Istanbul Medipol University
School of Engineering and Natural Sciences
Graduation Project
2022-2023

PROJECT TITLE
Millimeter Wave MMIC Switch Design
PROJECT ADVISOR
Asst. Prof. Hüseyin Şerif Savcı
TEAM MEMBERS
İbrahim Taha Gökce

Istanbul Medipol University
School of Engineering and Natural Sciences
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Project Code
Project Title: Millimeter Wave MMIC Switch Design
Project Advisor: Asst. Prof. Hüseyin Şerif Savcı
Project Team Members: İbrahim Taha Gökce
Sponsor Company (if any) : Tübitak (2209-B)

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Project Title:

Millimeter Wave MMIC Switch Design

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PROJECT OVERVIEW/SUMMARY/ABSTRACT

Communication and radar systems are increasingly being utilized in both civilian and military sectors. These systems often involve beam steering and the use of a single antenna for both transmission and reception, making switches a critical component. The primary objective of this project was to design, fabricate, and test an SP3T switch operating at millimeter frequencies, which would exhibit low insertion loss, good return loss, and strong isolation between output ports, as well as between input ports and off-state output ports.

During the design phase, schematic and layout designs were created, and simulations were conducted using the Advanced Design System (ADS) software. Based on a thorough review of relevant literature, the shunt-shunt diode topology was selected for the switch design. To enhance isolation and reduce the chip size, a coplanar waveguide (CPW) structure was employed.

An additional waveguide module design was planned to facilitate measurements of the 77 GHz switch. However, due to unforeseen risks, the waveguide measurements were postponed until the start of the master's degree program. In the interim, to demonstrate the switching functionality, measurements were conducted on a 5G band switch integrated into a module that utilized a microstrip transmission line.

The goal of this project was to address the increasing demand for reliable switches in communication and radar systems operating at millimeter frequencies. The successful design and testing of the SP3T switch, along with the planned measurement of the 77 GHz switch using the waveguide module, will contribute to the existing body of knowledge in this field. Any narrative or spelling errors in the original text have been corrected.

Keywords: Millimeter Wave, MMIC, SP3T Switch, RF Switch, Waveguide Switch Module

1. OBJECTIVE OF THE PROJECT:

Systems like communication and radar systems are now used more and more frequently in both the civic and military sectors. Switches are a key piece of equipment in these systems, which also employ beam steering and the utilization of a single antenna for both transmission and reception. The main objective of this project is to design, fabricate and measure an SP3T switch with low insertion loss, good return loss, high isolation between output ports and, between input ports and off state output ports at millimeter frequencies. After the successful completion of designing an SP3T (Single Pole Three Throw) MMIC (Monolithic Microwave Integrated Circuit) switch designed at millimeter frequencies, it can be used in a variety of applications such as:

- Frequency selection in radar and communication systems [1].
- As antenna selectors [2].
- Selecting signal paths in test and measurement systems.
- Can be used in RF embedded systems.

With a successful design, the switch should provide high levels of isolation between signals passing through the switch while keeping losses to a minimum. Additionally, the switch should have low power consumption.

2. LITERATURE REVIEW:

2.1. Usage Area of Switches

Since switches are a control device primarily utilized in communication systems, these are one of the core parts of mm-Wave technology. These switches are frequently utilized in a variety of applications, such as satellite, radar, defense, automotive, medical, imaging, RF and microwave, communication applications [1, 2, 3].

2.2. Performance Parameter of a MMIC Switch

There are several crucial performance factors to consider when selecting an MMIC switch for a certain application, including insertion loss, isolation, switching speed, power handling, and DC power consumption. Frequency range, and P1dB are some other variables. The definitions of these parameters are as follows [4, 5]:

- Insertion loss is a metric for power lost as a signal pass through a switch. It is commonly expressed in decibels (dB) and is determined as the difference between input and output power. In cases where the signal power is constrained, a lower insertion loss might be beneficial since it results in less power being lost when the signal passes through the switch.

- Isolation: This is a gauge of how isolated from one another the switch's various input ports are. When the switch is in a particular state, it is determined as the ratio of the power at one input port to the power at another input port and is commonly measured in dB. In applications where the signal power is constrained or where signals at many input ports may interfere with one another, a higher level of isolation means that less power from one input port will leak into another input port.

- Switching speed: This is a measure of how rapidly the switch can switch between multiple input ports. The time it takes for the switch to transition to a new state after the control voltage is applied is commonly measured in nanoseconds (ns). In applications where the input signal is changing quickly, having a switch that can react to changes in the input signal more quickly can be crucial.
- Power handling is a measurement of how much power a switch can manage without suffering performance degradation or physical harm. The highest amount of power that a switch can handle without breaking is commonly measured in watts (W). High-power applications may benefit from a switch's capacity to handle stronger impulses without being destroyed, which can be crucial.
- DC power consumption: This is a measurement of how much DC power the switch uses. It is commonly expressed in milliwatts and represents the power needed for the switch to function. The switch will use less power if its DC power consumption is lower, which might be significant in situations where power is scarce.
- Frequency range: This is a measurement of the range of frequencies that the switch can function over. The range of frequencies at which the switch can deliver the specified performance criteria is commonly measured in hertz (Hz). It can be crucial for applications where the input signal frequency is rapidly changing to have a switch that can operate across a wider frequency range.
- P1dB (1dB Compression Point): It is a useful way to compare several switches and choose the one with the highest power handling capability for high power applications. It indicates the input power level at which the output signal will be 1dB below the linear operating point.

2.3. MMIC Switch technology

Several technologies, such as PIN diodes, FETs, etc., can be used to make MMIC switches.

2.3.1. Active MMIC Switch technology

Since pin diode technology is utilized in this project, it has received greater emphasis than other active technologies.

PIN diode is a type of diode that is made using a type of semiconductor material known as P-type Intrinsic-N-type (PIN) material. PIN diode switches are electronic devices that use a PIN diode to switch an electronic signal on or off.

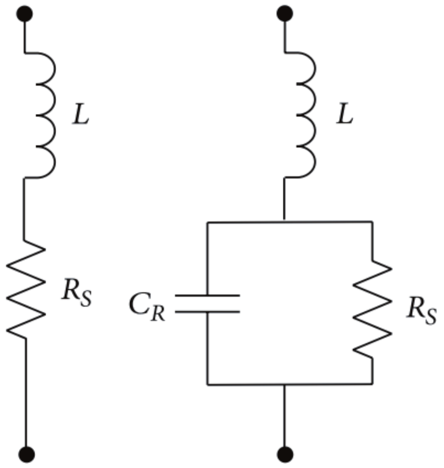

Figure-1 Forward Bias (Left) and Reverse Bias (Right) Models [6]

In the figure-1 left circuit, a forward bias pin diode model is given. It is modelled by a serial inductor and a resistor. The L value of this inductor is smaller as much as parasitic inductor because it is smaller than 1 nH generally. Also, resistor value is calculated by following formula:

$$R_s = \frac{W^2}{(\mu_n + \mu_p)\, Q} \ (\Omega) \qquad (1)$$

where :

$$Q = IF \ x \ \tau \ (in \ coulombs)$$
$$W = I \ region \ width$$
$$\tau = carrier \ lifetime$$
$$IF = forward \ bias \ current$$
$$\mu n = electron \ mobility$$
$$\mu p = hole \ mobility$$

Additionally, the reverse bias model of pin diode is given in the right circuit in figure-1. The capacitor of this circuit is calculated as follows:

$$C_R = \frac{\varepsilon \, A}{W} \qquad (2)$$

Where:

$$\varepsilon = dielectric \ constant \ of \ silicon$$
$$A = area \ of \ diode \ junction$$

PIN diode switches are typically used in applications where high switching speeds and low insertion loss are required. They are also used in applications where the switch needs to be able to handle high power levels without distortion or loss of signal quality. Some common applications for PIN diode switches include [8]

Figure-2 illustrates how a single series or shunt connected PIN diode can be used to create a basic untuned (SPST) Single Pole Single Throw switch.

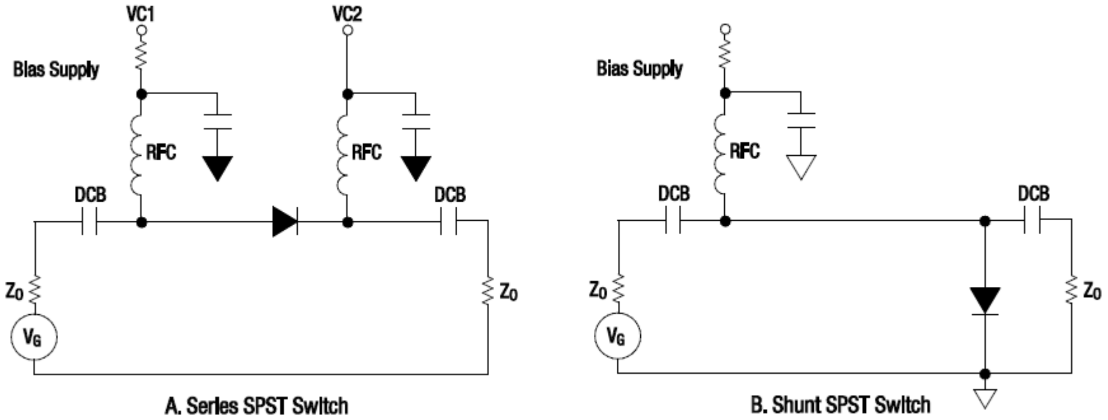

Figure-2 Seri and Shunt Diode Switch Topologies [6]

When a voltage of 5 V is applied to VC1 and 0 V is applied to VC2, the PIN diode becomes forward biased, resulting in a state where it exhibits low impedance to the RF signal.

As forward current increases, RS (series resistance) drops, reducing the switch's overall insertion loss. In the scenario where the polarities of VC1 and VC2 are reversed, the behavior of the PIN diode changes. It either presents itself as an open circuit or as a significant resistance, accompanied by reverse bias capacitance (CJ). This configuration results in high insertion loss and isolation within the structure, causing the majority of the energy to be reflected back towards the RF source. When the PIN diode is in a zero or reverse biased state, this sort of switch is hence reflective by definition. Using this precise bias circuitry and a single positive control voltage, the diode may be biased either forward or backward. Typically, a negative control voltage is required for a proper reverse bias on the diode in isolation condition. By utilizing only a positive supply voltage, this approach eliminates the requirement for the negative voltage while boosting the overall linearity of the device. However, because it is easier to heat sink a single shunt-placed diode, it results in greater isolation values across a wider frequency range and a device that can withstand more power.

Constructing multi-throw switches solely using shunt diodes can be challenging. However, Figure 3 showcases a band-limited shunt multi-throw switch design that overcomes this difficulty. It consists of two cascaded quarter-wavelength sections, each terminated by a shunt diode. This arrangement ensures that the OFF branch maintains a high input impedance at the common port (connected to the signal source). This prevents the impedance of the ON arm from being burdened, as it would typically occur in other configurations.

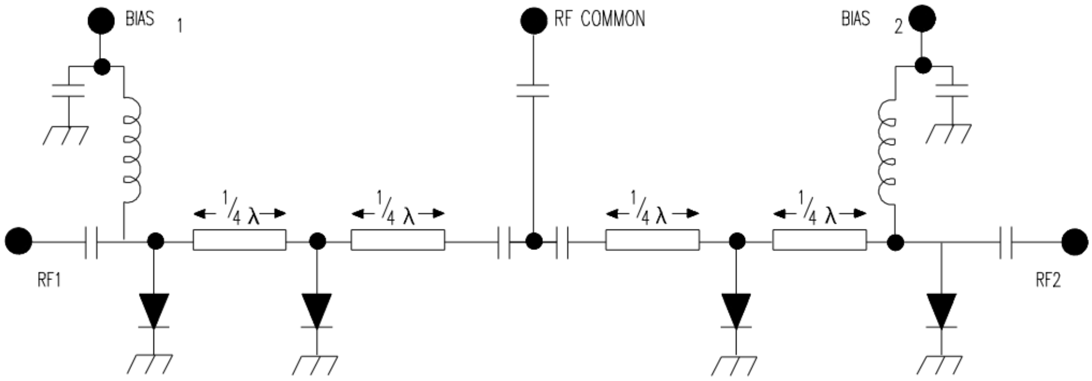

Figure-3 Shun-Shunt Quarter Wave Topology [6]

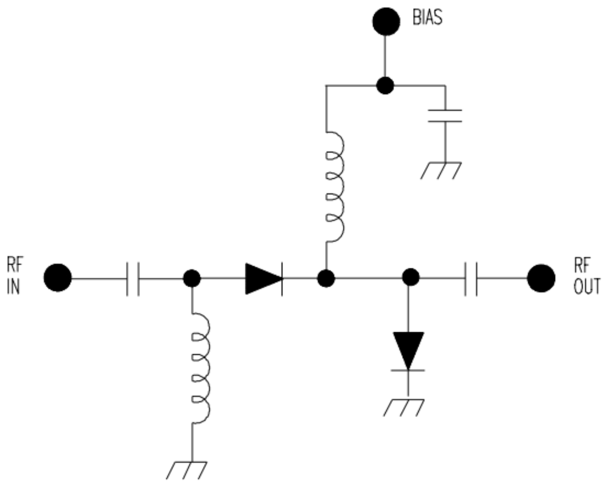

Figure-4 Seri-Shunt Topology [6]

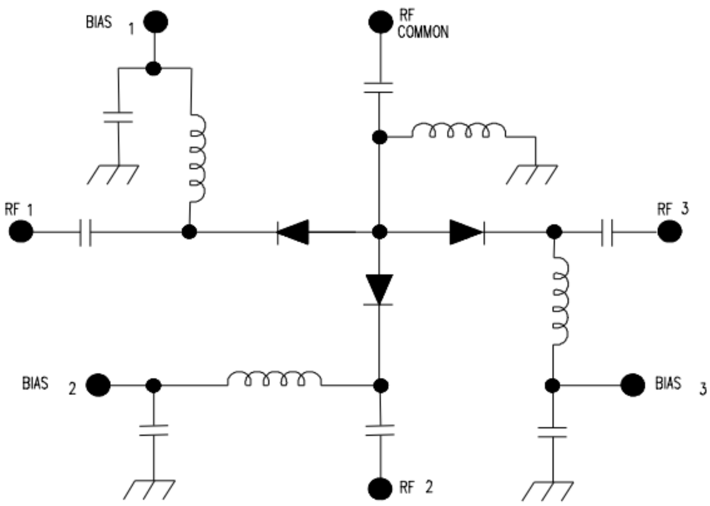

Figure-5 Tee Switch Topology [6]

The Series-Shunt Switch (Figure-4) and the TEE Switch are the two most basic compound switches (Figure-5). Although the overall performance of these circuits has improved, the VSWR and Insertion Loss have suffered due to the increased circuit complexity. The complexity of the bias circuit increases because not all diodes are simultaneously biased in either state. Table I provides a comparison of the overall performance metrics for Series-Shunt and TEE Compound Switches as well as Series-Shunt SPSTs. Any practical switch design will inevitably include trade-offs between performance parameters.[6]

Besides pin diode technology, it is also possible to design switches using transistor technology such as HEMT, SiC, pHEMT, InP, SOI, NMOS, and CMOS. The advantages and features of these technologies can be briefly summarized as follows[3]:

- HEMT and pHEMT are high-frequency devices that employ a heterostructure of materials to attain high electron mobility. This produces in high gain and low noise, making them excellent for high-frequency MMIC switch designs.
- SiC is a semiconductor with a broad bandgap, a high breakdown voltage, and good thermal stability, which makes it appropriate for high-power and high-temperature applications.
- InP, a III-V semiconductor material with high electron mobility and breakdown voltage, is often employed in high-frequency MMIC switch designs.
- SOI is a technique in which a thin layer of silicon is deposited on an insulator substrate. This technique is employed to decrease parasitic capacitances and enhance the performance of high-frequency MMIC switch designs.
- Popular in digital IC designs, NMOS and CMOS transistors are also utilized in certain MMIC switch designs. NMOS and CMOS are digital-only technology not commonly utilized in high-frequency MMIC switch designs.

2.3.2. Passive MMIC Switch technology

Coplanar waveguide (CPW) is used in designed MMIC switches because the ground plane provides a low-impedance reference for the signal, which reduces the parasitic capacitance and inductance of the transmission line. This means that the electrical length of the transmission line can be much shorter than other types of transmission lines for the same operating frequency, allowing for a more compact design.

Additionally, CPW is that it provides good isolation between the signal and ground, which is important in RF switching applications. This is because the signal is carried on a conductor strip that is separated from the ground plane by a dielectric material, which prevents current from flowing directly from the signal to the ground plane. This helps to prevent crosstalk and other forms of interference between the signal and ground [7].

2.4. Designing of Waveguide Module

The process of integrating MMIC high frequency chips into waveguide modules involves several key steps, which include designing the module, fabricating the components, and assembling them into a functional unit [8]. One of the most critical aspects of this process is the proper design of the waveguide structures, as they greatly influence the overall performance of the module. CST is a widely used software tool for designing and optimizing these structures as it allows for accurate modeling and analysis of their electromagnetic properties [9].

Once the design phase is completed, the next step involves fabricating the components needed for assembly. This includes creating microstrip lines that will be used to connect the MMIC chips to the waveguide structure. These lines are vital for ensuring optimal performance at high frequencies by minimizing losses and reflections within the system [10].

The assembly process typically involves bonding the MMIC chips to microstrip lines using bond wires – thin metallic wires that create electrical connections between different components. This method provides a reliable and low-loss connection while maintaining good mechanical stability [11]. It is crucial that these connections are made with utmost precision to prevent any degradation of signal integrity or system performance.

In conclusion, integrating MMIC high frequency chips into waveguide modules involves a series of complex steps that ensure optimal performance and reliability in communication systems. The use of tools such as CST for design, along with proper fabrication and assembly techniques like chip-to-microstrip lines and bond wires contribute significantly to achieving these goals.

2.4.1. Waveguide Structures

Waveguide structures find utilization in various applications, primarily due to their ability to confine and guide electromagnetic waves within a specific frequency range [12]. These structures are predominantly employed in the fields of telecommunication, radio-frequency engineering, and optical systems [13]. The underlying principle governing waveguides is the strategic manipulation of electromagnetic fields, which is achieved through confinement within particular geometries [14].

A significant advantage offered by waveguides includes minimal energy loss during transmission, resulting in reduced attenuation and improved signal quality [15]. Moreover, they provide excellent isolation from external interference, ensuring the maintenance of signal integrity [16]. Additionally, these structures facilitate further miniaturization and integration of components within electronic systems, paving the way for advanced technologies and devices [17].

In conclusion, waveguide structures boast an array of benefits such as minimal energy loss, superior signal isolation, and enhanced device miniaturization. Their unique characteristics make them indispensable in multiple applications across telecommunications, radio-frequency engineering, and optical systems.

2.4.2. Vivaldi Antennas for Waveguide

Vivaldi antenna designs have emerged as a viable solution for transitioning from microstrip lines to waveguides in waveguide structures where MMIC (Monolithic Microwave Integrated Circuit) chips are placed [18]. These designs offer several advantages, including wideband performance, ease of integration with other electronic components, and enhanced efficiency in propagating signals.

The primary focus of Vivaldi antenna designs is to facilitate the smooth transmission of signals from microstrip lines, which are utilized for MMIC chips, to waveguides that enable high-frequency signal propagation [19]. This transition can be challenging due to the intrinsic differences in impedance and modes of operation between microstrip lines and waveguides [20]. Vivaldi antennas effectively address this issue through their unique tapered structure, which allows for gradual impedance matching and mode transformation [21].

One of the advantages of employing Vivaldi antenna designs is their wideband performance. The shape of these antennas enables them to cover a broad frequency range, encompassing both the frequencies involved in microstrip lines and those used in higher-frequency waveguides [22]. This wideband behavior is crucial for many applications, such as radar and communication systems that require versatile frequency coverage.

Another advantage lies in the ease of integrating Vivaldi antennas with MMIC chips and other electronic components. Due to their planar structure, these antennas can be directly printed on the substrate hosting the MMIC chip or fabricated using standard PCB (printed circuit board) processes [23]. This compatibility simplifies assembly processes and allows for more compact device design.

Lastly, Vivaldi antenna designs enhance transmission efficiency in waveguide structures containing MMIC chips. The gradual impedance matching facilitated by these antennas minimizes signal degradation when transitioning between dissimilar transmission media such as microstrip lines and waveguides [24]. Consequently, this maximizes signal integrity while reducing power loss.

2.5. Comparison of Literature Review

As a result of literature study, table-1 provides a comparison of several MMIC Switch design studies utilizing various methods and technologies.

Table1: MMIC Switch Designs Found as a Result of Literature Review

Ref.	MMIC Process	Type	Topology	Freq	Min. Ins Loos (dB)	Isolation (dB)	Chip Size (mm^2)
[25]	AlGaAs	SP3T		75-100	1.3	33	1.6x1.13
[26]	AlGaAs	SP3T	Series-Shunt	0.05-50	0.8	31	1.3x1.3
[27]	GaAs	SP3T	1/4 λ Shunt	75-85	1.5	20	1x1
[28]	HJFET	SPST	Dis. FET, Shunt	DC-110	<2.55	>22.2	0.85x0.45
[29]	HEMT	SPST	Travelling wave concept, Shunt	DC-80	<3	>24	1x0.75
[30]	GaAs PIN Diode	SPDT	1/4 λ Shunt	75-110	1.1	21-22	0.94
[31]	GaAs PIN Diode	SPDT	Series-Shunt	0.01-70	1.1	20	0.74x0.57

3. ORIGINALITY:

The aim of this project is to create an MMIC with low insertion loss and high isolation values at 77GHz using PIN diode technology. As stated in the second section, there are relatively few SP3T MMIC switch studies in the literature. The aim of this project is to create an SP3T switch with PIN diode technology, which is cheaper than other MMIC production technologies in terms of originality, and it is aimed that this switch will have better performance parameters than those described in the literature.

4. SCOPE OF THE PROJECT AND EXPERIMENTS/METHODS:

1) Literature Review and Design Performance Specification

After choosing the project's subject and completing the literature research, the project's phases were established by identifying the desired outcomes. It was determined that the project is going to be proceed as the diagram shown in the figure-6. The literature review and the identification of targeted performance specifications according to the technology capabilities have been completed and these are presented in next part (project targets and success criteria).

2) Schematic Design

Schematic design was one of the primary job packages that was completed. In this work package, the Advanced Design System application was used to design the SP3T Switch using a schematic. The schematic presented here served as the basis for the project's layout design. Components from Win Semiconductor's PIN3-00 design kit file were added and utilized in the schematic design. Win Semiconductor offers this design kit file for the design of the components characterized for the design of the designs. Additionally, the results of the simulation of the schematic design were significantly less complex than those of the simulation of the layout and required fewer matrix operations to solve. Using tools such as optimizers and tuners, the required target values were quickly obtained. Therefore, rapid feedback and correction were provided when the required specification values were not met.

3) Layout Design

After the desired values were provided in the schematic design, the layout design commenced. In the layout design, the values derived from the schematic design served as initial values. However, because it operated at extremely high frequencies and was constructed using the coplanar wave guidance approach, it was not envisaged that the initial values acquired from the schematic would offer complete performance. In order to shorten the length of the transmission lines in the layout design, diodes acting as shunt capacitors and a coplanar wave guide structure were used to provide high impedance value. The results of the layout designs were determined using momentum microwave EM simulation. Momentum microwave provided more precise findings for the frequencies and dimensions of the design than Momentum RF did. Additionally, no diodes were included in the layout design. This is because the simulation performed in the layout did not function well for nonlinear components. Therefore, the cosimulation approach, which combines diodes and layout design on the schematic, was implemented.

4) Manufacturing

The chip was sent into production once the layout designs had yielded the required results and the design had passed the DRC inspection, which is the manufacturability control. Taiwanese company WIN Semiconductor's PIN3 manufacturing method was utilized for production.

5) Measuring

After the completion of production and the acquisition of the chips, it was planned to measure them by making contact with the pads on the chips using probes and a probe station equipment, followed by using a Vector Network Analyzer (VNA). However, due to the unavailability of the required probe tips, it was decided to design an additional waveguide module. Furthermore, each of the designed SP3T switch chips had three DC bias pads. These pads were intended to be used for controlling the switching chip through DC feed lines passing through a module. Due to difficulties encountered during the design's production phase, the measurement process has not been completed yet.

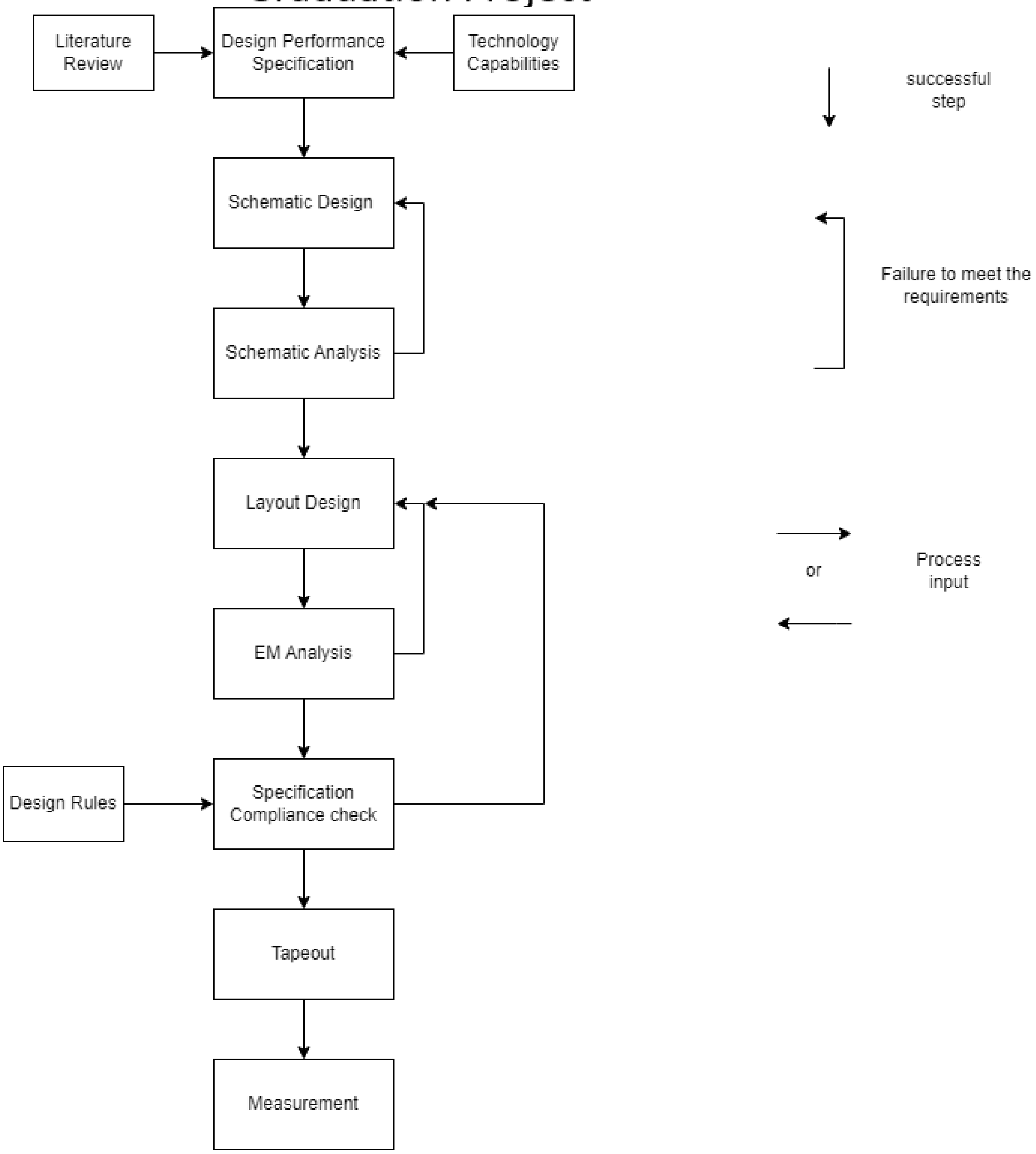

Figure-6 Work Packages Flow

5. PROJECT TARGETS AND SUCCESS CRITERIA:

1- The literature review of MMIC switch research plays a crucial role in identifying the target values of the switch to be constructed. The target of the first work package is to establish the design parameters for the MMIC switch. the success rate for this work package is 10%.

2- The second work package's success criterion is the achievement of the targeted values as a result of the simulation of the schematic design. The following are the goals: It is anticipated that the Insertion Loss value for all three output levers in the on state will be less than 2 dB, while the Return Loss value will be larger than 13dB. Additionally, an isolation value larger than 20 dB is expected between input and rf output ports in the off state, as well as between rf output ports. Lastly, it is anticipated that the frequency value it supplies for these objectives will include 77 GHz and that the bandwidth will exceed 5 GHz. 20% is the success rate for this work package.

3- The success criterion for the third work package is the achievement of the desired values as a result of the layout design. It is expected that the Insertion Loss value will be less than 2 dB and the Return Loss value will be larger than 13 dB. The targets will be identical to the schematic design. In addition, an insulation value over 20 dB is anticipated. Lastly, it is predicted that the frequency value it supplies for these objectives will include 77 GHz and that the bandwidth will exceed 5 GHz. 30% is the success rate for this work package.

4- At the conclusion of the chip manufacturing phase, the desired outcome is to have built more than 10 MMIC switch chips successfully. The success rate for this work package is 20%.

5- As a consequence of the measurement, it will be desired to obtain chips with an insertion loss of less than 2 dB, a return loss of larger than 13 dB, and an isolation value of greater than 20 dB, as seen in the layout design. A shift to frequencies lower than the planned frequency range will not be regarded a failure in the operating frequency because it permits the chip to run at mmWave frequencies, which still have distinct application regions. The percentage of successful measurements is 20%.

Table2: Work Packages and Success Percentage

Work Packages (WP's)	Success Percentage	Completed Percentage of WP
1) Determine Design Target Parameters	10 %	100%
2) Simulation of Schematic Design	20 %	100%
3) Simulation of Layout Design	30 %	100%
4) Manufacture of Chips	20 %	100%
5) Manufactured Chip measurement	20 %	75%

All work packages have been considered to be completed 100% without measurement. The reason for considering the measurement work package as 50% complete is as follows: The module designs required for the measurements of the 77GHz SP3T chip design have been completed, and the production of the part made of brass alloy is also finished. Only the PCB production remains. Additionally, as a measurement result, the SP3T switch operating in the 5G bands was measured by placing it within a module using microstrip lines and bond wires. It is evident from this measurement that there is a significant insertion loss in the transmission line that connects to the connector, as it is not properly matched within the module, and it is connected to numerous microstrip lines and bond wires along a long path. Therefore, it can be clearly observed that the operating frequencies and performances of the produced chips do not vary significantly.

6. RISKS AND B PLANS:

Table3: Risk and B Plans

Work Package #	Risk	B Plan
Wp 2 & Wp 3	The design may not be designed to meet the design criteria at 77 GHz.	The target can be revised so that the design frequency is at lower frequencies.
Wp 4	After manufacturing, the measurement results may shift to different frequencies.	The wide designed operating frequency band can ensure that the targeted frequency will still operate at the targeted frequency as a result of drift.
Wp 5	The probes and VNA required for measurements of manufactured switches may not be available.	To overcome the unavailability of four 75µm probes required for measuring the designed chip, an external module utilizing waveguides was designed to enable the measurement using waveguide transmission.
Wp 5	It may be observed that the designed chip does not work after measurements.	Another designed switch of type SP3T and SPDT designed for different frequencies can be replaced by the design in the final project.
Wp 4	The diode models in the PDK given by win semiconductor may be not correct.	The diodes used can be modeled according to the measurement results, so it can be explained why the design does not provide the targeted parameters.

7. DEMO PLAN:

The completed designs and productions of the SP3T switch operating in the 77 GHz band, the SP3T switch operating in the 5G band, as well as the SPDT and SPST switches, will be demonstrated under a microscope during the demo. Additionally, the waveguide external module designed and manufactured for the 77 GHz switch will be exhibited. Lastly, measurement results obtained with the microstrip module for the 5G band switch will be presented to demonstrate the switching capabilities of the switches.

8. FINANCIAL EVALUATION:

Table 4: Analysis of the project's costs

REQUIRED EQUIPMENT	QUANTITY	UNIT PRICE	TOTAL PRICE
Electronic Microscope	1	6000 TL	6000 TL
Consumables for Waveguide Module	1	1500 TL	1500 TL

Table-4 specifies the products/items acquired and utilized in the project budget. Consumables for the Waveguide Module, which include materials such as brass alloy and fasteners, are indicated. Additionally, electronic microscopes are used for the examination of the chips on the wafer during the production process.

The production cost of the manufactured 77 GHz SP3T pin diode is determined based on the ratio of the chip area to the total wafer area, considering the production cost of the entire wafer. The estimated production cost is approximately $570.

9. RESULTS:

9.1. Schematic Results

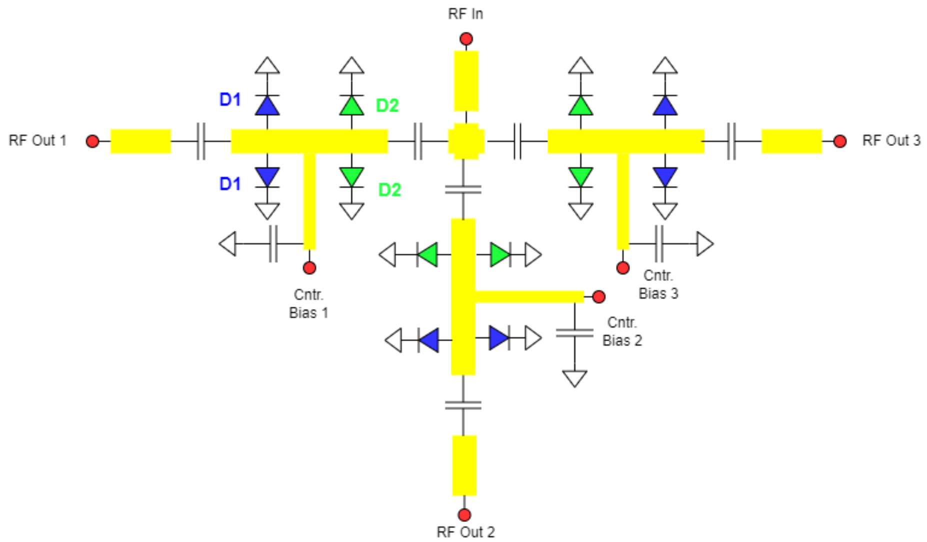

Figure-7 Schematic Design

Since the schematic design of the SP3T MMIC switch design includes too many components and the image is not very clear, a simplified schematic is given in figure-7.

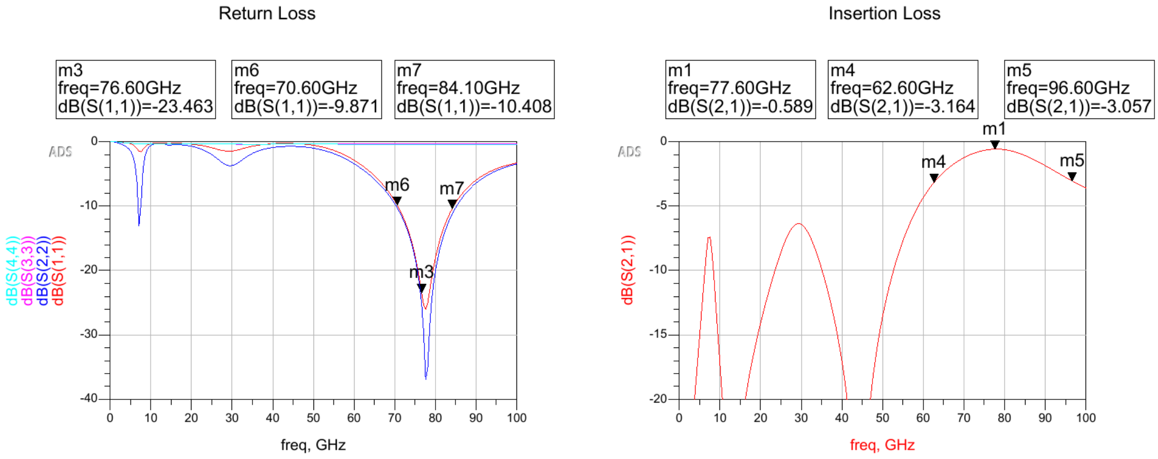

Figure-8 Schematic Design Result Return Loss and Insertion Loss When port-2 Is On State

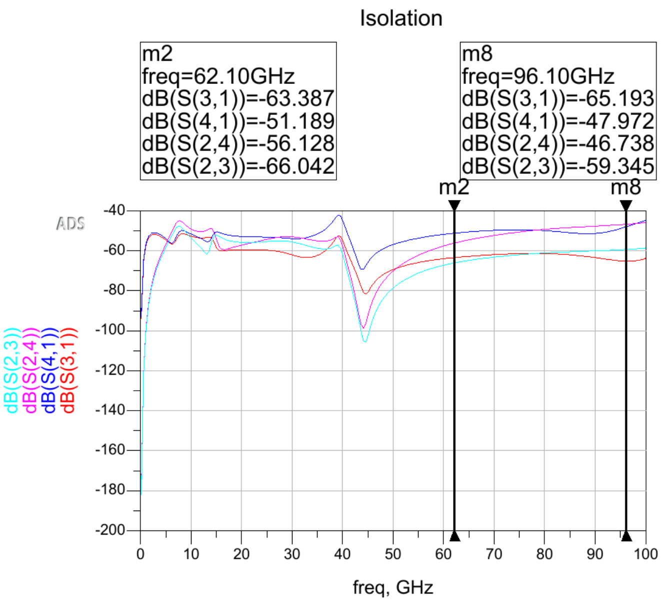

Figure-9 Schematic Design Result Isolation Value When port-2 Is On State

The results obtained in the schematic design, when port-2 is on state, are given in figure-8 and figure-9. Since port2 and port-4 are symmetric, the results of both are taken the same, so only the results of port-2 are included in the report.

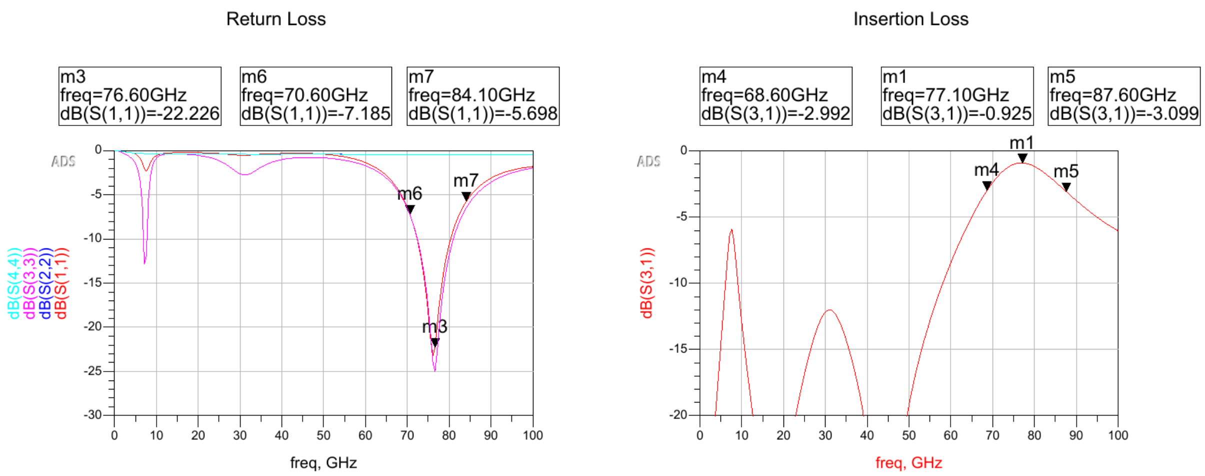

Figure-10 Schematic Design Result Return Loss and Insertion Loss When port-3 Is On State

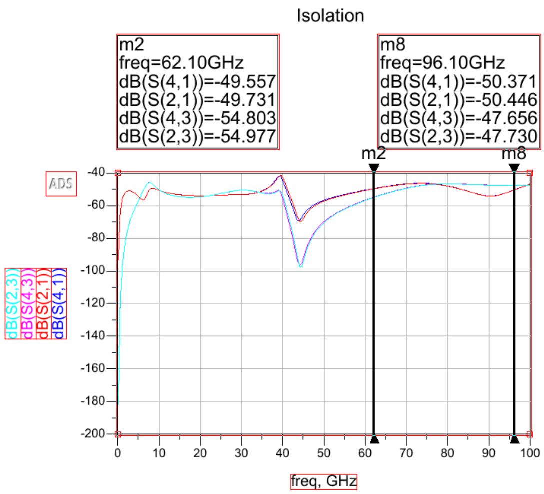

Figure-11 Schematic Design Result Isolation Value When port-3 Is On State

The results obtained in the schematic design when port-3 is on state are given in figure-10 and figure-11.

9.1. Layout Results

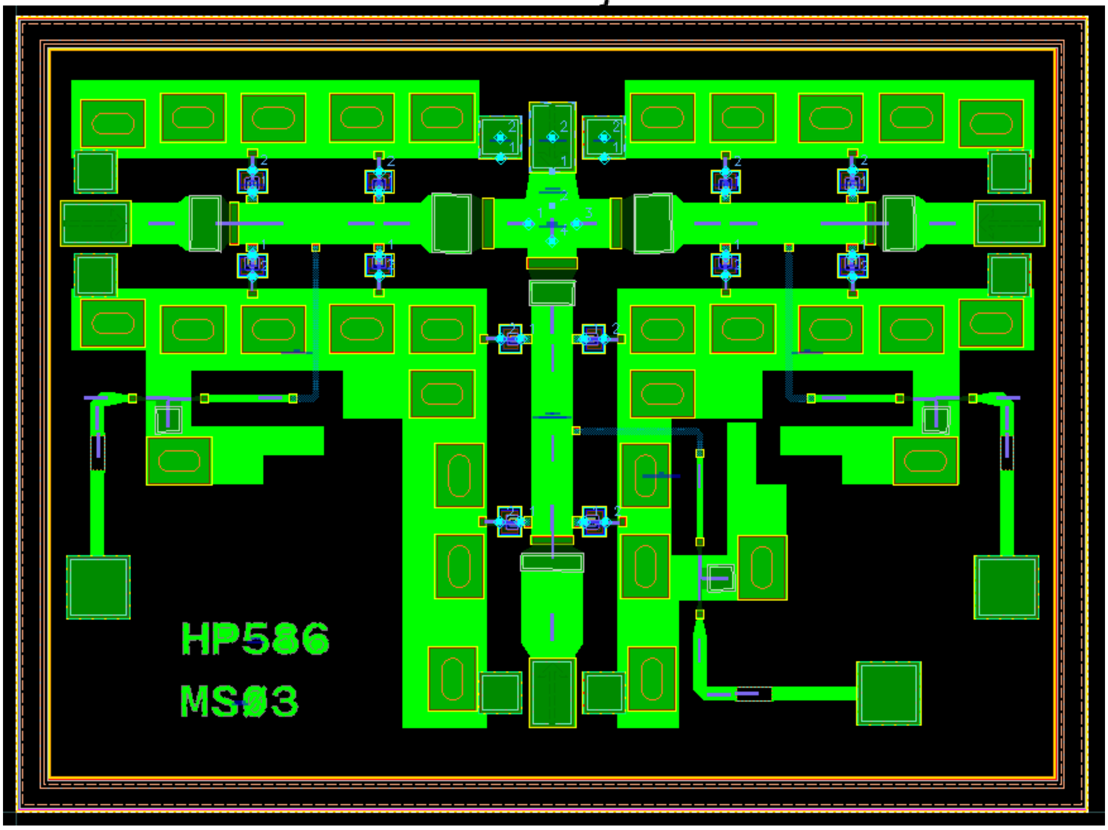

Figure-12 Layout Design of mmWave SP3T MMIC Switch

SP3T switch layout design is as shown in figure-12 (port-2 on the left, port-3 in the bottom middle, and port-4 on the right)

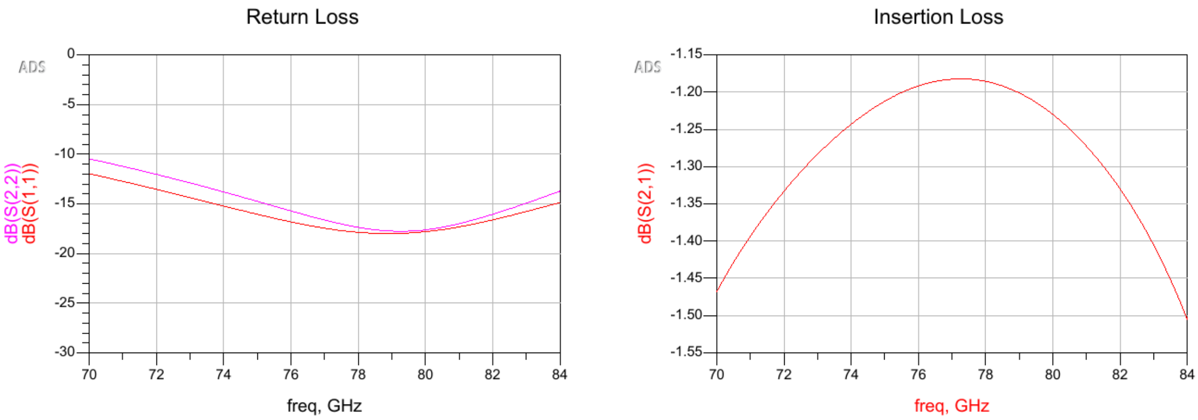

Figure-13 Layout Design Result Return Loss and Insertion Loss When port-2 Is On State

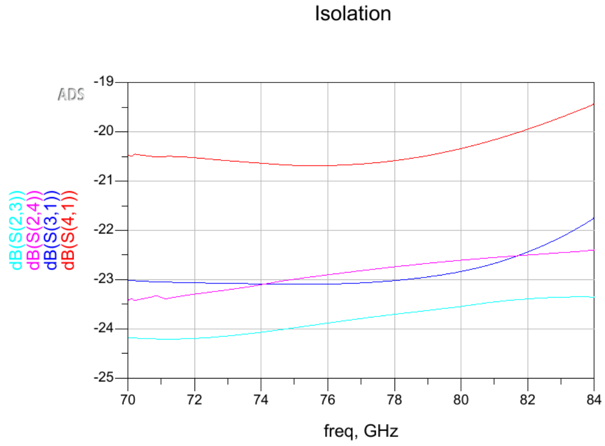

Figure-14 Layout Design Result Isolation Values When port-2 Is On State

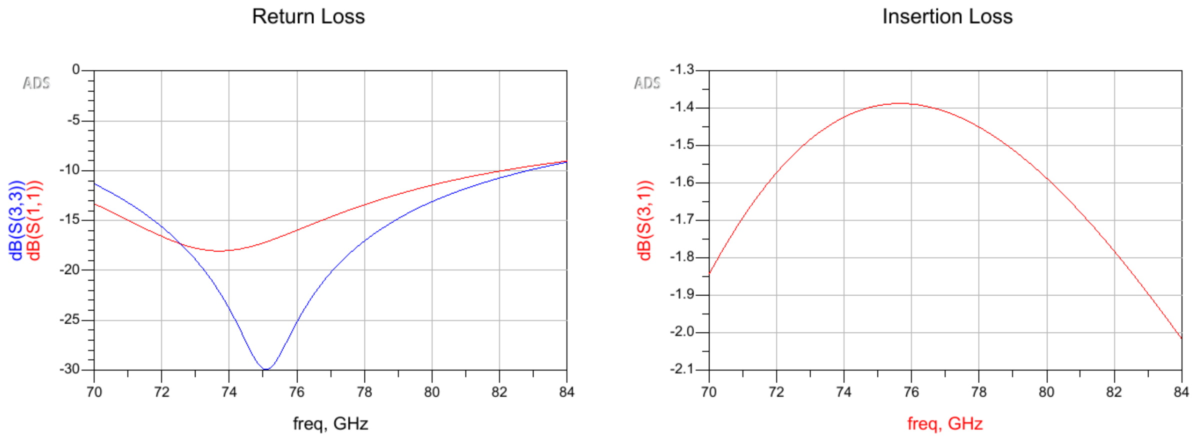

Figure-15 Layout Design Result Return Loss and Insertion Loss When port-3 Is On State

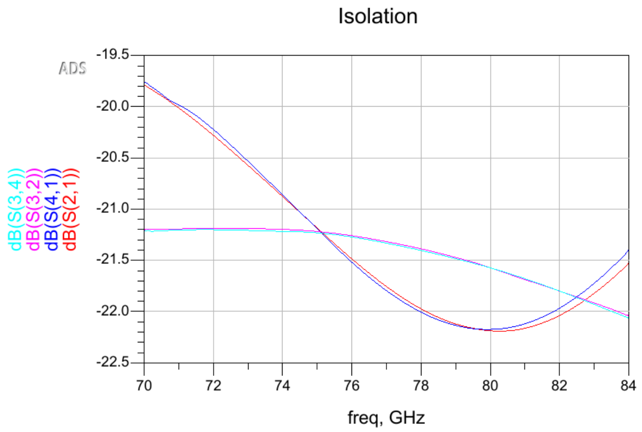

Figure-16 Layout Design Result Isolation Values When port-3 Is On State

Similar to the schematic, since port-2 and port-4 are two symmetrical ports, only the results for port-2 are included. The on-state results of port-2 are given in figure-13 and figure-14. Layout simulation results with port-3 on state are shown in figure-15 and figure-16.

As a result, it is clearly seen both in the schematic results and in the layout results that the Insertion Loss value is less than 2 dB, the Return Loss value is greater than 13 dB, and an insulation value over 20 dB is provided.

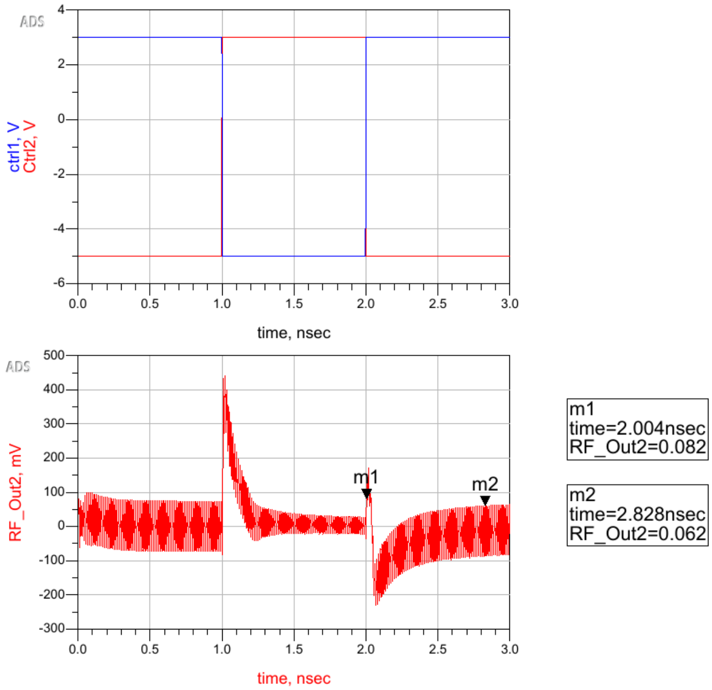

Figure-17 Switching Speed Simulation

The switching speed of the MMIC chip was measured to be approximately 1ns in the schematic simulation environment of ADS after replacing the DC supplies with square wave signal generators, as shown in the Figure 17. In this measurement, the voltage level difference between the ON and OFF states of the switch is not significant because a square wave signal generator is used, and the impedance value differs from the DC supply, causing a mismatch in the circuit. However, this does not hinder the determination of the switching speeds of the diodes present in the circuit.

9.3. Waveguide Module Result

A waveguide module has been designed for the purpose of obtaining measurements of the produced SP3T switch. The design of this module is illustrated in Figure 18.

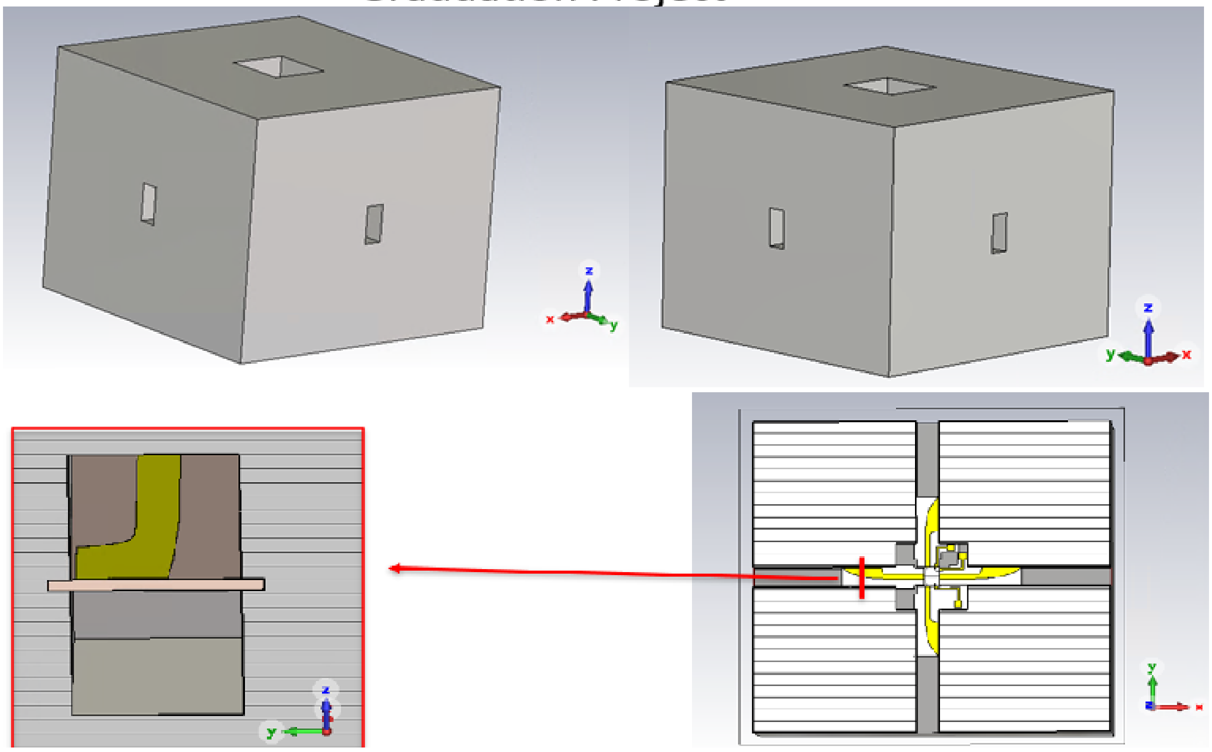

Figure-18 Waveguide Outer Module

In the simulation of this design, the SP3T switch was not directly integrated. This was due to the limitations of the CST program in MMIC analysis, and the inaccuracies associated with adding S-parameters using discrete ports at high frequencies. Instead, a 50-ohm transmission line was designed using GaAs material of the same dimensions as the chip switch. Furthermore, the design incorporates gold bond wires to transition from the 50-ohm line to a microstrip line designed with Rogers 5880 material. The signal is then converted to the waveguide through Vivaldi antennas. The transmission line in the GaAs material, serving as a replacement for the designed Vivaldi antennas and chip, is depicted in Figure 19.

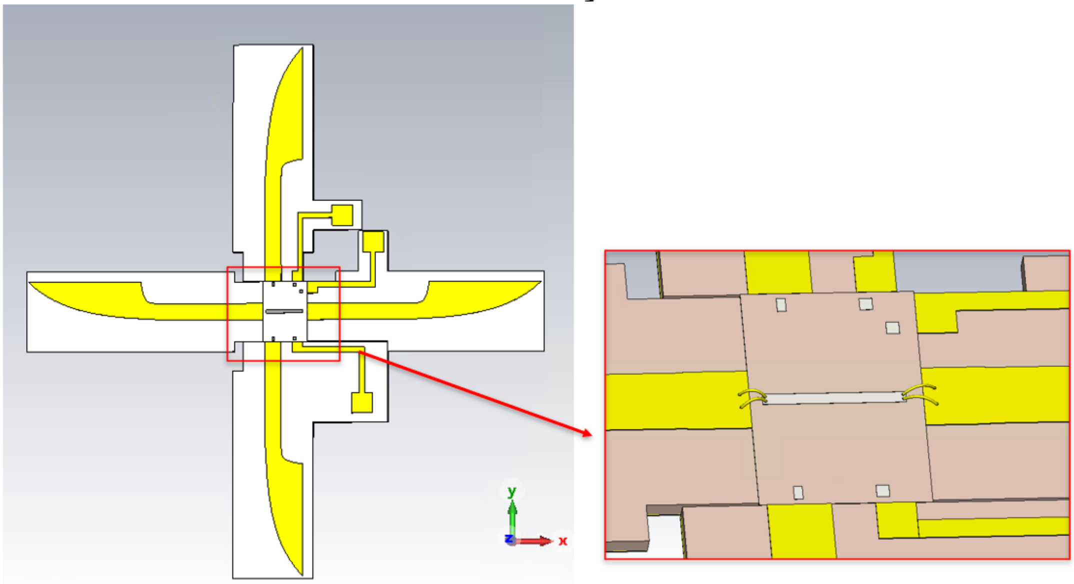

Figure-19 Rogers 5880 PCB and GaAs Z0 Ohm microstrip Components

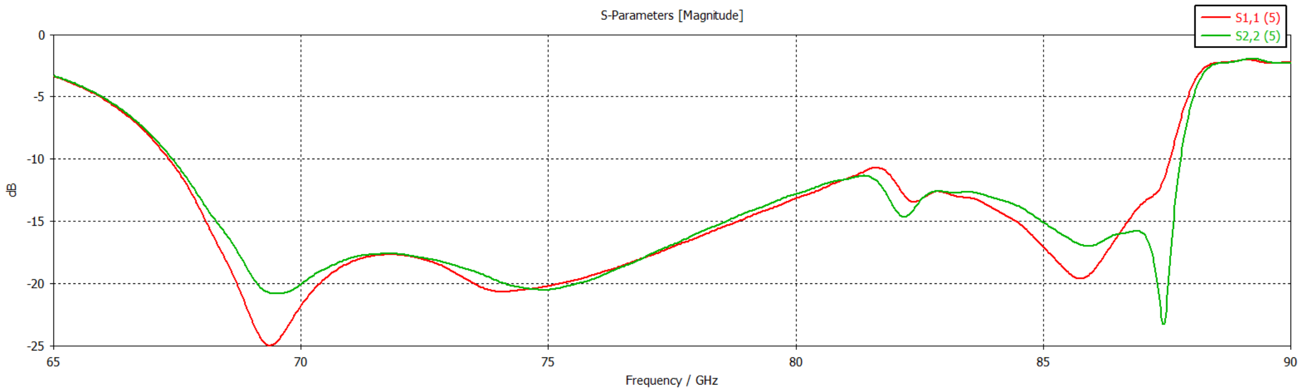

Figure-20 Waveguide Module Return Loss

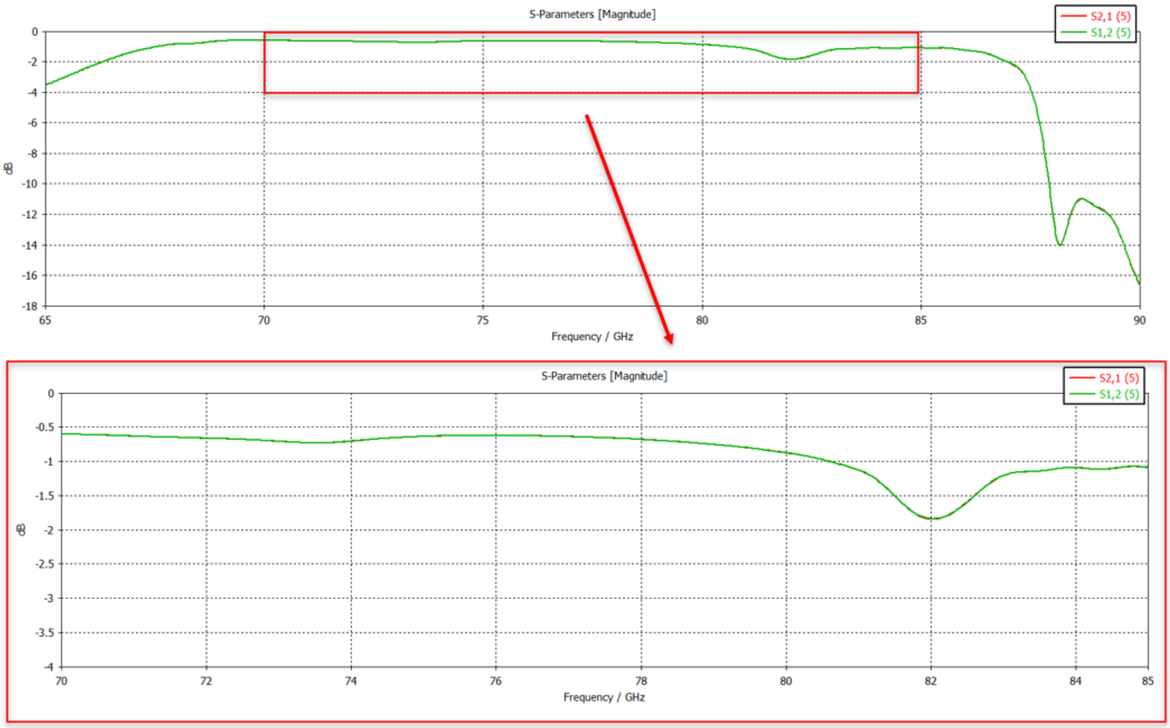

Figure-21 Waveguide Module Insertion Loss

The return loss results shown in Figure-20 and the insertion loss results shown in Figure-21 demonstrate the broad bandwidth and low loss characteristics of the designed waveguide module at these high frequencies. The length of the bond wires has a significant impact on these results. If there is excessive spacing between the chip and the Rogers5880 material, the long bond wires will introduce additional inductance, which can negatively affect the system's performance. However, this issue does not pose a significant problem for chip measurement, as before measuring the chip, a 50-ohm GaAs line will be placed instead of the chip in order to measure the loss values of the module. By subtracting these losses from the measurement results, only the measurements of the chip can be obtained.

The waveguide module, manufactured using a brass alloy, is presented in Figure 23 after production.

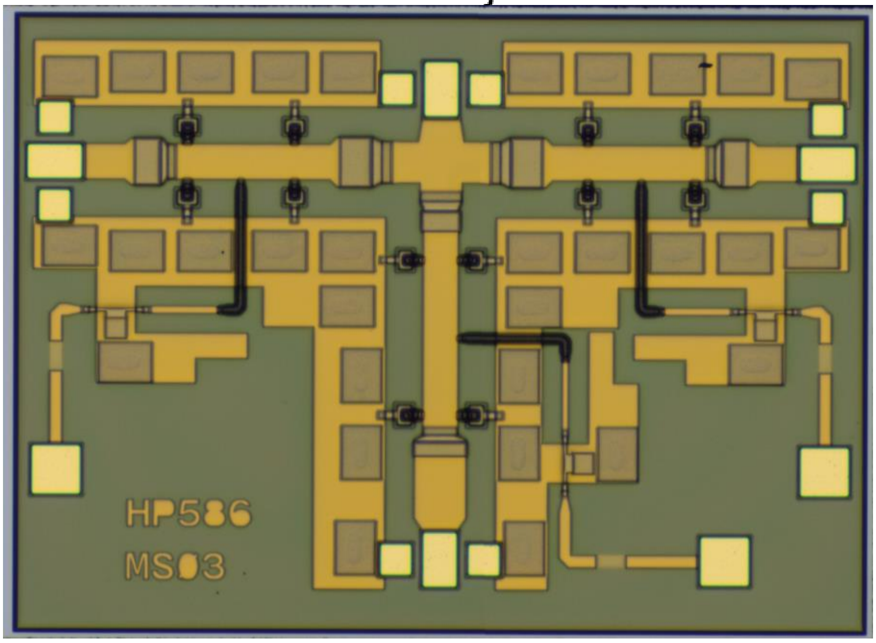

Figure-22 Manufactured 77GHz SP3T chip.

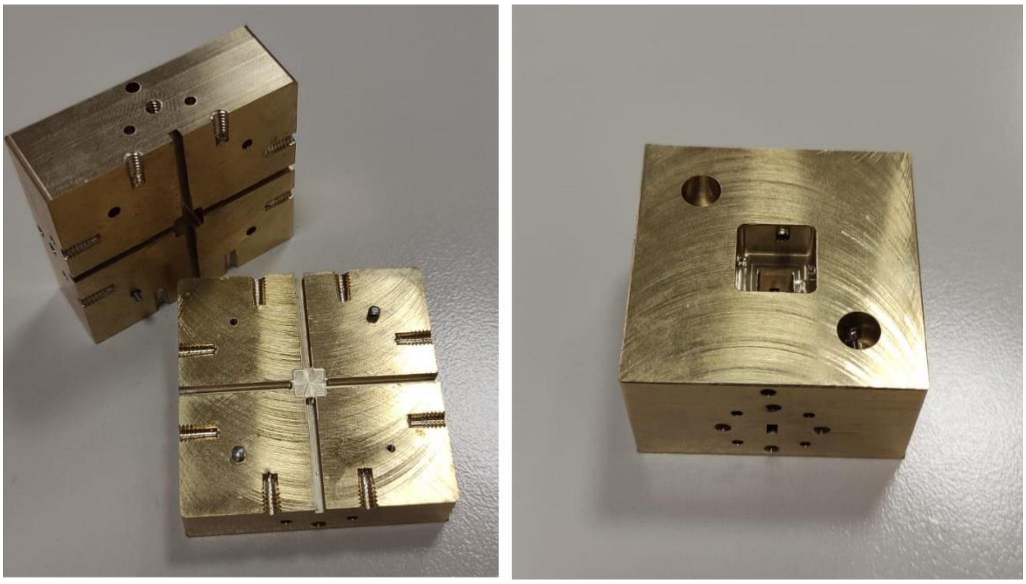

Figure-23 Manufactured Brass Waveguide

9.4. 5G Band SP3T Switch Results

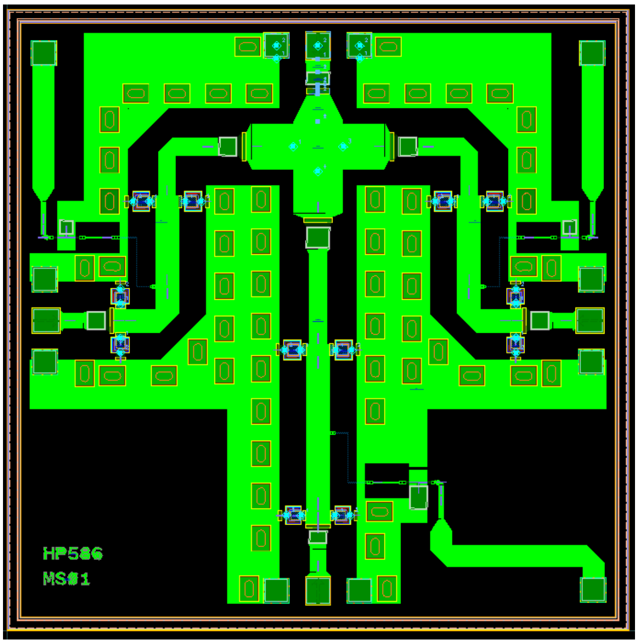

Figure-24 Layout Design of 5G SP3T Switch

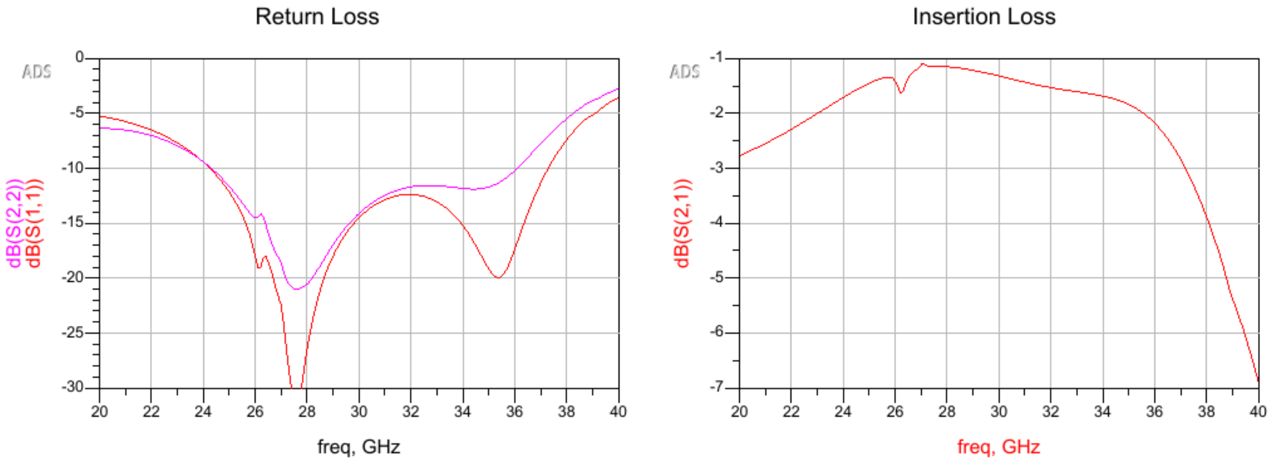

Figure-25 13 Layout Design Result Return Loss and Insertion Loss When port-2 Is On State

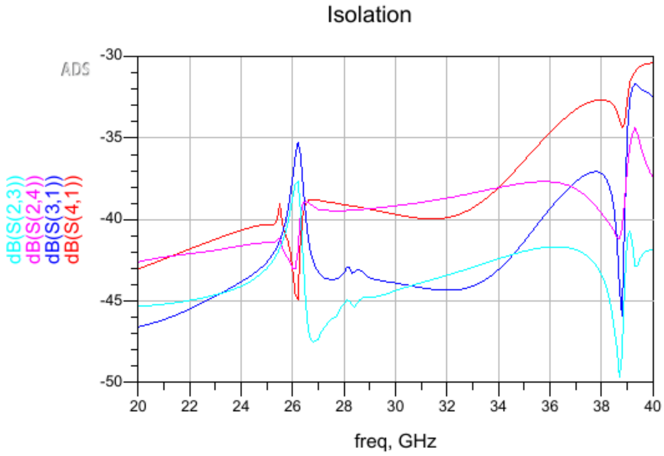

Figure-26 Layout Design Result Isolation Values When port-2 Is On State

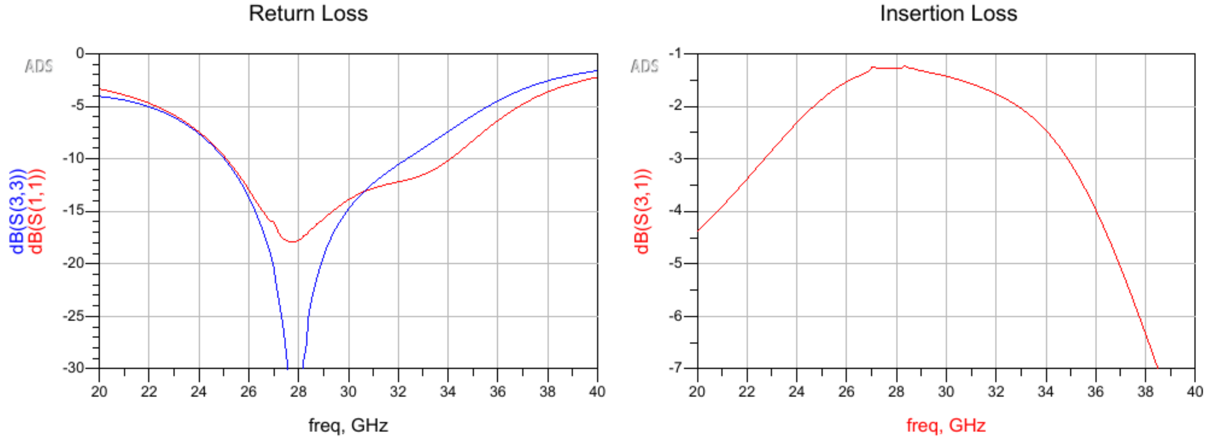

Figure-27 Layout Design Result Return Loss and Insertion Loss When port-3 Is On State

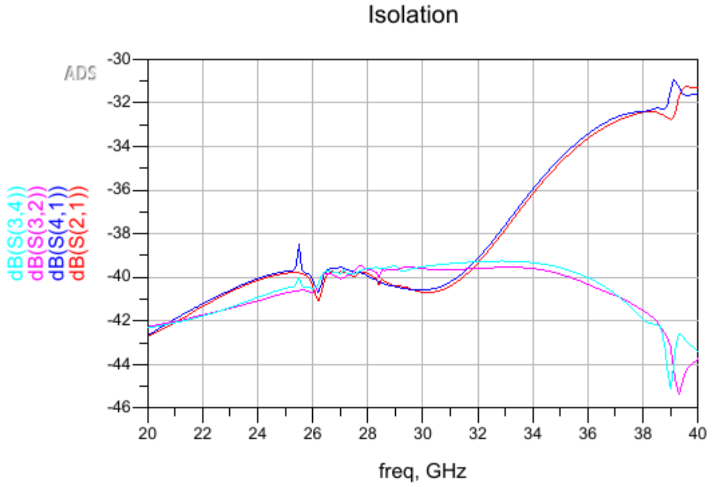

Figure-28 Layout Design Result Isolation Values When port-3 Is On State

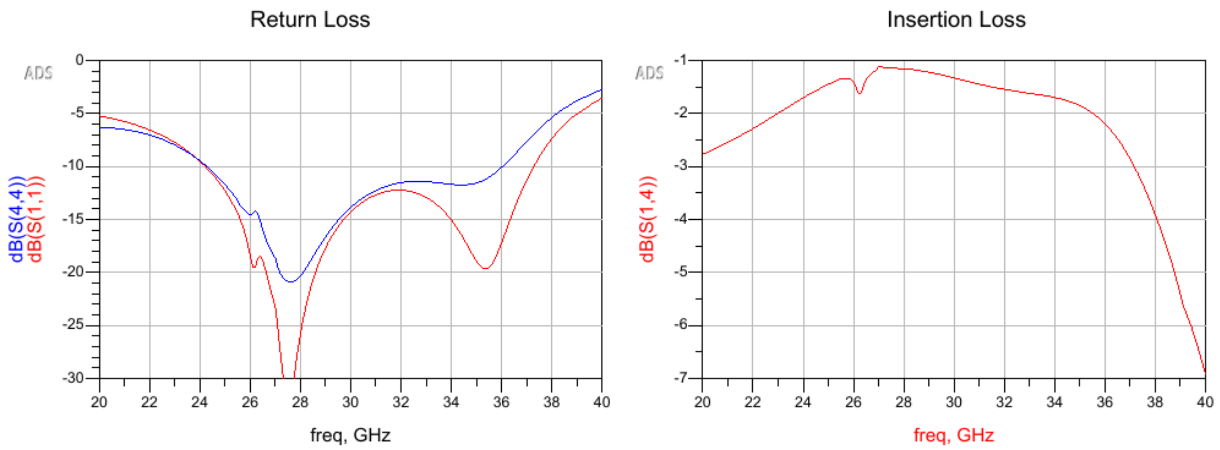

Figure-29 Layout Design Result Return Loss and Insertion Loss When port-4 Is On State

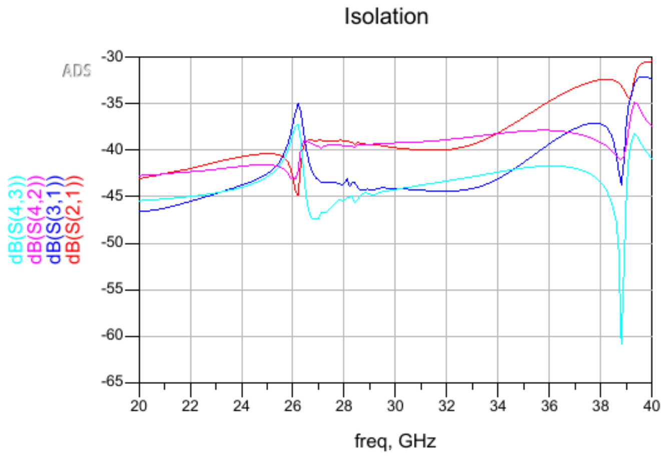

Figure-30 Layout Design Result Isolation Values When port-4 Is On State

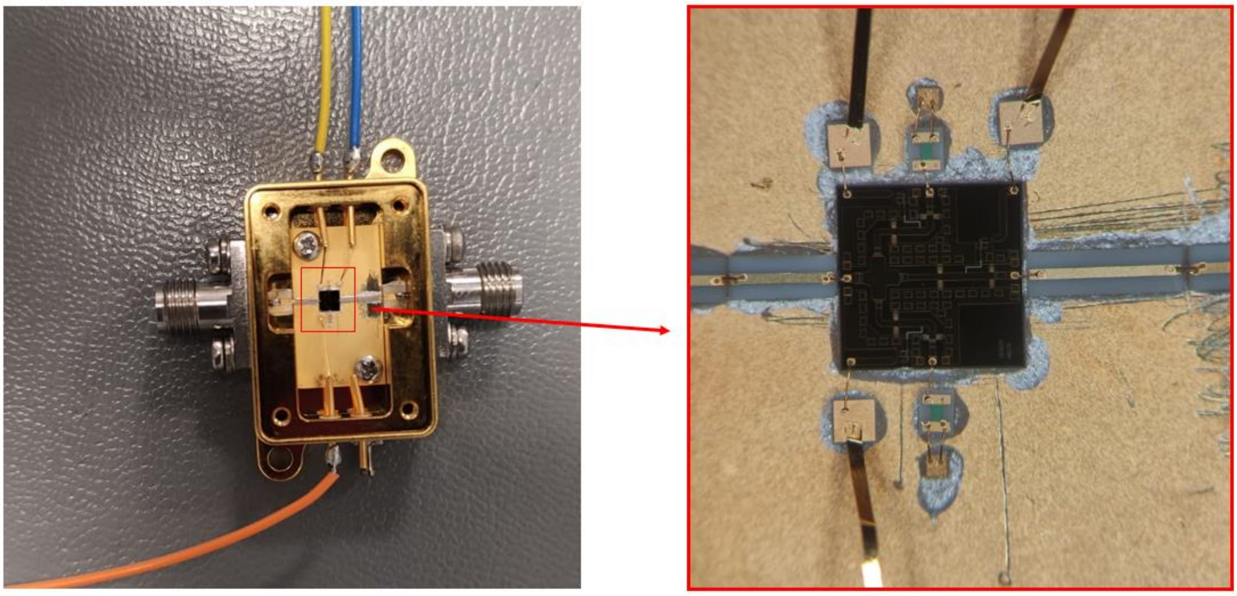

Figure-31 5G Band SP3T Switch Inside Microstrip Module

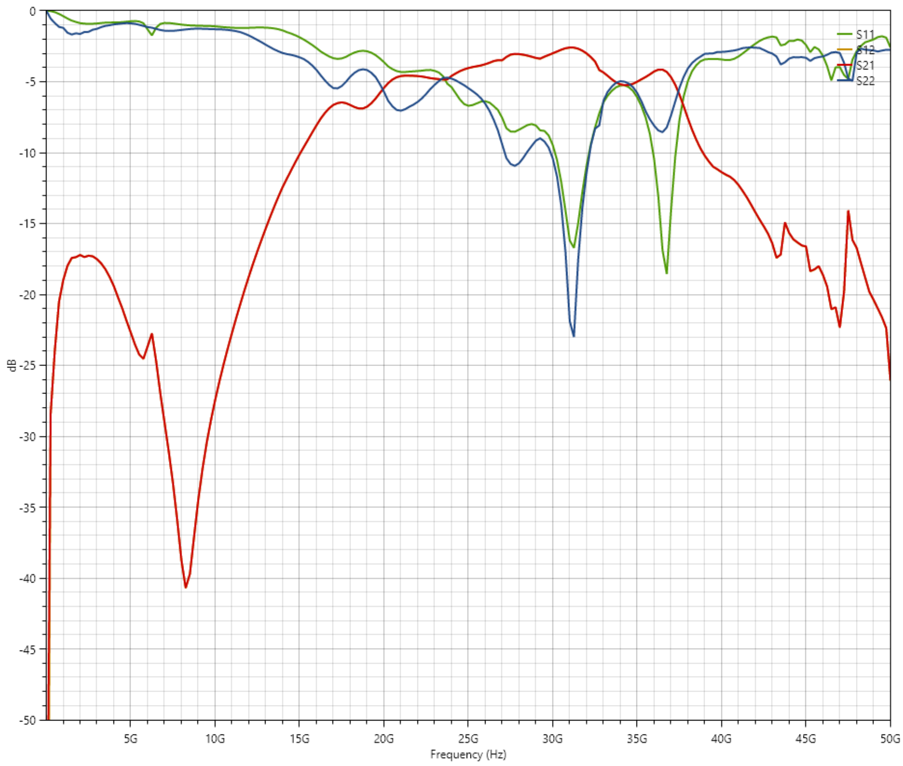

Figure-32 5G Band SP3T Switch Inside Module Measurement When Port-2 is On State

Figure-33 5G Band SP3T Switch Inside Module Measurement When Port-2 is Off State

10. DISCUSSION:

The schematic and layout results given in section-9 show that in both the schematic and layout findings, it is evident that the Insertion Loss value is less than 2 dB, the Return Loss value is larger than 13 dB, and an insulation value greater than 20 dB is provided. In other words, when compared to Table-1's results, the designed SP3T mmWave switch performed as well as or better than the majority of research in the literature. The production and delivery of the chip designed for the 77 GHz band were also successfully completed. However, due to the unavailability of 75 µm RF probes required for the measurement of the SP3T design, it was decided to obtain measurements in waveguide form. An additional waveguide module was designed for the chip, where the RF ports of the chip are transitioned to the microstrip line using bond wires and then converted to the waveguide form through Vivaldi antennas. The dimensions of the waveguide were selected according to the WR-12 standard, as it provides waveguide mode support within the 60 to 90 GHz range. The external module, made of brass, was manufactured using a CNC machine. However, the design including the microstrip line for transitioning the chip to the waveguide and the Vivaldi antennas could not be produced due to the unavailability of PCB prototyping machines at both TÜBİTAK MİLTAL and İstanbul Medipol University, where the production was planned to be carried out. Consequently, measurement results for the SP3T switch designed for the 77 GHz band could not be obtained.

As an alternative, measurements were performed on another designed SP3T switch operating in the 5 GHz band, using a module that incorporates microstrip lines. The simulation results and measurement results after integration into the module for the 5 GHz band switch are presented in Section 9.4. There is an insertion loss of approximately 3 dB between the simulation and measurement results in Section 9.4. This can be attributed to the direct connection of the chip to the module using bond wires and 50-ohm lines until the connector. The inductive effect of bond wires causes a clockwise rotation of the matching on the Smith chart when directly connected to the 50-ohm lines, indicating a significant mismatch caused by the module designed for the chip. However, despite these challenges, the measurement results clearly demonstrate that the chip performs the switching operation and provides satisfactory results despite the mismatch. In conclusion, the simulation results of the chip designed for the 77 GHz band meet the project objectives, and it has been decided to publish a study based on this work after obtaining measurement results with the completion of the waveguide external module at the beginning of the master's degree.

11. CONCLUSION:

The set targets at the beginning of the project, such as the schematic and layout simulation results, have been successfully achieved. These targets include Frequency Range: 76-78 GHz, Insertion Loss < 2 dB, Return Loss > 13 dB, Isolation > 20 dB, Switching Speed < 80 ns. Moreover, the project has also been successful in finding more than 4 similar studies for comparison through literature review and producing over 10 chips. Additionally, an additional waveguide structure was designed for measuring the 77 GHz switch, and the brass alloy part of the structure was manufactured. However, there were difficulties encountered during PCB production, specifically in laser processing, which prevented the measurement process from being completed until the end of the project. As a result, an alternative approach was taken, where a different SP3T switch designed for the 5G bands was measured inside a module using microstrip lines and bond wires. A comparison of the measurement results with the simulations revealed some degradation. Nevertheless, this degradation is expected and natural for a module that was produced without direct calculation, taking into account the inductance effect of numerous repeated bond wires within the module. Despite this degradation, the obtained results indicate that the produced chips closely align with the simulation results and exhibit high performance. Throughout the project, valuable experience has been gained in various areas, including MMIC design, circuit design involving nonlinear components, accurate implementation of electromagnetic simulations, waveguide module design, antenna design for chips, and chip measurements. Although the measurements for the 77 GHz chip have not been fully completed, it has been decided to finalize them during the upcoming master's degree program and proceed with publication.

12. PLAN FOR FUTURE STUDIES:

After completing the design of the waveguide module, the plan is to manufacture the PCB parts using Rogers 5880 and then use the module to measure the chip operating in the 77 GHz band. Additionally, measurements of the other three different pin diode switches will be taken. The results obtained from all four designed chips will be used to publish a research paper.

13. ASSESSMENT OF ENGINEERING COURSES:

The information obtained from the applied microwave, introduction to RF and microwave, electronics-1, signal system and circuit courses are used during the project.

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15. PROJECT ACTIVITIES AND WORK PLAN

Table 4 *The Work-Activity Plan for Project 1*

Work and Activity Project 1	**Responsible Group Member**	**Timeline**													
		1. week	2. week	3. week	4. week	5. week	6. week	7. week	8. week	9. week	10. week	11. week	12. week	13. week	14. week
1. Determine Design Target Parameters	İbrahim														
2. Schematic Design and Simulation	İbrahim														
3. Layout Design and Simulation	İbrahim														
4. DRC & Final Checks Before Manufacture	İbrahim														
4. Presentation	İbrahim														

Table 5 *The Work-Activity Plan for Project 2*

Work and Activity Project 2	**Responsible Group Member**	**Timeline**													
		1. week	2. week	3. week	4. week	5. week	6. week	7. week	8. week	9. week	10. week	11. week	12. week	13. week	14. week
1. Manufacture of The Chip	WIN Semic.														
2. Determine how and where the measurement will be made	İbrahim														
3. Designing the Chip Bias Supply	İbrahim														
4. Manufacture the WG module & chip bias feed structure	İbrahim														
5. Measurements	İbrahim														
6. Presentation	İbrahim														

16.1 LIST OF WORK PACKAGES

Table 6 *Detailed Definition of Work and Activity*

WP No	Detailed Definition of Work and Activity
1	Determine Design Target Parameters
2	Simulation of Schematic Design
3	Simulation of Layout Design
4	Manufacture of Chips
5	Manufactured Chip measurement

Table 7 *Work package targets, their assessment, and the contribution of each work package to the overall project success.*

Work package	Target	Measurable outcome	Contribution to overall success(%)
1	search the literature	find at least 4 similar studies to compare	10%
2	Simulation of Schematic Design	Frequency Range:76-78 GHz, Insertion Loss<2 dB, Return Loss>13 dB, Isolation>20 dB	20%
3	Simulation of Layout Design	Frequency Range:76-78 GHz, Insertion Loss<2 dB, Return Loss>13 dB, Isolation>20 dB, Switching Speed<80 ns	30%
4	Manufacture of Chips	obtaining more than 10 chips	20%
5	Manufactured Chip measurement	Frequency Range:76-78 GHz, Insertion Loss<2 dB, Return Loss>13 dB, Isolation>20 dB, Chip Size<1.6x1.6 mm^2,	%20
			Total:100

Table 8 *The work package distribution to project team members: Who works on which work package? Specify the percentage contributions.*

WORK PACKAGE DISTRIBUTION					
Project Member	WP1	WP2	WP3	WP4	WP5
İbrahim Taha Gökce	100%	100%	100%	100%	100%
Total	100%	100%	100%	100%	100%

17. BUDGET

Table 9 *Proposed Budget in TL*

	ITEMS				
	PEOPLE	MACHINE-INSTRUMENT	MATERIALS	SERVICE	TRAVEL
IMU FUND					
SPONSOR COMPANY FUND			Electronic Microscope, Vacuum Tweezers Tip Kit		
TOTAL			7500		

Table 10 *Actual Budget in TL (what you spent indeed)*

	ITEMS				
	PEOPLE	MACHINE-INSTRUMENT*	MATERIALS*	SERVICE	TRAVEL
IMU FUND		Electronic Microscope, Dremel ve Dremel Seti			
SPONSOR COMPANY FUND			Waveguide Material, PCB material		
TOTAL		8192	7500		

18. CURRICULUM VITAE

İBRAHIM TAHA GÖKCE

Küçüklüğümden beri yeni şeyler araştırmayı, keşfetmeyi ve edindiğim bilgileri kullanarak ürünler ortaya çıkarmayı büyük bir haz duyarak yapmaktayım. Büyük bir ilgi ve sevgi duyduğum mühendislik alanında kendimi geliştirerek yerli ve milli projelere katkıda bulunabilmek en büyük hedefimdir. Üniversite 1. sınıfta okulda ilk düzenli proje grubunun kurucu üyelerinden oldum. 2. sınıfta ise Takım kaptanlığı yaparak takımım ile birden fazla yarışmaya katıldım. 3. sınıfta ise yarı zamanlı olarak TÜBİTAK Bilgem'de yarı zamanlı bursiyer araştırma görevlisi olarak çalıştım. Proje takımlarında edindiğim bilgiler ve deneyimler ile takım çalışmasına yatkın ve yenilikçi düşünebilen bir takım üyesi olduğumu söyleyebilirim.

KİŞİSEL

İsim
İbrahim Taha Gökce

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Doğum yeri
Aydın

Cinsiyet
Erkek

Diller

Türkçe ★★★★★
İngilizce ★★★

İlgi Alanları

- Entegre Devreler
- Robotik
- Hava Araçları
- Gömülü Yazılım

Projeler

Tem 2022 - Ağu 2022
Stajer
ASELSAN REHİS, Ankara
Güç Yükselteç & MMIC Tasarımı

Eyl 2022 - Haz 2022
Bursiyer Araştırma Görevlisi
TÜBİTAK Bilgem, Kocaeli/Gebze
Verilog, System Verilog ile Sayısal Devre Tasarımı

Eki 2021 - Kas 2021
Stajer
TÜBİTAK Bilgem, Gebze
TÜTEL Sayısal Devre Tasarımı

Şub 2021 - Ağu 2021
TÜBİTAK 2247-C Stajyer Araştırmacı Burs Programı (STAR)
Görüntü/Video İşlemede Ters Problemlerin Derin Öğrenme ile Modelden Bağımsız Çözümü

May 2021 - May 2021
Takım Kaptanı
Boğaziçi Robot Kupası Drone Kategorisi'nde Birincilik

Oca 2021 - Eyl 2021
Takım Kaptanı
TEKNOFEST Uluslararası İnsansız Hava Aracı Yarışması Finalistliği (Döner Kanatlı)

Şub 2020 - Tem 2020
Aerodinamik Grup Lideri
TEKNOFEST Uluslararası İnsansız Hava Aracı Yarışması (Sabit Kanatlı)

Şub 2020 - Tem 2020
Görüntü İşleme
TEKNOFEST Tarım Teknolojileri

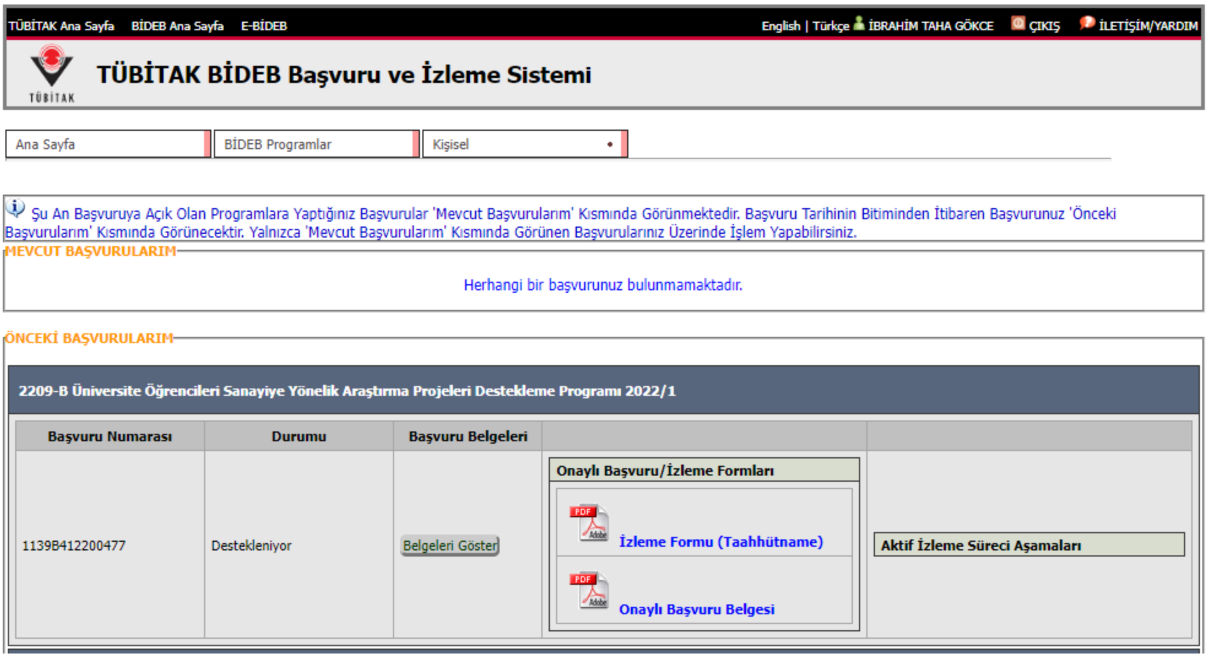
Eğitim ve Nitelikler

Eyl 2018 - Halen
Mühendislik ve Doğa Bilimleri Fakültesi
İstanbul Medipol Üniversitesi, İstanbul/Beykoz
Elektrik ve Elektronik Mühendisliği (Tam Burslu), Sınıf:4, GANO: 3,53

Eyl 2014 - Tem 2018
Nazilli Anadolu Lisesi, Aydın/Nazilli

Istanbul Medipol University
School of Engineering and Natural Sciences
Graduation Project

SUPPORT LETTERS (if any)



TÜBİTAK Ana Sayfa BİDEB Ana Sayfa E-BİDEB English | Türkçe İBRAHİM TAHA GÖKCE ÇIKIŞ İLETİŞİM/YARDIM

TÜBİTAK BİDEB Başvuru ve İzleme Sistemi

Ana Sayfa | BİDEB Programlar | Kişisel

Şu An Başvuruya Açık Olan Programlara Yaptığınız Başvurular 'Mevcut Başvurularım' Kısmında Görünmektedir. Başvuru Tarihinin Bitiminden İtibaren Başvurunuz 'Önceki Başvurularım' Kısmında Görünecektir. Yalnızca 'Mevcut Başvurularım' Kısmında Görünen Başvurularınız Üzerinde İşlem Yapabilirsiniz.

MEVCUT BAŞVURULARIM

Herhangi bir başvurunuz bulunmamaktadır.

ÖNCEKİ BAŞVURULARIM

2209-B Üniversite Öğrencileri Sanayiye Yönelik Araştırma Projeleri Destekleme Programı 2022/1

Başvuru Numarası	Durumu	Başvuru Belgeleri		
1139B412200477	Destekleniyor	Belgeleri Göster	Onaylı Başvuru/İzleme Formları: İzleme Formu (Taahhütname); Onaylı Başvuru Belgesi	Aktif İzleme Süreci Aşamaları