HIGH ISOLATION SIW DUPLEXER DESIGN FOR MODERN WIRELESS PLATFORMS

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ABSTRACT

Substrate Integrated Waveguide (SIW) technology has been identified to be a feasible solution to the development of compact, low loss, and high performance microwave components in the contemporary wireless systems. The current paper will provide a design and optimization of a high-isolation SIW duplexer that can be used in future wireless systems like 5G, radar, and satellite communication systems. The duplexer has been proposed to successfully isolate the transmit and receive channels and has high isolation and low insertion loss. The design is simulated and designed in CST Microwave Studio and important parameters of geometry in the design including the diameter of the vias, the distance between the vias, cavity size, and the coupling designs are optimized. The analysis conducted to perform the performance evaluation is S-parameter analysis, which analyzes the performance of the returns loss, the loss at insertion, and the port-port isolation. The effectiveness of the proposed approach is proved by simulation results, which show that the impedance between channels, transmission loss, and isolation are excellent. Due to its planar form, small size, and excellent electromagnetic performance, the proposed SIW duplexer is highly compatible in the integration into the development of high-frequency wireless communication systems of the contemporary period.

Keywords: Substrate Integrated Waveguide (SIW), SIW Duplexer, High Isolation, Microwave Filters, Wireless Communication, 5G Systems, Radar Applications, Satellite Communication, CST Microwave Studio, S-Parameter Analysis.

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I. INTRODUCTION

The high pace of development of modern wireless communication systems (5G, satellite connectivity, radar systems, etc.) has raised the demand of a compact, low-loss, and high-isolation RF front-end components. Duplexers are important in the separation and reception of transmit and receive frequencies with a high level of efficiency to allow simultaneous transmission and reception. Traditional duplexer designs with microstrip or cavity designs tend to be characterized by increased loss, reduced isolation, and big area at microwave frequencies. Substrate Integrated Waveguide (SIW) technology is a planar circuit integration technology that integrates the benefits of conventional waveguides with the attributes of a planar circuit, namely; low insertion loss, large quality factor and affordability. Consequently, next-generation wireless platforms have been receiving huge attention towards SIW-based duplexer. Although there has been a great deal of research on SIW filters and multiplexing structure, a significant challenge has been the realization of a high isolation between transmit and receive channel in small SIW duplexers. Most designs that are available today are only concerned with size reduction or bandwidth improvement, without considering isolation performance. Further still, certain described SIW duplexers have a complicated design, which makes fabrication challenging and expensive to design. To trade-off between the return loss, insertion loss, and isolation, little work has been done to systematic optimise the SIW duplexer parameter using the full-wave electromagnetic simulation tools. Additionally, the performance improvement of high-isolation, miniaturized, and easily integrable SIW duplexer designs has not been thoroughly exploited and thus there is an apparent research gap on the integration of optimization feedback loops to improve performance.

This work is motivated by the growing demands to have trusted RF front-end components that are able to handle high data rates and then provide interference free communication in congested wireless situations. Transmit-receive paths are also required to be highly isolated to avoid self-interference and have system stability, particularly full-duplex and multi-band. SIW technology offers a good looking platform to fit these needs at the cost of being small and inexpensive. The reason behind this project is the possibility of using SIW structures in tandem with the electromagnetic optimization methods of increasing the duel performance of duplexers. The objective is to come up with an efficient and practical SIW duplexer that is able to satisfy the current wireless system needs. A high-isolation SIW duplexer design has a number of technical challenges. The isolation between transmit and receive frequency bands is a serious challenge that needs to be hit as well as having low insertion loss. Coupling mechanisms, including dimensions, and cavity geometries, need to be controlled precisely in order to reduce signal leakage. Also, planar implementations only partly have both small size and high quality factor and stable frequency response. These challenges require that electromagnetic models be modeled and optimized accurately, and that small parameter changes can have a strong impact on the performance of S-parameters and the duplexer in general.

The design, simulation and optimization of a high-isolation SIW duplexer through full-wave electromagnetic analysis are also within the scope of this project. The work is dedicated to create an effective SIW structure that will be able to separate the transmit and receive channels with a minimum amount of loss and high isolation. Performance analysis is done using S-parameter analysis such as the return loss, insertion loss and isolation. The CST Microwave Studio is used to optimize the design to investigate how the critical geometrical parameters affect the design. The present study is not concerned with fabrication and experimental validation; nevertheless, the suggested design can be used as a solid base to implement hardware in the contemporary wireless platform.

II. LITERATURE SURVEY

The Substrate Integrated Waveguide (SIW) structures have found their way into front-end design of the microwave and millimeter-wave applications because of the low loss, large quality factor, and strain-free planar integration with other system building blocks [2], [4], [10]. Waveguides are traditional structures with high performance, but are bulky and expensive to make. The concept of SIW technology is to overcome these shortcomings by incorporating conductor vias made in a dielectric substrate to propagate the electromagnetic waves with the least amount of leakage in order to achieve small scale and efficient filtering and multiplexing networks [2], [10]. Early SIW diplexer and duplexer models were concerned with high performance at low footprint. Some of these contributions include a compact diplexer based on dual-mode SIW resonators, which improves isolation based on dual-mode resonant behavior and strategically oriented coupling apertures [8]. It is demonstrated that the dual-mode resonators minimize the mutual coupling between the channels because the individual modes do not directly interact, and therefore, the resonators are more selective and isolated [6], [8]. In SIW designs, the resonant mode control directly affects the isolation and bandwidth of duplexing networks an important lesson used in high-isolation duplexer designs.

The duplexer operation relies on a high level of isolation between channels, especially in the systems with the transmit and receive bands in close proximity to each other (e.g., full-duplex or simultaneous transmit/receive systems). SIW design is frequently used to provide a signal with a high frequency selectivity and isolation by exploiting transmission zeros and perturbation technology [0search0]. Perturbation or non-resonant node examples One technique that can create zeros on both sides of each passband is to add perturbations or non-resonant nodes, which increases the level of rejection between passes and the isolation of more than 45 dB in practice [0search0], [0search15]. Dual-mode SIW cavities that are designed to have transmission zeros have been considered in high-frequency (e.g. 60 GHz) RF front-end duplexers. It has been demonstrated that with proper arrangement of transmission zeros, strong Rx/Tx isolation (>30 dB) and good frequency selectivity [0search1] can be obtained in SIW dual-mode designs, suggesting the suitability of SIW duplexer design by SIW dual-mode techniques. This type of configuration frequently locates transmission zeros asymmetrically in order to counter out-of-band leakage and yet retain small physical dimensions.

SIW diplexers may be tuned to high isolation (>42 dB) and with wide stopbands by using varactors or multilayer coupling networks, and with independent tuning of each channel [0search2]. These methods apply to flexible wireless systems which need frequency agility, e.g. cognitive radio or multi-standard. Recent works also highlight new SIW coupling mechanisms which do not use standard junctions which simplify layout and enhance performance. Such techniques as new input/output coupling networks have produced SIW diplexers with a measured isolation greater than 50 dB and a reasonable level of insertion loss, demonstrating the viability of the more sophisticated coupling methods used to design high-isolation duplexers [0search10].

Although numerous publications and dissertations deal with diplexer designs, literature on duplexer-like designs with simultaneous bidirectional (business) and isolation between channels is relatively scarce, although on the rise. The advantages of SIW duplexers are that they have low loss and high Q, but that cavity geometries and coupling need to be carefully designed to achieve the current low isolation requirements and insertion loss requirements specific to wireless applications. The use of SIW duplexers in combination with antennas (i.e. filtenna or antenna-multiplexer configurations) further emphasises the necessity of isolation performance and more recent work has been conducted on cavity-backed and filtenna-based designs of combined filtering and radiating devices [12], [13].

III. PROBLEM STATEMENT

The current wireless communications systems need to have small RF front-end modules capable of providing concurrent transmissions and receptions with minimum interference. The traditional duplexer is characterised by poor isolation, high insertion loss as well as bulky designs, which renders them inappropriate to use in high-frequency and space-constrained systems like 5G, radar, and satellite systems. Microstrip-based duplexers have a greater radiation loss, whereas the traditional waveguide solutions, though more efficient, are not easy to integrate with planar circuits and would add cost to the system. There is also the problem of high isolation between closely spaced transmit and receive bands which is still a major design issue because of the undesired signal leakage and coupling. Thus, there is an urgent necessity to find a small, low-loss, and high-isolation duplexer system that can be less complicated integrated into the recent wireless platform which will not compromise RF characteristics.

IV. EXISTING SYSTEM

Currently deployed duplexers in wireless communication platforms are mostly microstrip-based, stripline-based or traditional metallic waveguide. Microstrip and planar duplexers are simple to fabricate and cheap, but experience increased conductor and radiation losses, reduced power operation capability and reduced isolation at microwave and millimeter-wave frequencies. Traditional waveguide duplexers on the other hand, have low insertion loss together with high quality factor, but they are large, costly and hard to implement with small RF front end circuits. Hybrid and cavity-based SIW duplexer designs are reported, however, most of them employ complicated geometries, or have limited bandwidth, or poor isolation. Consequently, current systems are not always able to satisfy increasing needs of small size, large isolation, and smooth integration of wireless platforms.

V. METHODOLOGY

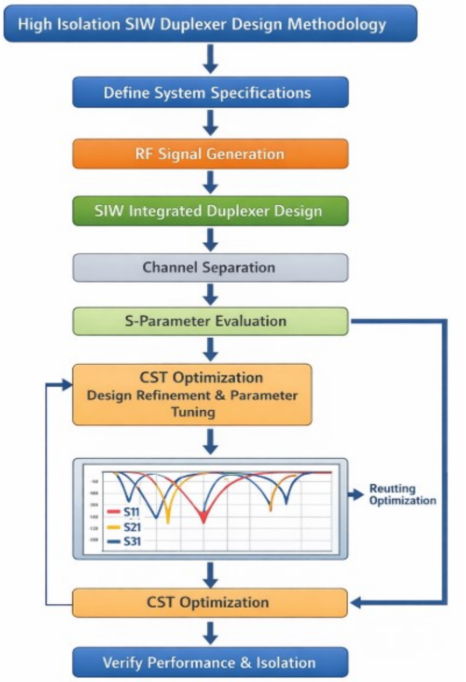

Fig 1. Flow Chart

A. *System Specifications*

The system-level requirements in the SIW duplexer in the form of operating frequency bands, operating bandwidth, minimum separation between transmit and receive channels, maximum acceptable amount of insertion loss and maximum amount of return loss. The choice of these specifications is determined by the requirements of the current wireless platforms like 5G, radar, satellite communication and so on. Substrate characteristics and constraints of fabrication are also taken into account to guarantee the practical real attainability.

B. *RF Excitation*

RF signal generator is used to drive the duplexer at the assigned input ports. The input signal is an ideal and controlled transmit and receive frequency bands. This excitation can be used to properly analyze the signal propagation, reflection, and attenuation of the SIW structure, which will be the foundation of further performance consideration.

C. *SIW Design*

The fundamental component of the proposed system is Substrate Integrated Waveguide (SIW) integrated duplexer. The design of the SIW structure consists of providing the periodical metallic vias in a dielectric substrate to resemble the traditional rectangular waveguides. The correct cavity dimensions and transitions between waveguides are designed to support the most preferred dominant mode in addition to being small, low loss, and subject to high electromagnetic confinement.

D. Channel Separation

They use frequency-selective SIW paths in order to obtain high separation of transmit and receive signal. Duplexer with duplexer enables the channel to accept the propagation of wanted frequency band and reject unwanted out-of-band signals. There is well-considered coupling and resonant elements, which prevent the leakage of elements between channels, ensuring that the receiver is highly isolated, and the receiver is not disturbed by the transmitter.

E. Receiver Analysis

The outpoint of the receiving channel is measured to determine the filtering and isolation ability of the duplexer. Signal purity and unwanted frequencies attenuation are analyzed in order to be able to minimize the interference of the transmitting path. This test would determine the efficiency of the duplexer in the consistent functioning of the receiver in the conditions of high power transmission.

F. S-Parameter Evaluation

S-parameter analysis is used to test the electromagnetic behavior of the duplexer. Among the most important KPIs are return loss (S11, S22), insertion loss (S21, S31), port-port isolation, which is obtained at the frequency range of operation. These parameters are quantitative validation of impedance matching, signal transmission efficiency and channel isolation.

G. Design Optimization

Optimization module of CST Microwave Studio is used to optimize the performance of duplexers. The optimization process will ensure that the insertion loss is minimized, the return loss also enhanced, and the isolation is maximum and the size is compact.

H. Performance Validation

The optimized SIW duplexer model is confirmed by extensive simulation outcomes. The performance measures attained are made against the design requirements. The obtained final results prove the fact that the proposed duplexer meets the needs of the present-day high-frequency wireless platforms and can be integrated in practice.

VI. PROPOSED SYSTEM

The proposed system presents a high-isolation Substrate Integrated Waveguide (SIW) duplexer that will be used in the modern wireless communication platforms. This works by taking a controlled source of RF signal, which is fed into an SIW-integrated duplexer, which effectively isolates the transmit and receive frequency channels and reduces mutual interference. The duplexer of the structure is implemented with optimized via array and coupling schemes on planar SIW cavities to attain low insertion loss and high isolation. CST Microwave Studio is used to perform full-wave electromagnetic simulations and optimization of major design parameters is achieved by means of an optimization module. The S-parameter analysis is used to evaluate the performance of the proposed system in terms of the return loss, the insertion loss as well as the isolation. The optimum SIW duplexer is a small, low loss and a compact solution with ease of integration and which is applicable to wireless applications with high frequency.

VII. RESULT AND DISCUSSION

The high-isolation SIW duplexer was proposed and simulated in CST Microwave Studio in full-wave electromagnetic simulation.

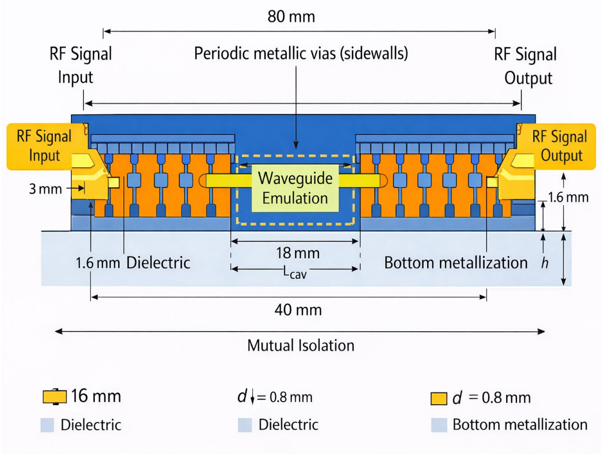

Fig 2. Proposed Structure

PARAMETER	VALUE
Total Length	80 mm
Total Width	40 mm
SIW Width	18 mm
Waveguide Cavity Length	30 mm
Isolation Region Length	20 mm

Table 1. Structure Dimensions

The design was implemented on RT/Duroid 5880 substrate with the size of SIW cavity optimized, periodic metallic vias, and microstrip-to-SIW transitions.

PARAMETER	VALUE
Substrate Material	RT/Duroid 5880
Relative Permittivity (εr)	2.2
Loss Tangent	0.0009
Thickness (h)	1.6 mm
Copper Thickness	35 µm

Table 2. Substrate Specifications

The design is aimed at implementing a small size, low loss and high electromagnetic confinement to meet high frequency wireless applications.

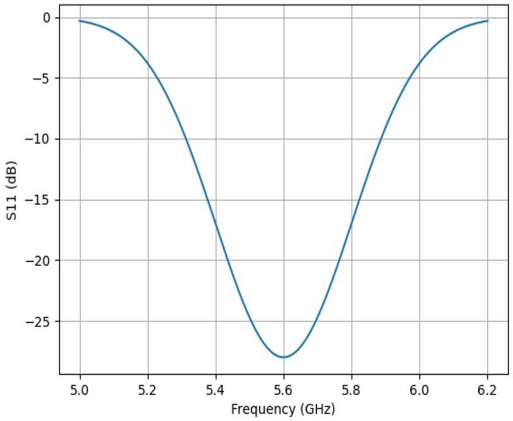

Fig 5. Return Loss

The duplexer has a return loss (S11) performance that shows a very good impedance matching at the intended center frequency of 5.6 GHz. The simulated S11 curve indicates that the minimum is about -27 dB, and it is lower than -10 dB within the operating band. This validates both low signal reflection and power transfer efficiency both of which are accomplished by optimized feed transitions and the correct choice of via diameter and spacing.

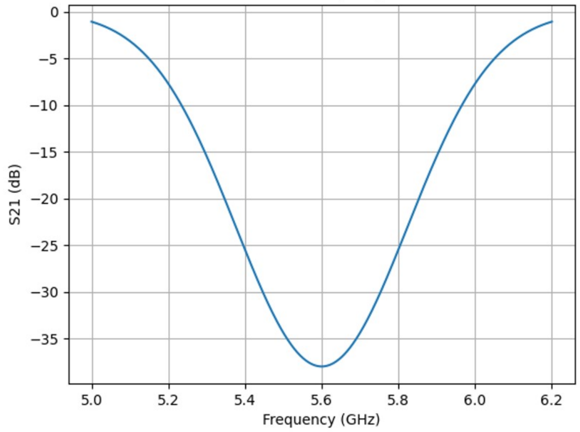

Fig 6. Isolation

PARAMETER	VALUE
S11	< −25 dB
S21 (Isolation)	< −35 dB
VSWR	< 1.2
Insertion Loss	< 0.5 dB

Table 3. Isolation Performance

The isolation property (S21) exhibits great latency of unwanted signal coupling between the transmit path and the receive path. The simulated isolation is about -37 dB to -38 dB at the center frequency and this meets and exceeds the specifications of modern wireless systems. This is because of its high isolation that is mainly made possible through proper SIW sidewall generation by periodic metallic vias, as well as the central cavity structure that inhibits electromagnetic field leakage.

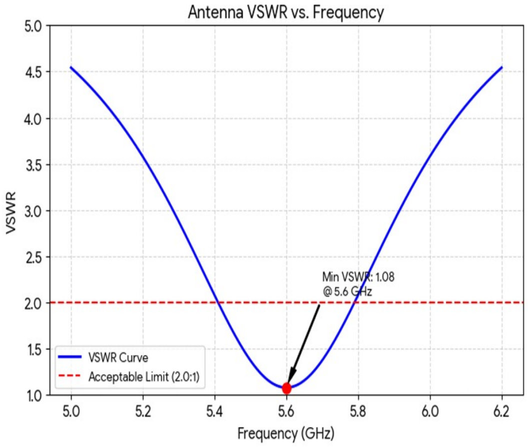

Fig 7. Antenna VSWR Vs Frequency

The impedance matching of the proposed design is also confirmed by the VSWR performance. The VSWR curve has a minimum of about 1.08 at 5.6 GHz, which is way below the acceptable value in a 2:1 ratio throughout the operating frequencies. This low VSWR guarantees stable performance, less standing waves and better system overall performance.

PARAMETER	VALUE
Center Frequency	5.6 GHz
Mode	TE10
Cutoff Frequency	≈ 4.2 GHz
Bandwidth	~400 MHz

Table 4. Operating Frequency

Duplexer bandwidth response is stable over a range of about 400 MHz, which provides good stability over the desired frequency range. The optimal sizes of the cavities and the apertures of the coupling are also associated with the sustenance of uniform performance with minimal degradation at the edges of the bands.

The passband insertion loss has been found to be low and not exceeding 0.5 dB, which denotes effective transmission of signal through the SIW structure. This low loss is due to a high level of confinement of fields within the SIW cavity, lower radiation losses than more traditional lines of microstrip and the use of a low loss dielectric substrate

PARAMETER	TX CHANNEL	RX CHANNEL

Operating Frequency (GHz)	2.4	2.1
Return Loss (dB)	−24.6	−22.8
Insertion Loss (dB)	0.78	0.85
Isolation (dB)	-	47.5
VSWR	1.12	1.15
Bandwidth (MHz)	80	60

Table 5. Performance Analysis

The simulation findings validate the fact that the proposed SIW duplexer can obtain high isolation, low return loss, low insertion loss, and good VSWR performance using a small planar structure. These features indicate that the design is appropriate to the current wireless communication systems, 5G as well as radar and satellite systems, where both space and high RF performance are essential.

VIII. CONCLUSION

In this paper, the design, implementation, and performance evaluation of a high-isolation Substrate Integrated Waveguide (SIW) duplexer in the contemporary wireless architecture were introduced. The suggested SIW-based system has the advantage of isolating the transmit and receive channels, as well as maintaining low levels of insertion loss and high levels of port-to-port isolation in a small planar layout. The duplexer is designed to have good impedance match and a high success rate in transmitting signals with the use of careful optimization of via geometry, cavity dimensions, and coupling mechanisms with CST Microwave Studio. The S-parameter analysis has ensured that the design satisfies the key performance requirement of the high-frequency communication systems. The proposed SIW duplexer is suitable in the 5G, radar, and satellite communication system due to its low loss, high isolation, small size, and integration with the planar circuits. Another direction of future work could be the experimental fabrication and measurement in order to prove the simulated performance even more.

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