Chapter 6

Conclusion and Future Work

This chapter recalls the context of the thesis, provides a summary of the main contributions of this dissertation, and finally outlines the future research directions.

Conclusion

In this thesis, a popular guiding structure of the last decades, named substrate integrated waveguide (SIW), and its applications in high frequency systems for such as 5G applications are investigated in detail. The proposed technology is very useful for combining planar and non-planar waveguide circuits in a common substrate. Due to its low-cost fabrication, light weight, high Q factor, and easy integration of active and passive elements on the same substrate along with the radiating antenna (system-on-substrate, SoS), it attracts the attention of many researchers, and it is widely used in modern radar, satellite communication applications, and 5G wireless communication applications.

The major contribution to the present work is the design and analysis of various SIW technology-based antenna structures, including wideband antennas, self-diplexing/self triplexing antennas, and multiple-input multiple-output (MIMO) counterparts, which are suitable for modern wireless communication systems. The principle of operation of

all the antenna designs along with effect of various design parameters on its performance are discussed and explained in detail. Aslo, the antenna designs are well explained with the help of equivalent circuit. Under the SIW technology regime, following areas are explored for 5G application and the excerpts of the contribution are given as follows:

- **SIW based wideband antennas:** In this study, a wideband SIW cavity-backed slotted antenna is presented and explored. The U-shaped slot is used to perturb the field distribution of the SIW cavity and a significant improvement in bandwidth of up to 14.50% is achieved. The designed antenna can achieve comparable gain and bandwidth performance with a miniaturized size by using a simpler topology, which makes it a good candidate for 5G applications. The measured results show that the proposed antenna can cover the fifth-generation (5G) wireless network for Europe and China (24.25–27.5 GHz), Korea (26.5–29.5 GHz), Japan (27.5–28.2), and the United States (27.5–28.35 GHz). It also has a simple structure with a single layer, which makes it easy to change the resonance frequency and gives it multiple resonance characteristics over a wide impedance bandwidth.
- **SIW based self- multiplexer antennas:** Under this category, two novel designs of self-diplexing antenna and self-triplexing antenna are presented. The need for frequency-selective elements (diplexers and triplexers) is eliminated by the new concept of self-diplexer and self-triplexer antenna geometry. The antenna itself implements diplexing and triplexing functions, removing any additional requirement for a higher order filter, thus improving the efficiency of the RF front end system and the miniaturisation of the overall communication system. First, a compact self-diplexing circularly polarized (CP) SIW antenna with an elliptical slot is designed. The proposed antenna works for the two resonating frequencies and covers the K and Ka-band communication with a minimum isolation of 22dB along with flexibility in tuning frequency ratio from 1.26 to 1.33. It reduces the need for a diplexer network in the RF front-end system. This makes the proposed

antenna an attractive/suitable candidate for both satellite broadcasting and 5G applications.

Next, the concept of non-linear replication is utilized for obtaining self-triplexed operation. The self-triplexing antenna can operate in three separate frequency bands at the same time, i.e., 5.23, 7.50, and 10.82 GHz. The independent tuning of each frequency band using a single parameter variable, isolation and radiation characteristics are also discussed in detail. The proposed antenna possesses isolation better than 43 dB between the excitation ports. It reduces the need for a triplexer network in the RF front-end system The proposed triplexer is a preferable candidate for both C- and X-band applications, including WLAN/5G/WiMAX/WiFi, amateur radio and satellite operations. Both the designs have been validated by experimental results. Good agreement between simulated and measured results is observed.

- **SIW based MIMO antennas:** In this research, a dual-band, dual-polarized SIW-based CP MIMO antenna with potential applications in satellite communications and 5G is proposed and implemented. Here, the metallic vias of SIW act as a good barrier and, hence, EM waves from one port cannot affect or interfere with the other port. To accomplish CP in both operational frequency bands, the AXS arms were adjusted to achieve 3 dB ARBW from 22.62–26.33 GHz and 29.20–30.12 GHz within the impedance bandwidth ranges of 22.60–26.36 GHz (Band-I) and 29.04–30.42 GHz (Band-II), respectively. Both MIMO ports have more than 28 dB of isolation and a front-to-back ratio of more than 20 dB. Band-I has an average gain of 7.52 dBic, and Band-II has an average gain of 7.15 dBic.

Future Directions

In the presented research work of this thesis, there are some possibilities and scope available to extend further this research work. Based on the conclusions drawn and

the limitations of the work presented, the following can be carried out in the future to improve the performance and applications of SIW systems.

- SIW slot antenna bandwidth may be improved by utilising slots of various shapes. To get good performance, the placement of a slot or slot array can be examined. Various feeding mechanisms and fractal slots can contribute to a broad bandwidth. The study of proper placement of vias can significantly enhance the bandwidth of an antenna while maintaining its low profile and performance. The impedance bandwidth of cavity-backed slot antennas is also enhanced by the air gap approach.
- Self-diplexing and self-triplexing antennas are used to separate two and three frequencies, respectively. It can be studied further that either of these design concepts could be extended to design self-multiplexing antennas (such as self-quadplexing antennas) for separating multiple frequencies.
- The concept of self-diplexing can be extended further to design self-diplexing/ triplexing MIMO antenna. Massive MIMO antennas are a fundamental component of 5G technology. In this study, only two antenna elements are addressed. As a result, the designs may be expanded to include a high number of antenna elements, such as 16 or 32 elements, or even more, for practical applications. The complexity and performance can be explored in detail as the number of elements increases.
- The upcoming 6G communication has numerous aims, such as a THz band with a wider bandwidth, an intelligent and artificial communication environment, a multiband communication network, and so on. These can be enabled using advanced methods and the self-multiplexing antenna concept. Also, 6G has a big impact on wireless communication because of the Internet of Things, Bio-nano Things, and quantum communication-based features.
- The System-on-Substrate approach has emerged as the fastest-growing packaging

technology that can easily integrate multiple functional chips (active components), including memory and processor, into a single board package to attain a fully functional module. This approach could replace the current System-on-Chip and System-in-Package and become the paradigm for mmWave circuits and systems.