3rd URSI AT-AP-RASC, Gran Canaria, 29 May – 3 June 2022

Design of Substrate Integrated Coaxial Line (SICL) based Dual Band Antenna for X and Ka Band

Naman Baghel*(1) and Soumava Mukherjee(2)
Indian Institute of Technology Jodhpur, Rajasthan, India, 342037
(1) baghel.1@iitj.ac.in
(2) soumava@iitj.ac.in

Abstract

This paper presents the design of dual band Substrate Integrated Coaxial Line (SICL) based colocated antennas to operate at X-band and Ka band. A SICL based cavity backed slot antenna excited by the dominant TEM mode of the SICL cavity is designed to operate at 10 GHz. A SICL based 29 GHz slot antenna array using C-shaped slots is excited by the dominant TEM mode of the SICL transmission line. A SICL based feed network comprising of a novel SICL based dual band transmission line for the two band enables simultaneous feeding to the two antennas. The proposed dual band antenna achieves compactness by closely placed antennas utilizing the shielded nature of the SICL. The designed antenna exhibits a gain of 5.8 dBi at 9.9 GHz and 8.1 dBi at 29.24 GHz. The cross-polarization level is below 25 dB and 16 dB at the two frequencies. The proposed antenna achieves front-to-back ratio of 15 dB and 14.7 dB at the two frequencies. The proposed antenna finds its suitability in hybrid systems intended for integrated microwave and 5G millimeter wave applications.

1 Introduction

There is an ever-growing demand for larger bandwidth and high data rate in the telecommunication system. Edholm's law of bandwidth similar to the Moores Law, predicts the data rate with time required in the telecommunication industry [1]. It depicts exponential rise in data rates with time, irrespective of wireline (Ethernet), nomadic (Wi-Fi), or wireless (cellular telephony) nature of systems. Extended Reality (XR) services have started to emerge in current 5G systems. The real time interaction with remote, virtual, and real objects possible with XR systems place intensive demands of high data rate on networks. Taking into account expected speed of 50-100 Mbps by 5G end users, we may expect data rate of 0.5-1.0 Tbps for such applications with high mobility [2].

High level modulation schemes applied to achieve high data rates restricts the analog front end with imposing strict requirements. Another solution is increasing bandwidth employing technological but social efforts worldwide in the existing dense and less-harmonized frequency spectrum [3]. Micorwave and millimeter wave frequency band FR3

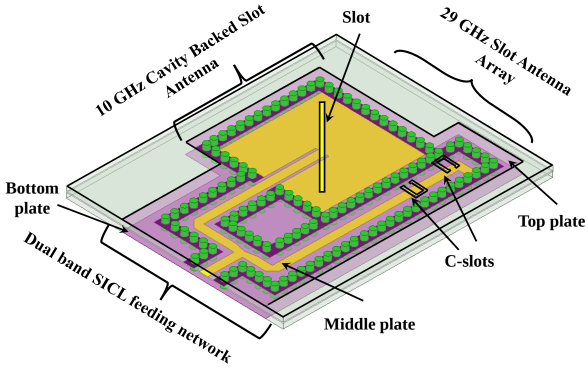

Figure 1. Proposed SICL based dual band multiantenna.

(centered at 10 GHz) and FR2 (beyong 24 GHz) provides much available unlicensed spectrum for applications requiring high data rates. Moreover, Foschini and Gans [4] and then Telatar [5] suggested the use of multiple transmit (Tx) and receive (Rx) antennas to achieve higher data rates over wireless links. Multiantenna technique provides a promising means to increase the spectral efficiency of a system without the requirement of extra bandwidth.

This paper presents a compact dual band antenna formed by the two colocated antennas utilizing the pattern diversity at two frequencies. A 10 GHz SICL based cavity backed slot antenna and a SICL based 1 x 2 slot antenna array operating at 29 GHz are integrated together for different bands. A one to two way SICL transmission line is designed to simultaneously feed the two antennas. Generally, two different feed networks are required to feed the two antennas operating in different frequency bands. The novelty of the proposed work lies in realizing a simplified dual band SICL feed network to simultaneously feed the two antennas operating in two distinct bands. A compact dual band cavity backed slot antenna has been proposed using SICL technology. The advantage of broadband unimodal operation is efficiently utilized to design dual band feeding network. The simulated results depicts the potential of this novel concept to catch attention and become popular among researchers for various end user applications.

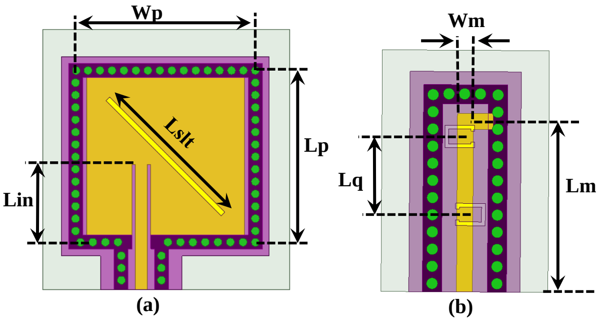

Figure 2. Geometry of the proposed SICL based (a) cavity backed slot antenna and (b) slot antenna array.
The dimensions are (in mm) : *Lp = 11.2, Wp = 11.6, Lslt = 11, Lin = 6.25, Wm = 0.85, Lq = 4, Lm = 9.85*

2 Design

The proposed design is implemented on Substrate Integrated Coaxial Line (SICL) transmission line using two dielectric substrate Taconic TLY 5 (permittivity ε_r = 2.2, height 0.25 mm each) bonded together by Taconic FR-28 bond layer (2.75<ε_r<2.9, height 0.1 mm). The top and bottom conducting ground plates are connected together through the sidewall vias that run throughout the length of transmission line [7]. Optimum shielding is ensured to the middle plate by encapsulating it within the structure of sidewall vias and the top, bottom conducting plates [7]. The design of the proposed dual band antenna is shown in Fig. 1.

2.1 SICL based Cavity Backed Slot Antenna

An approximately half wavelength ($\lambda_g/2$) square cavity is designed by shorting the middle plate of the SICL to the sidewall vias along the two opposite edges, forming perfect electric conductor (PEC) boundary and keeping the other two edges separated from the sidewall vias, forming perfect magnetic conductor (PMC) boundary while maintaining shielding in the lateral direction [8]. A cavity backed slot antenna (CBSA) is designed by etching a 45° inclined conventional half wavelength ($\lambda_g/2$) slot on the top plate of the SICL cavity as shown in Fig 2(a). The inset feed length *Lin* has been optimized to obtain optimum impedance match at the resonant frequency. The amount of coupling between the SICL cavity and feed line has been controlled by having a small offset in feeding transmission line from the center of the SICL cavity [8].

2.2 SICL based Slot Antenna Array

To design 1x2 C-shaped slot antenna array, two C-shaped slots are etched on the top plate of the SICL transmission line as shown in Fig 2(b). The middle strip of the SICL transmission line is shorted to the ground by introducing a bend and connecting it to the sidewall conducting via. In order to attain high impedance at the first slot, an open-circuited line is effectively created by placing the slot at quarter-wavelength ($\lambda_g/4$) distance from the short circuited end. Similar effect for the second slot is achieved by placing it at a spacing *Lq* of $\lambda_g/2$ from the first slot. A 50 Ω characteristic impedance is achieved by adjusting the width of the middle strip *Wm* keeping the height of the substrate constant [7]. A C-shaped slot with width 0.2 mm and mean length 4 mm is chosen for the proposed antenna [9]. To ensure equal excitation of the slots, the slots are offset from the center ao as to adjust the coupling with the SICL line. The orientation of the slots are changed in order to compensate 180° phase shift of successive slot antenna element.

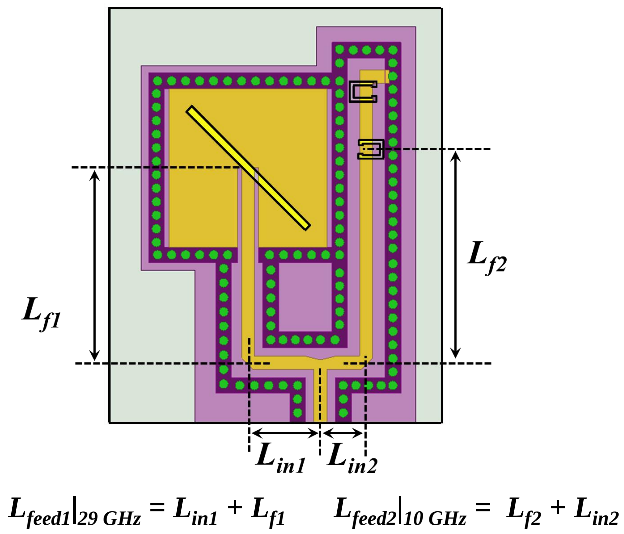

Figure 3. Geometry of the proposed SICL based dual band array with simplified SICL feeding network.
The dimensions are (in mm) : *Lcav = 14.11, L_f1 = 1.3, L_in1 = 6.5, L_in2 = 3, L_f2 = 9.2, L_bent = 1.75*

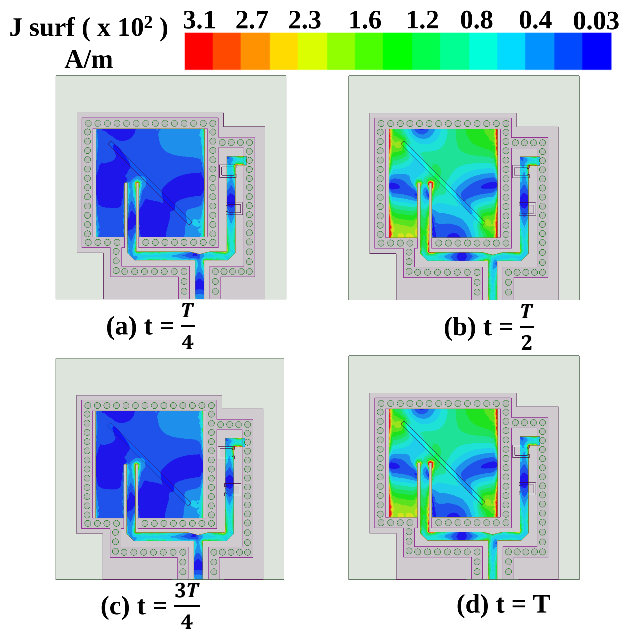

Figure 4. Surface current plotted in the middle plate at 10 GHz for the proposed SICL based dual band antenna.

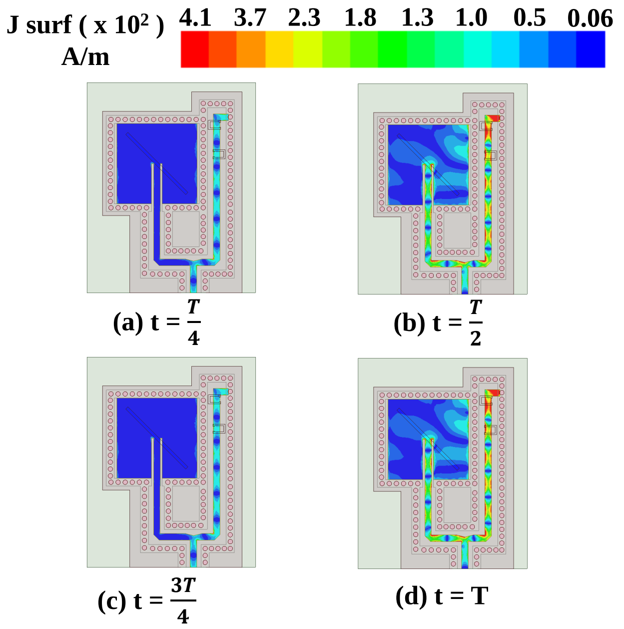

Figure 5. Surface current plotted in the middle plate at 29 GHz for the proposed SICL based dual band antenna.

3 Working Principle

The SICL based 10 GHz cavity backed slot antenna and the SICL based 29 GHz slot antenna array are placed in closed proximity to form colocated (X/Ka) dual band antenna. To utilize frequency multiplexing over a single channel, a dual band SICL transmission line is proposed feed the two colocated antennas simultaneously. One to two way SICL transmission line is designed in such a way that the arm feeding the 29 GHz slot array behaves as open-circuited line at 10 GHz and 10 GHz CBSA is excited. Simultaneously the other arm feeding 10 GHz CBSA behaves as open-circuted line at 29 GHz and excites only the slot array at 29 GHz. The design principle of the feeding network is based on routing the input power to one arm making it active while keeping the other arm inactive. The important parameter to design a dual band SICL feeding line is the length of the arms operating at different frequencies. The length of the feeding arm is choosen so as to make it make one antenna matched at its operating frequency and make the same antenna open-circuited at the other frequency. At 10 GHz,

Table 1. Summary of Working Principle

Frequ-ency	Arm length	Arm 1	Arm 2	Working antenna
10 GHz	Arm2 at$l\|_{10GHz}$ = 17.6 mm	Active (Match-ed)	Inactive (open-circuit)	10 GHz CBSA
29 GHz	Arm1 at$l\|_{GHz}$ = 17.1 mm	Inactive (open-circuit)	Active (Match -ed)	29 GHz Slot

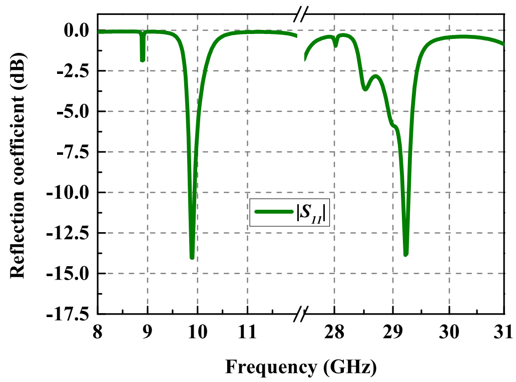

Figure 6. Reflection coefficient for the proposed SICL based dual band antenna.

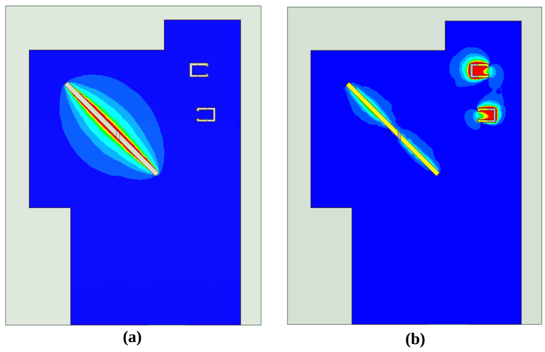

Figure 7. Electric field distribution at (a) 10 GHz and (b) 29 GHz for the proposed SICL based dual band antenna.

the arm feeding the slot array is tuned to $\lambda_g/2$ + odd multiples of $\lambda_g/4$ at 10 GHz from its short-cicuited end. This makes the arm2 open circuited at the junction and input power is routed to 10 GHz CBSA. Similarly at 29 GHz, the arm feeding the 10 GHz CBSA is made to behave like an open-circuited line at the junction by tuning its length to $\lambda_g/2$ + odd multiples of $\lambda_g/4$ at 29 GHz from the short-cicuited end of the SICL cavity. There by an arm matches one antenna at its resonant frequency and the behaves like an open-circuited SICL line at the other frequency. This makes the broadband SICL line to have dual band performance by simultaneous feeding to both the antennas.

4 Simulation Results

In the proposed design, dual band antennas is obtained using simultaneous feeding through a simplified dual band SICL transmission line. The simulated reflection coefficient of the antenna is shown in Fig. 6. The proposed antenna resonates at 9.9 GHz and 29.24 GHz. The surface current depicted in Fig. 5(a) shows the current flow in the cavity backed slot antenna (CBSA) at 9.9 GHz and the excitation of the slot in CBSA is shown by the electric field in Fig. 7(a). The current flow in the middle plate and the electric field in Fig. 5(c,d) for the proposed antenna at 29 GHz shows the excitation of the slot antenna array. Thus, the simplified feeding network excites both the antenna simultaneously at their operating frequencies. The radiation

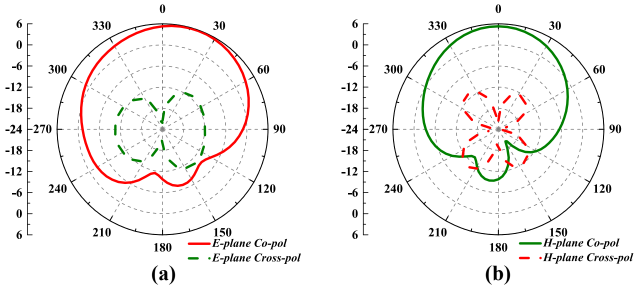

Figure 8. Radiation pattern in (a) E-plane and (b) H-plane at 10 GHz for the proposed dual band SICL antenna.

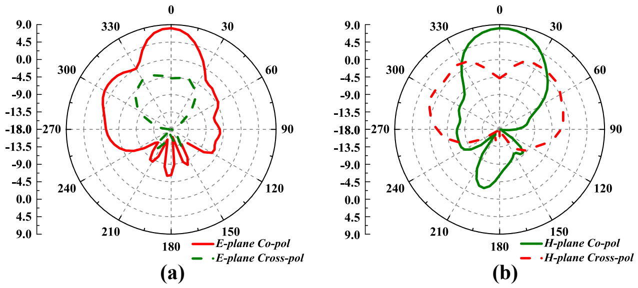

Figure 9. Radiation pattern in (a) E-plane and (b) H-plane at 29 GHz for the proposed dual band SICL antenna.

pattern is plotted in Fig. 6(a,b) for 9.9 GHz CBSA and Fig. 6(c,d) shows the radiation pattern at 29.24 GHz for the proposed antenna. The designed antenna exhibits a gain of 5.8 dBi at 9.9 GHz and 8.1 dBi at 29.24 GHz. The cross polarization is below 25 dB at 9.9 GHz and 16 dB at 29 GHz respectively. The bottom plate of the SICL acts as the back reflector and thereby provides a Front to Back ratio of 15 dB and 14.7 dB at the two operating frequencies.

5 Conclusion

This paper presents a novel and simplified SICL based feeding network for dual band operation. The broadband unimodal opertion of the SICL transmision line helps in attaining dual band performance for the feed network. The novelty of the proposed antenna is the simplified feeding network that makes the simultaneous excitation of two colocated dual band antennas possible.

6 Acknowledgements

This work is supported by INSPIRE Faculty Award (DST/INSPIRE/04/2016/001549), Department of Science and Technology (DST), Govt. of India.

References

[1] S. Cherry, ”Edholms law of bandwidth,” *IEEE Spectrum*, vol. 41, p. 50, July 2004.

[2] A 5G Americas White Paper, ”Mobile Communication Towards 2030,” [White Paper] Nov. 2021, https://www.5gamericas.org/wp-content/uploads/2021/11/Mob-Comm-Towards-2030-WP.pdf.

[3] T. Kaiser, A. Bourdoux, S. Choi, R. Kohno, Q. Li, C. Mecklenbräuker, B. Ottersten, C. Papadias, S. Paul, A. Paulraj, P. van Rooyen, and J. Winters, ”When will smart antennas be ready for the market?,” *IEEE Signal Processing Magazine*, Mar. 2005.

[4] G. J. Foschini and M. J. Gans, ”On Limits of Wireless Communications in a Fading Environment when Using Multiple Antennas,” *Wireless Personal Commun.*, vol. 6, no. 3, Mar. 1998, pp. 31135.

[5] E. Telatar, ”Capacity of Multi-antenna Gaussian channnels,” *European Transactions on Telecommunications*, vol. 10, no. 6, Nov.Dec. 1999, pp. 58595.

[6] H. Boche, A. Bourdoux, J. R. Fonollosa, T. Kaiser, A. Molisch and W. Utschick, ”Antennas: state of the art,” *IEEE Vehicular Technology Magazine*, vol. 1, no. 1, pp. 8-17, March 2006.

[7] F. Gatti, M. Bozzi, L. Perregrini, K. Wu and R. G. Bosisio, "A Novel Substrate Integrated Coaxial Line (SICL) for Wide-Band Applications," *2006 European Microwave Conference*, Manchester, 2006, pp. 1614-1617.

[8] N. Baghel and S. Mukherjee, "Slot antenna excited by novel substrate integrated coaxial line cavity for millimetre wave application," *Electronics Letters*, vol. 56, no. 7, pp. 317-319, 30 3 2020.

[9] N. Baghel and S. Mukherjee, "Design of a Substrate Integrated Coaxial Line Based 2x4 Slot Antenna Array for Millimeter Wave Application," *2018 Asia-Pacific Microwave Conference (APMC)*, Kyoto, 2018, pp. 1561-1563.