TE_{20} Mode Excitation in Substrate Integrated Waveguide

Lindo A O, Anju P Mathews and C K Aanandan
Microwave Propagation Research Laboratory (MPRL), Department of Electronics,
Cochin University of Science & Technology, Kochi, India

Abstract: This paper presents a new technique to excite TE_{20} mode in Substrate Integrated Waveguide (SIW). The differential feed selectively induces TE_{20} mode and suppresses other modes including TE_{10} mode. SIW designed and fabricated for a cutoff frequency 5GHz. Above cutoff, S_{11} stays below -10dB and S_{21} stays above -3dB. The TE_{10} mode is absent and below calculated cutoff, there exists no transmission so that the mixing of the mode is avoided. The electric fields and magnetic fields are in agreement with the theoretical prediction.

***IndexTerms* – SIW, Higher order modes, transition, waveguide.**

I. INTRODUCTION

The wireless communication is the key to connect people and systems in the modern era. When 5G networks are deployed, more and more devices come into the network with wide range of bandwidth requirements. High resolution video and virtual reality contents demand very high data rates so that conventional microwave bands becomes insufficient. New standards are popping up every day with millimeter-wave band in focus. The use of higher frequency bands helps to not only achieve the desired link capacity but enable dramatic size reduction as well. Conventional planar transmission lines like microstrip, coplanar waveguide and slot lines are employed very effectively and easily in the legacy systems operating in microwave frequency. As the frequency of operation moves towards millimeter-wave, different losses during the transmission through these structures become significant to a level that the integrity of the system turns questionable. The losses generally can be of three kinds. Dielectric losses due to the energy dissipation in the dielectric, conductor losses due to finite conductivity and skin depth of the conductor and radiative and surface wave losses due to imperfect isolation. Classically, waveguide is the go to solutions for millimeter-wave regime. But they are bulky, rigid and expensive since they are made of very conducting metal with precise machining. Substrate integrated waveguide is the first and most effective solution which integrates best of both world in terms of rectangular waveguide features and scalability of planar technology [1].

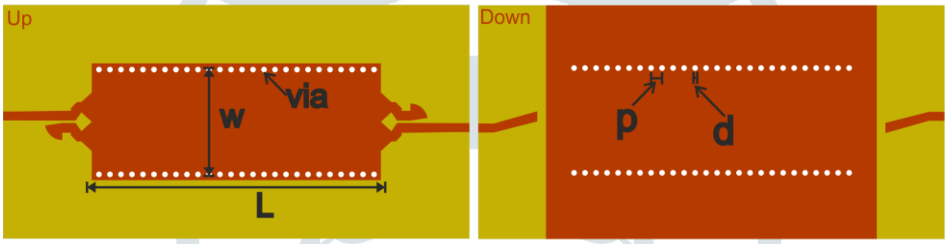
Substrate Integrated waveguide is the dielectric filled rectangular waveguide implemented on a laminate. The sidewalls are approximated with periodic metallized posts. SIW can support TE modes and unable to support TM mode of propagation. This is due to the surface current paths are intact for TE modes and discontinuous for TM modes. SIW is apt for millimeter-wave systems with its inherent signal isolation properties which significantly reduces the radiation loss. There are several variations proposed to the original geometry to achieve different improved properties like compactness, bandwidth enhancement, reduction of fabrication profile etc. Half mode substrate integrated waveguide (HMSIW) is a modified SIW with half the width and supporting $TE_{0.5,0}$ mode. SIW without via holes are proposed to rule out the complexity of having via holes altogether to achieve similar performance. This employs a differential feed mechanism to push the fields to create a traveling mode without significant losses. The coupled $TE_{0.5,0}$ mode is created and give similar performance of a SIW/HMSIW[2]. The key point in this design is a coplanar strip line to microstrip transition which provides opposite phased differential field at the SIW for the entire band of operation.

Recently, there are some reports in the literature which make use of higher order modes in SIW [3] [4]. More flexible fabrication constraints and applications in antenna array and sensor prompted research interests in TE_{20} in SIW as well [5]. To excite the mode in SIW, simple microstrip power divider and microstrip slot coupling methods are employed [6] [7]. The lack of bandwidth in the path length based differential structure limits the performance of the waveguide. In some designs, the presence of mode mixing causes lack of control over signal integrity.

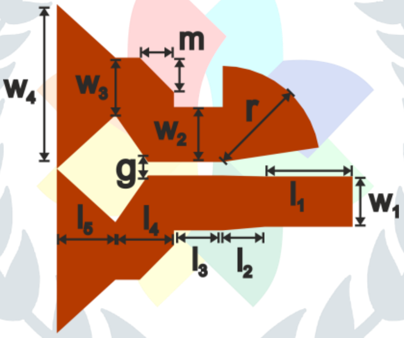
Here we are proposing a SIW structure which supports only pure TE20 mode which eliminates these short-comings. The broad operating bandwidth and mode purity are ensured due to coplanar strip differential arrangement. The working of the waveguide is analyzed thoroughly and the simulation results are compared to the measurement.

II. DESIGN

The design consists of a transition and SIW itself. The transition consists of a Double Sided Parallel Strip Line (DSPSL) to Coplanar Strip transmission line with a radial stub as shown in figure 1. The width W_1 of the DSPSL is selected such that the input impedance equal to 50 Ohm. This is optimized with port mode analysis. The length of the line is l_1. The top portion of the strip continues to extend further to widen the width to W_2. The path of the bottom part is diverted to align with the radial stub on the other side. To achieve the mode conversion with least reflection; the radius “r” and arc angle are optimized using full 3d simulation. The next section of the transition is a coplanar strip line with an optimum width of separation ‘g” and strip width W_2. This extends further to length l_3. The next transition is to achieve differential microstrip mode from the coplanar field. This is achieved by gradually widening the separation and the width of the strip. A meandering with a dimension “m” is employed to minimize the reflection from the edges. The transition starts with a width W_2 and lands on the waveguide with a widthW_4. The waveguide is having a width W and the side walls are replaced by arrays of metal via. The length of the waveguide set to be L. The waveguide ends with the same transition structure.



(a) Top (b) Bottom



(c) Transition

Figure 1 W_1=3.5, W_2=3, W_3=3.5, W_4=10, W=40, L_1=3, l_2=15, l_3=5.4, l_4=3.6, l_5=3.6, l=100, g=0.5 m=2.1, r =6, d=0.5, p=1.(Units are in mm).

III. SIMULATION

The full 3D numerical simulations are done using CST Microwave Studio frequency domain solver. General purpose broadband sweep with tetrahedral mesh with adaptive mesh refinement is used for all the simulations. Open add space boundaries are used for better numerical accuracy. For better representation of the entire computation domain, local meshing is performed on individual components. The simulations were repeated and verified with CST Transient solver with adaptive meshing and increased convergence time. In simulation, lossy Rogers RT Duroid 5880 with thickness 0.79mm is used as substrate (Tan delta =0.0009). Perfect electric conductor model is selected for all the conducting elements. Multicore, multithreaded, parallel frequency point calculations are used for better simulation efficiency.

The S parameter from the simulation are show in Figure 2. The cutoff frequency for TE_{20} mode in SIW with width 40mm is 5GHz. The simulation results agrees with the calculation. From Cutoff to 10 GHz, S_{21} stays above -3dB and the S_{11} stays below -10dB. Below cutoff, strong rejection is observed. This proves the absence of TE_{10} and the purity of the allowed mode.

The expressions for cutoff frequency($fc_{TE_{20}}$)for TE_{20} mode and the guided wavelength (λ_g)are give below.

$$fc_{(TE_{20})} = \frac{c}{a_s} \qquad a_s = a_d + \frac{d^2}{0.95*p} \qquad a_d = \frac{a}{\sqrt{\epsilon_r}} \qquad \lambda_g = \frac{\lambda_0}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}}$$

Where c is the velocity of light in free space, a is the width of the waveguide, d is the diameter of via, $\epsilon_r$is the relative permittivity of the substrate and $\lambda_0$is free space wavelength.

Various components of electric fields are plotted here. Figure 3(a) shows the vertical electric field across the face of the waveguide. For TE_{20}, there should be two half wave variations in transverse field. From the simulation also the same characteristics are observed. The field is plotted along entire width of the substrate. The fields are zero from -40 to -20, because this space stays outside via array. This also gives the insight in to the field leakage through the side boundary. Since the fields are negligible even in the vicinity of the side walls, the effective isolation from and to the surroundings are ensured. The same applies to the region from 20 to 40. In between -20 to 20, the field manifests a full sinusoidal variation as predicted by the theory.

The transverse mode also require the component of the field along the propagation direction to be zero. Here the wave propagation is along y direction. The Ey component plotted along the y direction is shown in Figure 3(b). When compared with maximum Ez component which is in order of 3000 v/m, the Ey maximum component barely reaches 30 v/m which is very small. The Ez component along the y direction is also plotted in figure 3(c).

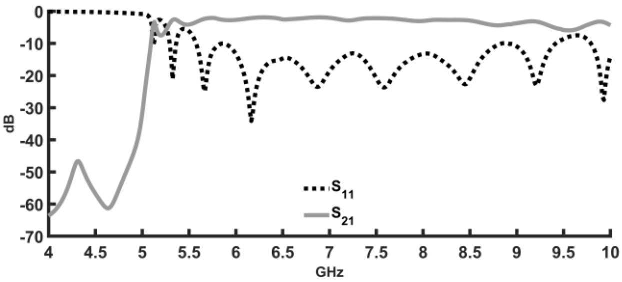
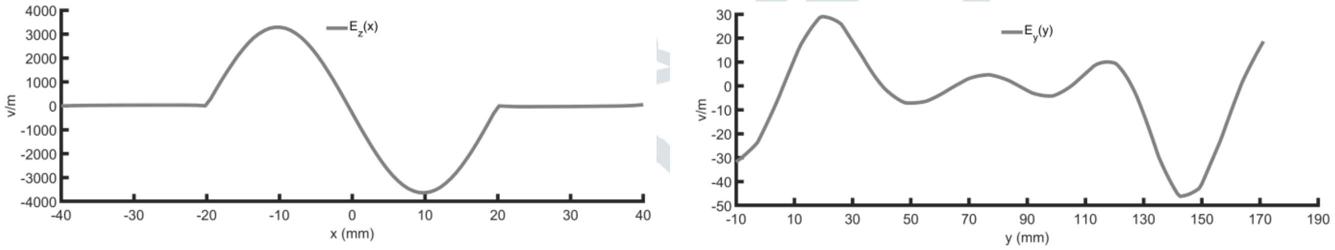
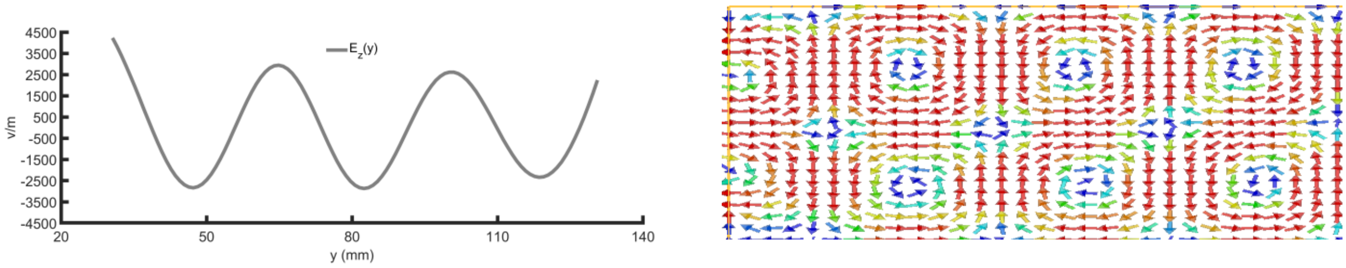


Figure 2 Simulated S parameters (CST MWS Frequency Solver)

The wave propagate in a sinusoidal fashion with very small attenuation and good phase regularity. The guided wavelength is calculated from the plot by finding the adjacent equi-phase points and that is equal 40mm. This matches the value computed from theory. To confirm TE_{20} propagation mode, the magnetic field in the xy plane is plotted in figure 3(d). Two symmetric rotating magnetic fields are visible in the plot which exactly matches pattern for TE_{20} mode.



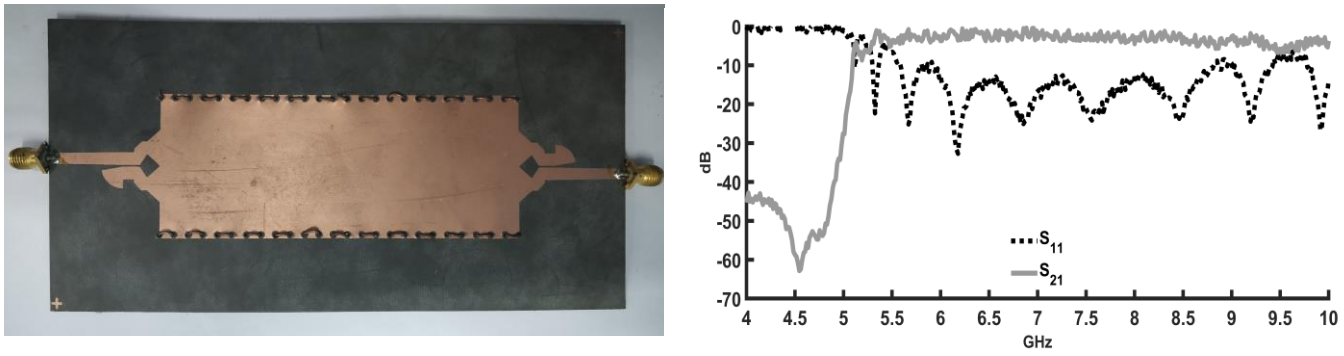
(a) $E_z(x)$ (b) $E_y(y)$



(c) $E_z(y)$ (d) H field (xy plane)

Figure 3 Simulated Field plots

IV. Fabrication & Measurement



(a) (b)

Figure 4 (a) Fabricated structure (b) Measured S parameters

The structure is fabricated on Rogers RT Duroid5880 with copper cladding on both sides. Standard photo lithography and chemical etching are employed for the fabrication. SMA connectors are used at the ends to make measurements. Fabricated structure is shown in figure 4(a). The measurements are taken with Rohde & Schwarz ZVB20 vector network analyzer. Measured S parameters are shown in Figure 4(b). Cutoff stays around 5GHz and the S_{21} and S_{11} are in good agreement with simulation.

V. CONCLUSION

A single mode TE20 mode SIW is proposed, numerically optimized, and fabricated. The wideband feeding structure provides better bandwidth. The mode is identified with simulated electric and magnetic field and compared with theoretical prediction. The field leakage is minimal. The guided wavelength and frequency cutoff are compared with theory, simulation and experiment.

REFERENCES

[1] Bozzi, M., A. Georgiadis, and K. Wu, “Review of substrate-integrated waveguide circuits and antennas,” IET Microwaves, Antennas & Propagation, Vol. 5, No. 8, 909, 2011.

[2] Lindo Ouseph, Anju Mathews, and Aanandan Chandroth , “Substrate Integrated Waveguide without Metallized Wall Posts,”Progress In Electromagnetics Research Letters, Vol. 77, 7–12, 2018.

[3] Junfeng Xu, Zhi Ning Chen, Xianming Qing, Wei Hong. A Single-layer SIW Slot Array Antenna with TE20 Mode, Proceedings of the Asia-Pacific Microwave Conference 2011.

[4] Peng Wu, Graduate Student Member, IEEE, Jirong Liu, and Quan Xue, Fellow, IEEE. A Single-layer SIW Slot Array Antenna with TE20 Mode, Proceedings of the Asia-Pacific Microwave Conference 2011., IEEE Trasactions on microwave theory and techniques, vol.63,no. 6,june2015.

[5 Anirban Sarkar, Abhishek Sharma, Moitreya Adhikary, Animesh Biswas, M. J. Akhtar7. TE20Mode SIW based Bi-directional Leaky-wave Antenna. 2017 IEEE Applied Electromagnetics Conference (AEMC).

[6] Anirban Sarkar | Abhishek Sharma | Animesh Biswas | M. Jaleel Akhtar. TE20 mode substrate integrated waveguide based high gain eight-beam leaky-wave antenna for multi-directional radiation coverage. International Journal of RF and Microwave Computer-Aided Engineering · June 2018.

[7] Tu, W. H. and K. Chang, “Wide-band microstrip-to-coplanar stripline-slotline transitions,” IEEE Trans. Microw. Theory Tech., Vol. 54, No. 3, 1084–1089, March 2006.