Utilization of CSRR for Frequency Lowering of X-Band SIW Antenna

Kusmadi
Department of Electrical Engineering
Faculty of Engineering
Universitas Sangga Buana
Bandung, Indonesia
kusmadi.andinata@gmail.com

Ade Saputra
Department of Electrical Engineering
Faculty of Science and Technology
UIN Sunan Gunung Djati
Bandung, Indonesia
adesapurta04.get@gmail.com

Mochamad Yunus
Department of Electrical Engineering
Faculty of Engineering
Universitas Pakuan
Bogor, Indonesia
mochyunus@unpak.ac.id

Achmad Munir
Radio Telecommunication and Microwave Laboratory
School of Electrical Engineering and Informatics
Institut Teknologi Bandung
Bandung, Indonesia
munir@ieee.org

***Abstract*—This paper deals with the frequency lowering of substrate integrated waveguide (SIW) antenna working at the X-band frequency by utilizing complimentary split ring resonator (CSRR). The proposed X-band SIW antenna is constructed by use of an extended half-circle shape of radiator with 2 concentric ring slots of CSRR upon it. A microstrip line technique is used to feed the proposed X-band SIW antenna. While the configuration of X-band SIW antenna is designed on a 1.6mm thick FR4 epoxy dielectric substrate with the dimension of 22mm (width) by 36mm (length). To show the potency of frequency lowering, a conventional SIW antenna, i.e. SIW antenna without CSRR, is also designed on the same dielectric substrate. From the characterization result, it shows that the proposed X-band SIW antenna has the resonant frequency 12% lower than the resonant frequency of conventional SIW antenna.**

***Index Terms*—complimentary split ring resonator (CSRR), frequency lowering, substrate integrated waveguide (SIW) antenna, X-band frequency**

I. Introduction

A rapid growth of wireless communication technology has sparked the need for developments in antenna designs. Some applications of wireless communication systems such as cellular phones, personal computer (PC) wireless cards, and various remote-sensing devices require antennas with compact dimension to suit with the limited size of devices [1]–[2]. In addition, these antennas are expected to be low-profile, efficient, and electrically small to be integrated into terminals of wireless communication devices. It has been already known that conventional microstrip antennas has low-profile and high efficiency but inherently narrow band [3]–[4]. In modern wireless communication, the microstrip antenna is frequently implemented as a front-end part of wireless communication devices. Hence, the size miniaturization of microstrip antenna has become a critical issue in reducing the entire dimension of communication system.

The common method for reducing the size of microstrip antenna is by utilizing a dielectric substrate which has high permittivity. However, this affects the antennas to be more expensive, less radiation efficiency, and having narrow excessive bandwidth [4]. Several attempts in overcoming those drawbacks have been investigated by many researchers by implementing many design techniques including the inserted slot and truncation [5], the corrugation structure [6], the inverted-F structure [7], and the shorting pin [8]. However, all of those techniques have limitation in their design which have complex structure and less performance for frequency lowering affecting to the size miniaturization. So, the design techniques for miniaturizing microstrip antenna with artificial materials and/or metamaterials have been reported to provide more contributions in size reduction [9]–[12]. These would include SRR and/or CSRR which is incorporated into the microstrip antenna, although those have been restrictively engaged for a single antenna.

Further, based on the Babinet principle and the duality concept the CSRR is the negative images of SRR. The basic working mechanism for both resonators is the same except in exciting 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 [13]. The two slot rings in the CSRR are coupled and thereby allow negative permittivity and permeability. In particular, many of the existing CSRRs are combined with substrate integrated waveguide (SIW) [14]–[15]. The SIW technology have been recently used to implement compact and low-cost wireless communication devices with the performance comparable to that of a bulky waveguide [16]–[18]. By implementing SIW combined with CSRR, a compact antenna can be designed with emphasizing for frequency lowering.

978-1-5386-8333-0/18/$31.00

In this paper, an SIW antenna working at the X-band frequency is proposed by utilizing CSRR upon its radiator. The CSRR utilization is aimed to lower the resonant frequency of antenna by advantaging the feature of CSRR as a small electrically resonator. The proposed X-band SIW antenna is designed on a 1.6mm thick FR4 epoxy dielectric substrate and configured by an extended half-circle shape of radiator which is fed by a microstrip line technique. Meanwhile, the CSRR which is incorporated into the radiator consists of 2 concentric ring slots. Moreover, a conventional SIW antenna, i.e. SIW antenna without CSRR, is also designed on the same dielectric substrate to demonstrate the feasibility of frequency lowering. Both SIW antennas are then characterized through simulation and their results are compared each other.

II. Brief Overview of SIW Antenna Design

A. X-Band SIW Antenna with CSRR

The SIW is basically implemented by arranging rows of metallic cylinders or vias applied as the sidewalls of waveguide [19]. These vias are usually embedded in a dielectric substrate connecting the top and bottom metal layers. Some merits of using SIW which have been implemented on some devices are the possibility to incorporate non-planar waveguide structures in planar substrates [20]. Whilst, the combination of SIW and CSRR has been implemented to gain wireless communication devices with compact size [14], [17].

There are many CSRR parameters that affect the performance of the SIW antenna, such as CSRR shape, gap between ring slots, width of ring slots, number of ring slots, and CSRR size. Fig. 1 shows the construction of X-band SIW antenna with CSRR incorporation. The proposed SIW antenna is intended to work at the X-band frequency for wireless communication application. To operate at the desired X-band frequency, the radiator of SIW antenna which takes a shape of extended half-circle has the width (w_p) of 18mm and the length (l_p) of 18mm. The overall structure of SIW antenna which has the width (w_a) of 22mm and the length (l_a) of 36mm is designed on an FR4 epoxy dielectric substrate with the thickness (t_a) of 1.6mm.

Meanwhile, the CSRR incorporated into the radiator has the gap between ring slots (g_r) of 1.0mm, the outer ring diameter (d_{ro}) of 4.15mm, and the inner ring diameter (d_{ri})

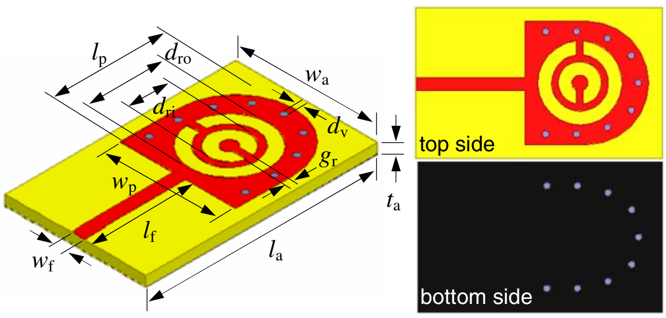


Fig. 1. Construction of X-band SIW antenna with CSRR incorporation.

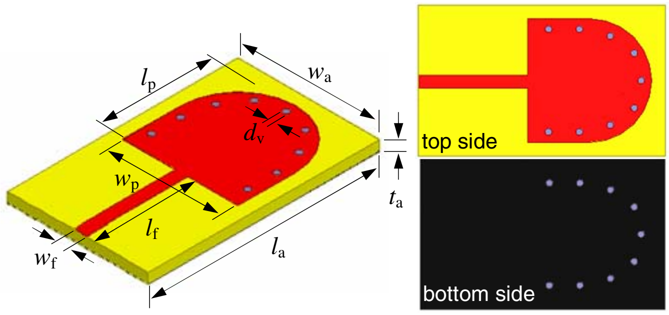


Fig. 2. Construction of conventional X-band SIW antenna.

of 1.15mm. Nine surrounding vias made of metal copper are put on the edge of radiator behaves the sidewalls of waveguide connecting the radiator to the groundplane. Each via has the diameter (d_v) of 1.0mm. The radiator is fed using a microstrip feeding line technique with the width (w_f) of 1.95mm and the length (l_f) of 16mm. The dimension of microstrip feeding line has been optimized to achieve good performance of X-band SIW antenna.

B. Conventional SIW Antenna

Furthermore, to demonstrate the potentiality of frequency lowering, a conventional SIW antenna is also designed by using the same dielectric substrate, i.e. FR4 epoxy dielectric substrate. The dimension of conventional SIW antenna as well as its radiator are the same with the proposed X-band SIW antenna. Fig. 2 shows the construction of conventional SIW antenna which has the width (w_a) of 22mm and the length (l_a) of 36mm, and nine surrounding vias at the edge of radiator. Each via has the diameter (d_v) of 1.0mm. The radiator of conventional SIW antenna which is made of metal copper has the width (w_p) of 18mm and the length (l_p) of 18mm. Similar to the counterpart design, the conventional SIW antenna is fed by a microstrip line technique with the width (w_f) of 1.95mm and the length (l_f) of 16mm.

III. Characterization and Result

Parameters of antenna which are focused in the characterization cover reflection coefficient (S_{11}), gain, and radiation pattern. Fig. 3 plots the reflection coefficient of X-band SIW antenna with CSRR and conventional SIW antenna. The resonant frequency of X-band SIW antenna with CSRR is 11.05GHz with the S_{11} value of –13.27dB and the –10dB working bandwidth of 531MHz (10.778GHz–11.309GHz). Whilst the conventional SIW antenna has the resonant frequency of 12.55GHz with the S_{11} value of –16.99dB and the –10dB working bandwidth of 772MHz (12.242GHz–13.014GHz). The result indicates the frequency lowering of 12% for the proposed X-band SIW antenna compared to the conventional SIW antenna. The result also shows that the utilization of CSRR affected the increase of antenna impedance yielding the mismatch impedance indicated by the worse S_{11} value of proposed X-band SIW antenna.

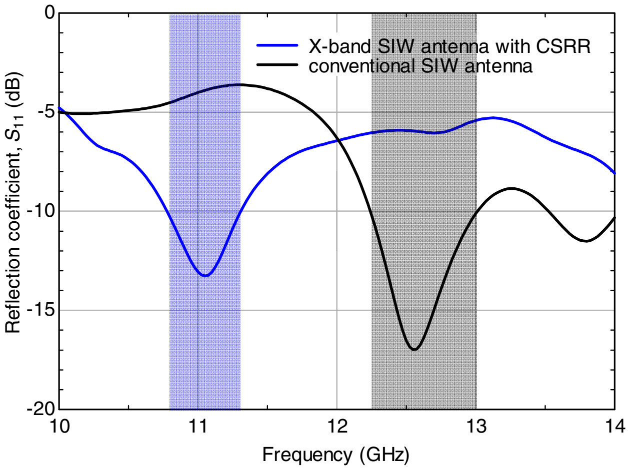


Fig. 3. Reflection coefficient of X-band SIW antenna with CSRR and conventional SIW antenna.

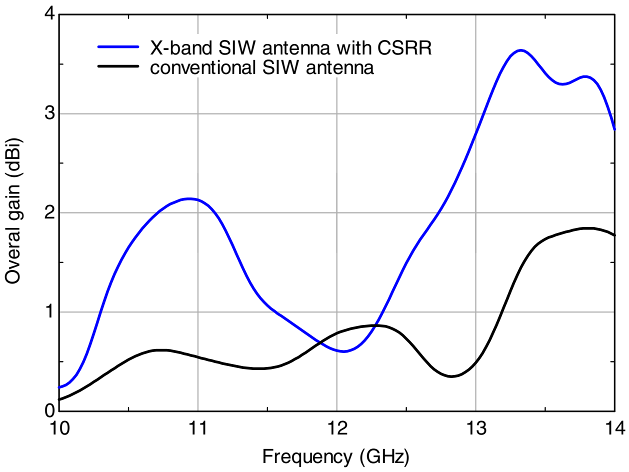
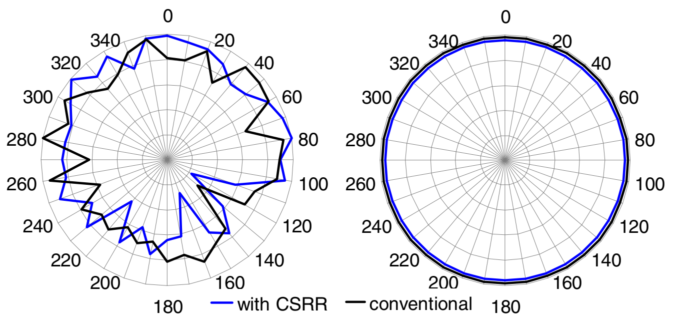


Fig. 4. Gain of X-band SIW antenna with CSRR and conventional SIW antenna.



(a) E–plane (b) H–plane

Fig. 5. Radiation pattern of X-band SIW antenna with CSRR (at 11.05GHz) and conventional SIW antenna (at 12.55GHz).

Furthermore, the gain achievement of both SIW antennas is depicted in Fig. 5. At resonant frequency of 11.05GHz, the X-band SIW antenna with CSRR achieves the gain of 2.097dBi, whereas the conventional SIW antenna has the gain of 0.657dBi at its resonant frequency. Although the proposed X-band SIW antenna has the gain averagely higher than the conventional SIW antenna, however both SIW antennas still share a known characteristic of common microstrip antenna which is having low gain. Fig. 5 shows the E– and H–planes radiation pattern for both SIW antennas. It seems that the utilization of CSRR for the SIW antenna has no significant effect to its radiation pattern, in which this is beneficial for wireless communication application as the SIW antenna with CSRR could be applied without any modification.

IV. Conclusion

The utilization of CSRR for frequency lowering of X-band SIW antenna has been presented in comparison with the conventional SIW antenna. The X-band SIW antenna with CSRR as well as the conventional SIW antenna has been designed on a 1.6mm thick FR4 epoxy dielectric substrate with the dimension of 22mm (width) by 36mm (length). The characterization of X-band SIW antenna with CSRR has demonstrated to work at the resonant frequency of 11.05GHz in which this was 12% lower than the resonant frequency of conventional SIW antenna of 12.55GHz. In addition, further investigations for improving the performance of X-band SIW antenna with CSRR are currently under progress as well as its experimental characterization.

References

[1] J. R. James and P. S. Hall, Handbook of Microstrip Antennas, 2-Vol ed., The Institution of Engineering and Technology, 1989.

[2] C. A. Balanis, Antenna Theory Analysis and Design, John Wiley & Sons, 1997

[3] D. Guha and Y. M. M. Antar, Microstrip and Printed Antennas: New Trends, Techniques and Applications, Wiley, 2010.

[4] P. Bhartia, I. Bahl, R. Garg, and A. Ittipiboon, Microstrip Antenna Design Handbook, Artech House, 2000.

[5] N. Fadilah and A. Munir, "Slot and corner truncation for enhancing bandwidth of circularly polarized patch antenna," in 3rd International Conference on Wireless and Telematics (ICWT), Palembang, Indonesia, Jul. 2017, pp. 31–34.

[6] S. Lee, J. Woo, M. Ryu, and H. Shin, "Corrugated circular micro-strip patch antennas for miniaturisation," Electron. Lett., Vol. 38, No. 6, pp. 262–263, Mar. 2003.

[7] A. Munir, A. Harish and Chairunnisa, "Size reduction of UHF planar inverted-F antenna with patch geometry modification," in International Symposium on Antennas and Propagation (ISAP), Kaohsiung, Taiwan, Dec. 2014, pp. 537–538.

[8] M. Yunita and A. Munir, "Reconfigurable radiation pattern of microstrip antenna using shorting post," in 2nd International Conference on Information Technology, Computer, and Electrical Engineering (ICITACEE), Semarang, Indonesia, Sep. 2015, pp. 292–296.

[9] M. A. Gunung, A. Munir and Chairunnisa, "Size reduction of compact dual-band antenna based on metamaterials," in 6th International Conference on Telecommunication Systems, Services and Applications (TSSA), Bali, Indonesia, Oct. 2011, pp. 204–208.

[10] Chairunnisa, Sutinah, and A. Munir, "Metasurface-backed monopole printed antenna with enhanced bandwidth," in International Symposium on Antennas and Propagation (ISAP), Phuket, Thailand, Oct.-Nov. 2017, pp. 1–2.

[11] F. Rahmadani and A. Munir, "Microstrip patch antenna miniaturization using artificial magnetic conductor," in 6th International Conference on Telecommunication Systems, Services and Applications (TSSA), Bali, Indonesia, Oct. 2011, pp. 219–223.

[12] A. G. Hadiwijaya and A. Munir, "Artificial dielectric material for lowering resonant frequency of microstrip circular patch antenna," in International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS), Nusa Dua Bali, Indonesia, Nov. 2015, pp. 556–559.

[13] J. B. Pendry, A. J. Holden, D. J. Robbins, and W. J. Stewart, "Magnetism from conductors and enhanced nonlinear phenomena," IEEE Trans. Microw. Theory Techn., Vol. 47, No. 11, pp. 2075–2084, Nov. 1999.

[14] L. S. Wu, X. L. Zhou, Q. F. Wei, and W. Y. Yin, "An extended doublet substrate integrated waveguide (SIW) bandpass filter with a complementary split ring resonator (CSRR)," IEEE Microw. Wireless Compon. Lett., Vol. 19, No. 12, pp. 777–779, Dec. 2009.

[15] U. S. Utami, N. Ismail, and A. Munir, "SIW power divider and its performance analysis affected by number of incorporated CSRRs," in 4th International Conference on Wireless and Telematics (ICWT), Bali, Indonesia, Jul. 2018.

[16] Y. D. Dong, and T. Itoh, "Miniaturized substrate integrated waveguide slot antennas based on negative order resonance," IEEE Trans. Antennas Propag., Vol. 58, No. 12, pp. 3856–3864, Dec. 2010.

[17] E. A. Z. Hamidi, U. S. Utami, N. Ismail, and A. Munir, "Compact SIW power divider with CSRRs for WLAN application," in Progress in Electromagnetics Research Symposium (PIERS), Toyama, Japan, Aug. 2018.

[18] N. Ismail, R. A. Siregar, H. Nusantara, and A. Munir, "Wideband substrate-integrated-waveguide BPF incorporated with complimentary-split-ring-resonators," in Progress in Electromagnetics Research Symposium (PIERS), Toyama, Japan, Aug. 2018.

[19] F. Xu and K. Wu, "Guided-wave and leakage characteristics substrate integrated waveguide," IEEE Trans. Microw. Theory Techn., Vol. 53, No. 1, pp. 66–73, Jan. 2005.

[20] Y. Dong, T. Yang, and T. Itoh, "Substrate integrated waveguide loaded by complementary split-ring resonators and its applications to miniaturized waveguide filters," IEEE Trans. Microw. Theory Techn., Vol. 57, No. 9, pp. 2211–2223, Sep. 2009.