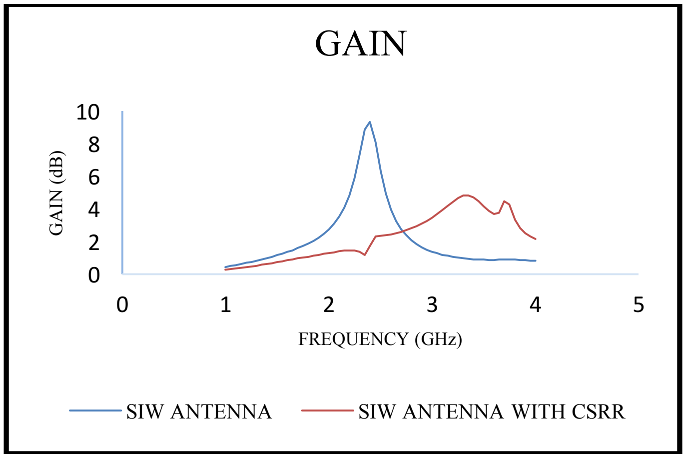
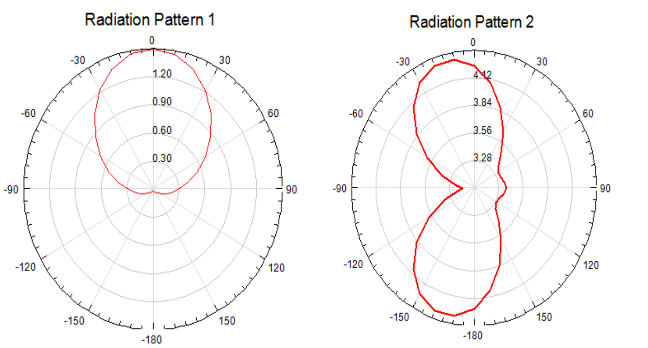


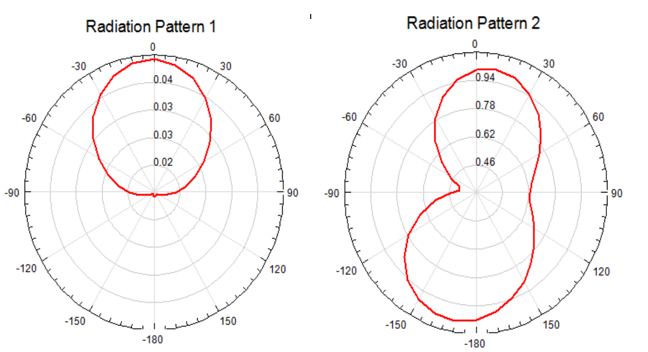
Fig. 5. Gain of SIW Antenna and SIW Antenna with CSRR result

Figure 6 represent the radiation pattern of SIW antenna where the value of $\varphi = 0°$ and $\Theta = 90°$. And figure 7 represent the radiation pattern of SIW antenna with CSRR where the value of $\varphi = 0°$ and $\Theta = 90°$.



(a) (b)

Fig 7. 2D radiation patterns of SIW antenna , (a) φ plane, (b) θ plane



(a) (b)

Fig 7. 2D radiation patterns of SIW antenna with CSRR , (a) φ plane, (b) θ plane

Table III shows the comparison of the various performances between the SIW antenna and SIW antenna with CSRR. From the graph, the return loss,VSWR and gaim SIW antenna with CSRR is better from the basic SIW antenna.

TABLE III. COMPARISON OF PARAMETER PERFORMANCE RESULT BETWEEN THE BASIC SIW ANTENNA AND SIW ANTENNTA WITH CSRR

Design	**Resonant frequency, f_r (GHz)**	**Return loss (dB)**	**VSWR**	**Gain (dB)**
SIW Antenna	2.4	- 17.491	1.308	9.366
SIW Antenna With CSRR	2.4	- 44.413	1.012	1.706

IV. CONCLUSION

The characterization of SIW antenna with CSRR has been numerically investigated. The SIW antenna with CSRR which use FR4 Epoxy dielectric substrate has had the dimension of 22mm x 36mm. The SIW antenna with CSRR is demonstrated to work at resonant frequency of 2.4GHz with return loss of -44.413dB, VSWR 1.012 and gain of 1.706dB. using the CSRR the dimension of antenna is miniaturized by 59.2%. Therefore, the proposed antenna successfully supports Wireless services in compact mobile devices.

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