Electrically small Sixty-Fourth Mode Substrate Integrated Waveguide Monopole Antenna

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An electrically small substrate integrated waveguide (SIW) antenna is investigated in the present work. The electrical size of the circular cavity SIW is reduced by repetitive segregation along the quasi-magnetic wall (QMW) to form sixty-fourth mode SIW (SFMSIW) antenna while maintaining comparable performance to the full- mode SIW. The ground plane behind the antenna is removed to obtain quasi-omnidirectional radiation pattern. The proposed antenna operates from 3.3 GHz to 3.72 GHz making it suitable for Worldwide Interoperability for Microwave Access (WiMAX- IEEE 802.16) applications. The S-parameters and radiation patterns have been investigated by EM-simulations and measurements. A realized peak gain of 4.1 dBi is obtained at the operating frequency of the antenna.

Introduction: The past decade has witnessed an expeditious development in the domain of compact, low profile, planar antenna design which are suited for wireless communication systems. The SIW technology provides a low cost solution and is increasingly being used by researchers to develop miniaturized microwave and millimetre wave components. Ridging and folding the geometry are some of the classical miniaturization techniques which have been applied on SIW to form ridge SIW (RSIW) and folded SIW (FSIW) [1]. As the centre of the SIW geometry has a magnetic field minimum for the first mode, it can equivalently be replaced by a magnetic wall and the geometry can be segregated along the QMW for miniaturization. This forms the basis of half-mode SIW (HMSIW), quarter-mode SIW (QMSIW) and eighth-mode SIW (EMSIW) structures [2– 5]. Attempts have also been made to design SIW antennas with omnidirectional radiation characteristics [6].

In this letter, a compact sixty-fourth mode SIW (SFMSIW) antenna is proposed, which is a section of the circular SIW cavity. The proposed antenna occupies only 1.5625% of conventional SIW cavity while maintaining similar performance characteristics. The ground plane beneath the antenna has been removed to obtain quasi-omnidirectional radiation characteristics, while a conductor strip has been added to ground the end-wall vias.

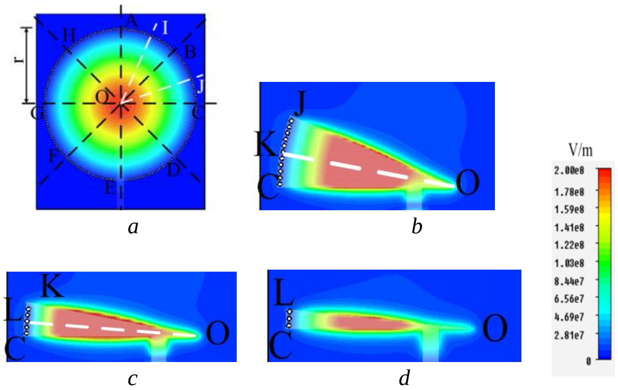

Fig. 1 *Simulated magnitude of electric field distribution*
a Circular SIW cavity
b sixteenth mode SIW (SMSIW)
c thirty-second mode SIW (TMSIW)
d SFMSIW

Antenna Design: Fig. 1(a) shows the magnitude of electric field distribution of circular SIW cavity in the TM_{010} mode (3.5 GHz). It can be segregated further along the QMW (shown by black and white lines) to form SMSIW, TMSIW and SFMSIW as shown in Figs. 1(b), (c) and (d) respectively. Hence, size miniaturization is obtained in this process while maintaining almost similar resonant frequency. The ground plane beneath the antenna has been removed to obtain quasi-omnidirectional radiation characteristics. A metallic strip has been placed on the bottom plane to ground the end-wall vias. The proposed antenna is illustrated in Fig. 2.

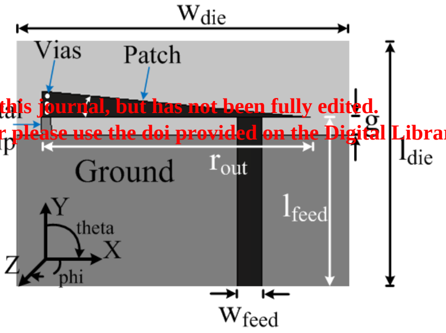

Fig. 2 *Configuration of the proposed SFMSIW Monopole Antenna*

Rogers RT/Duroid 5880 substrate with dielectric permittivity, ε_r = 2.2, substrate thickness, h = 1.57mm and loss tangent, tan δ = 0.0009 has been used for the present work. One-sixty fourth section of circular SIW cavity has been used which occupies 1.5625% of the circular SIW cavity. The antenna has been fed by microstrip feed of length (l_{feed}) 30mm and width (w_{feed}) 5.2mm, respectively. Copper vias having a diameter of 0.6mm and center to center spacing of 0.9° have been used. The geometrical dimensions of the parameters are: r_{out} = 48mm, l_{die} = 42mm, w_{die} = 55mm and g = 3mm.

Measurements: Fig. 3 shows the simulated and measured reflection coefficients of the proposed SFMSIW monopole antenna. The measured results show that S_{11} frequency response is below -10 dB from 3.3 GHz to 3.72 GHz (fractional bandwidth, FBW 11.79 %) [Simulation: 3.27 – 3.62 GHz (FBW 10.11%)]. The simulated and measured radiation patterns (E_θ) in xy- and yz- planes are given in Fig. 4. The cross-pol is 10 dB below the co-pol pattern suggesting that the antenna is linearly polarized. The measured gain and efficiency at the operating frequency of the antenna are 4.1 dBi and 92.1% respectively. Figs. 3 and 4 suggests that there is good agreement between the simulated and measured results for both S- parameters and radiation patterns.

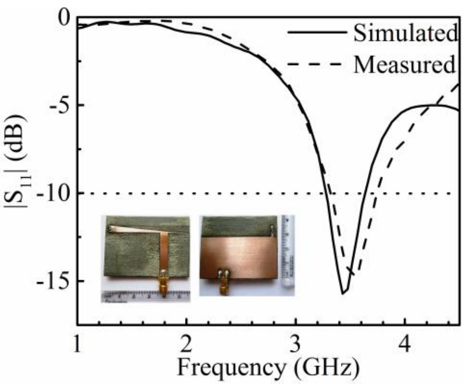

Fig. 3 *Simulated and measured reflection coefficients of the proposed antenna (antenna front and back have been shown in inset)*

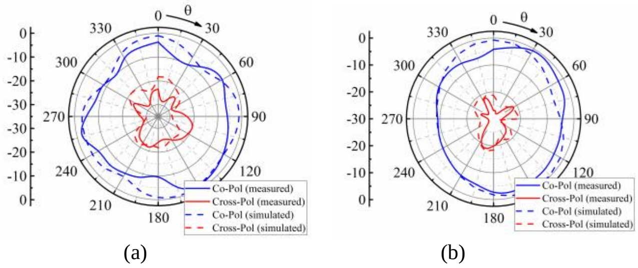

Fig. 4 *Measured co-polarization and cross-polarization patterns at 3.56 GHz*
a xy- plane
b yz- plane

Conclusion: This research demonstrates a technique to obtain omnidirectional radiation pattern from SIW antennas by removing the ground plane beneath the antenna. Moreover, a substantial size reduction of the antenna structure is obtained when compared to other SIW antennas at the same operating frequency. The operating frequency, omnidirectional radiation characteristics and ease of fabrication make it a competing candidate for WiMAX applications.

References

1. Ding, Y., Wu, K.: 'Miniaturization Techniques of Substrate Integrated Waveguide Circuits', *IEEE MTT-S Int. Microwave Workshop Series on Art of Miniaturizing RF and Microwave Passive Components*, Chengdu, China, December 2008, pp. 63– 66, doi 10.1109/IMWS.2008.4782262.
2. Wang, Y., Hong, W., Dong, Y., Liu, B., Tang, H., Chen, J., Yin, X., Wu, K.: 'Half Mode Substrate Integrated Waveguide (HMSIW) band pass filter', *IEEE Microw. Wireless Compon. Lett.*, 2007, **17**, (4), pp. 265– 267, doi 10.1109/LMWC.2007.892958.
3. Jin, C., Li, R., Alphones, A., Bao, X.: 'Quarter-Mode Substrate Integrated Waveguide and Its Application to Antennas Design', *IEEE Trans. Antennas Propag.*, 2013, **61**, (6), pp. 2921– 2928, doi 10.1109/TAP.2013.2250238.
4. Sam, S., Lim, S.: 'Electrically Small Eighth-Mode Substrate-Integrated Waveguide (EMSIW) Antenna with Different Resonant Frequencies Depending on Rotation of Complementary Split Ring Resonator', *IEEE Trans. Antennas Propag.*, 2013, **61**, (10), pp. 4933– 4939, doi 10.1109/TAP.2013.2272676.
5. Kang, H., Lim, S.: 'Electrically Small Dual-Band Reconfigurable Complementary Split-Ring Resonator (CSRR)-Loaded Eighth-Mode Substrate Integrated Waveguide (EMSIW) Antenna', *IEEE Trans. Antennas Propag.*, 2014, **62**, (5), pp. 2368– 2373, doi 10.1109/TAP.2014.2308532.
6. Lacik, J., Mikulasek, T., Raida, Z., Urbanec, T.: 'Substrate Integrated Waveguide Monopolar Ring-Slot Antenna', *Microw. Opt. Technol. Lett.*, 2014, **56**, (8), pp. 1865–1869, doi 10.1002/MOP.28465.