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# Single Sideband Mixer

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# Abstract

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This thesis presents the design, fabrication, testing, and verification of a Single Sideband (SSB) mixer circuit composed of two Double Sideband (DSB) mixers, two 90-degree hybrids, and a Wilkinson. The study aimed to demonstrate the circuit's efficacy in modulating and demodulating RF signals with precise sideband suppression, laying the groundwork for advancements in RF communication technology.

The circuit design was accomplished using NI MWO AWR software, leveraging its simulation capabilities to ensure optimal performance. The DSB mixers were strategically chosen to generate upper and lower sidebands, combined using 90-degree hybrids to attain the desired single-sideband modulation. A Wilkinson was integrated to ensure effective power distribution to the DSB mixers.

The designed circuit was fabricated using a microstrip technology printed circuit board (PCB) substrate. The fabrication process involved milling and soldering techniques, ensuring precise component placement and interconnections.

The testing involved utilizing VNA, Signal generators, and Spectrum analyzers to analyze the circuit's frequency and phase response, sideband suppression, and conversion efficiency.

The experimental results validated the successful generation of single-sideband signals with a suppressed carrier and a single sideband, demonstrating the efficacy of the designed SSB mixer circuit. The insights gained from this project contribute to a deeper comprehension of SSB modulation techniques and practical RF circuit implementation.

## Contents

Appendices

## List of Abbreviation

AC Alternating Current

AM Amplitude Modulation

AWR Applied Wave Research

BLH Branch Line Hybrid Coupler

BPF Band Pass Filter

CG Conversion Gain

CL Conversion Loss

dB Decibels

dBm Decibels per milliwatt

DBM Double-balanced Mixer

DC Direct current

DSB Double Side Band

FM Frequency Modulation

IC Integrated Circuit

IF Intermediate Frequency

ISM Industrial, Scientific, and Medical

LO Local Oscillator

LSB Lower Side Band

MLIN Microstrip Line

MSUB Microstrip Substrate

MWO Microwave Office

NF Noise Figure

NI National Instruments

PCB Printed Circuit Board

PM Phase Modulation

QAM Quadrature amplitude modulation

RF Radio Frequency

SBM Single-Balanced Mixer

SSB Single Sideband Mixer

USB Upper Side Band

VNA Vector Network Analyzer

# 1 Introduction

An essential source of innovation in the area of communication systems is the study of modulation and demodulation techniques. One method that works well for maximizing utilization and improving transmitter and receiver efficiency is single-sideband (SSB) modulation and demodulation. SSB modulation is an essential technique in applications where bandwidth conservation is crucial, since it reduces information by delivering one sideband in addition to the carrier signal.

SSB modulation lies on the SSB mixer, which combines principles with engineering expertise. This thesis focuses on an exploration of the SSB mixer correlated to a symphony involving two Double Sideband (DSB) mixers, two 90-degree hybrids, and a power divider. The focus of this study lies in arranging DSB mixers as catalysts for generating either upper sideband or lower sideband. The interaction between two 90-degree hybrids ultimately leads to Single Sideband modulation and demodulation. To ensure power distribution among components, a power divider comes into play creating an environment where collaborative harmony flourish.

The journey described in this thesis is a transformation, from ideas to physical reality. The NI AWR Microwave Office software provides a platform where theoretical designs are carefully conceived and optimized. This digital method prepares the components for milling, soldering, printed circuit board (PCB) assembly, and testing with measuring instruments like spectrum analyzers, vector network analyzers, and signal generators. The completion of this journey represents the validation of a self-designed SSB mixer, a testament to both intellectual ability and precise craftsmanship. This thesis incorporates the aspect of the journey delving into the design, development, and validation of the SSB mixer, which brings about a modulation and demodulation that reacts through modern communication channels.

## 2 Single-Sideband Mixer

A Single-Sideband (SSB) Mixer is a type of mixer used in Radio Frequency and microwave systems for the modulation or demodulation of single-sideband signals. Single-sideband modulation or demodulation is a technique that transmits or receives only one of the sidebands (either upper or lower) of the modulated signal, which can be more efficient in terms of bandwidth utilization compared to double-sideband (DSB) modulation.

A single sideband (SSB) mixer is designed to suppress the other sideband, while producing or extracting only the upper sideband (USB) or lower sideband (LSB). By combining a local oscillator signal with an input RF or IF signal, the process converts frequencies. After mixing, a frequency-shifting operation is applied to remove one of the sidebands. Filtering can also be used to further suppress the unwanted sideband.

The Radio Frequency signal ($\omega_{RF}$) and the Intermediate frequency signal ($\omega_{IF}$), when combined with $\omega_{LO}$, the two different RF input signals with frequencies $\omega_{RF} = \omega_{LO} \pm \omega_{IF}$ will down-convert to the same IF frequency. The upper and lower sidebands of a double-sideband transmission are these two frequencies. Assuming a positive IF frequency, the desired response can be chosen arbitrarily as either the USB ($\omega_{LO} + \omega_{IF}$) or the LSB ($\omega_{LO} - \omega_{IF}$). These two replies can be separated into distinct output signals using the image reject mixer, which is depicted in Figure 1. The same circuit is commonly referred to as a single-sideband modulator when it is utilized for up-conversion. In this case, the IF input signal is received by the IF hybrid's USB port or LSB, and the mixer's RF port generates the appropriate single-sideband signal. We can use the small-signal approximation to investigate the image reject mixer. The RF input signal be expressed as

$$v_{RF}(t) = V_{USB} cos(\omega_{LO} + \omega_{IF})t + V_{LSB} cos(\omega_{LO} - \omega_{IF})t \qquad (1)$$

Where $V_{USB}$ and $V_{LSB}$ stand for the upper and lower sideband amplitudes, respectively. [14, 637-650.]

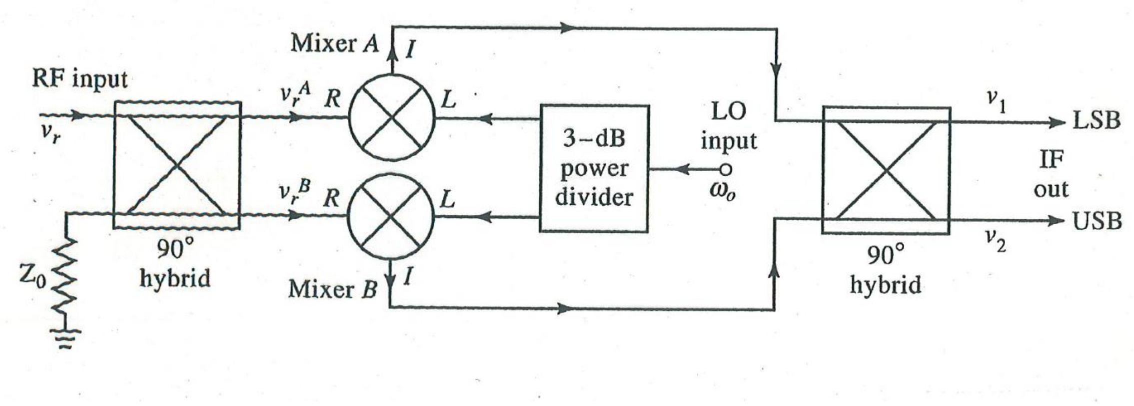

Figure 1. The Architecture of an SSB Mixer.

As Figure 1 depicts SSB mixer consists of two DSB Mixers, Wilkinson power divider, $3dB\ \ 90°$ BLH and lumped element $3dB\ \ 90°$ hybrid coupler.

The time-domain representation of the Upper Sideband (USB) of an SSB signal is a real-valued sinusoidal waveform. It can be expressed in the mathematical equation as follows:

$$V_{USB}(t) = A_{USB} * \cos\left[2\pi(f_{LO} + f_{IF})t + \Phi_{USB}(t)\right] \tag{2}$$

Where:

- $V_{USB}(t)$ represents the time-domain signal for the Upper Sideband.
- $A_{USB}$ is the amplitude of the USB.
- $f_{LO}$ is the carrier frequency.
- $f_{IF}$ is the Intermediate Frequency.
- $\Phi_{USB}(t)$ represents the phase of the USB signal.

In this representation, the USB signal is a real-valued cosine waveform centred at the frequency $(f_{LO} + f_{IF})$ with an amplitude $A_{USB}$. The $90°$ hybrid is designed to introduce a $90°$ phase shift to one of its output ports ($\Phi_{USB}(t)$ =+$90^0$). [15,70-144.]

The time-domain representation of the Lower Sideband (LSB) of an SSB signal is like that of the USB but with some differences in frequency. It can be expressed as follows:

$$V_{LSB}(t) = A_{LSB} * \cos\,[2\pi(f_{LO} - f_{IF})t + \Phi_{LSB}(t)] \tag{3}$$

Where:

- $V_{LSB}(t)$ represents the time-domain signal for the Lower Sideband.
- $A_{LSB}$ is the amplitude of the LSB.
- $f_{LO}$ is the carrier frequency.
- $f_{IF}$ is the Intermediate Frequency.
- $\Phi_{LSB}(t)$ represents the phase of the LSB signal.

In this representation, the LSB signal is also a real-valued cosine waveform but centred at the frequency $(f_{LO} - f_{IF})$ with an amplitude $A_{LSB}$. The Lower Sideband (LSB) lagging the carrier by 90 degrees $\Phi_{LSB}(t)$ = -90°. [15,70-144.]

## 2.1 Component Selection

DSB Mixers (ZX05-12MH-S+): These are nonlinear devices that mix two input signals, producing sum and difference frequency components at their outputs.

90-Degree Hybrids: These passive devices split an input signal into two equal-amplitude signals with a $90°$ phase shift in between. They were designed at the NI AWR Microwave Office.

Wilkinson Power Divider: An input signal is divided into two output signals with the same amplitudes using this passive device. It was designed in the NI AWR Microwave Office.

## 2.2 Frequency Plan

Varied parts of the world have varied frequency allocations for the ISM (Industrial, Scientific, and Medical) band; nevertheless, a popular frequency range for applications such as RFID (Radio Frequency Identification) is approximately $902MHz\ to\ 928MHz$. Here is the frequency plan:

- Radio Frequency (RF): $f_{LSB} = 902MHz\ and\ f_{USB} = 928MHz$
- Local Oscillator Frequency (LO): $f_{LO} = 915MHz$
- Intermediate Frequency (IF): $f_{IF} = 0MHz - 13MHz$

## 2.3 Single-Sideband Modulation (SSB Modulation)

SSB modulation is a method of encoding information onto a carrier signal. Instead of transmitting both sidebands and the carrier as in double sideband (DSB) modulation, the modulation method involves suppressing one of the sidebands and the carrier, leading to a more bandwidth-efficient transmission. The modulation starts with a carrier signal, typically a high-frequency sine or cosine wave. The baseband signal or the information signal is mixed or multiplied with the carrier signal using a mixer. This process shifts the baseband signal's frequency to the desired RF frequency range, creating a modulated signal. SSB modulation is unique in that it suppresses one of the sidebands (either the USB or LSB) and transmits only the other sideband. A basic message signal and an unmodulated carrier are depicted in Figure 2 below. It also displays the outcome of utilizing SSB-SC to modulate the carrier with the message. You will see that the modulated carrier is not the same frequency as the carrier or the message.

In up-converter transmission, a baseband signal's frequency can be changed to a higher frequency appropriate for transmission via a communication channel using the Single Sideband modulation technique. The modulated baseband signal is combined with a higher frequency carrier signal during the up-conversion process. The mixer's RF port serves as the output and the IF port as the signal input in up-converter applications as it shows in Figure 2. The $f_{RF}$ outputs at both the $f_{LSB} = f_{LO} - f_{IF}$ and $f_{USB} = f_{LO} + f_{IF}$ frequencies are produced by the mixer. These are known as the lower sideband and the upper sideband, respectively. $[18,81 - 85; 14,643 - 650.]$

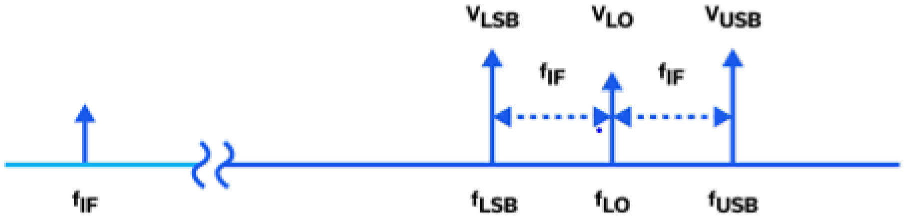

Figure 2. SSB Mixer representation in up converter [10].

The phasing method and the filter method are two methods available to remove one of the sidebands. This study will go over the alternate, phasing approach, which implements SSB modulation using In-phase (I) and Quadrature (Q) mixers. I&Q mixers play a crucial role in achieving phase cancellation to generate the SSB signal.

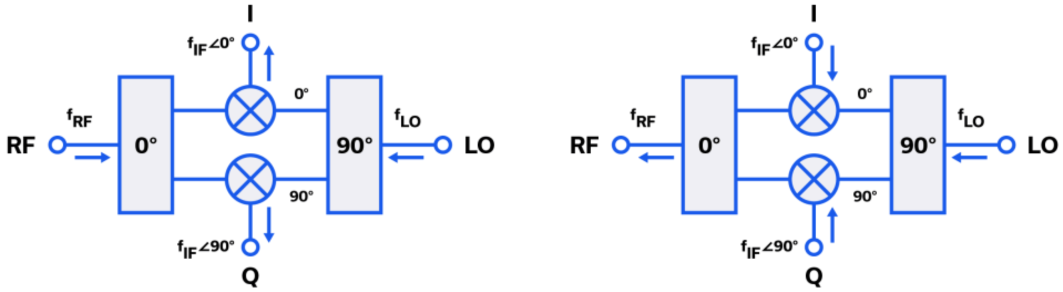

Figure 3. I&Q mixer port configurations down converter (left) and up converter (right) applications [10].

As Figure 3 depicts the mixer transform one RF input into two IF outputs that are 90° out of phase with one another when down-conversion takes place. For up conversion, the opposite is true [10].

## 2.4 Single-Sideband Demodulation (SSB Demodulation)

Extracting the original data from an SSB signal that has been received is a process known as SSB demodulation. Instead of transmitting both sidebands and the carrier as in double sideband (DSB) modulation, the modulation method involves suppressing one of the sidebands and the carrier, leading to a more bandwidth-efficient transmission. A more effective use of the available frequency spectrum is made possible by SSB demodulation, which removes redundant information.

The SSB signal is received by the receiver's antenna and passed through the RF front-end. It has been used phase cancellation instead of filtering to eliminate one of the sidebands and the carrier. The phasing signal is mixed or multiplied with a local oscillator signal at the same frequency as the carrier used during modulation. The resulting baseband signal contains the original information. For voice or audio signals, this is typically the audio signal that can be amplified and sent to a speaker or further processed for data extraction [1].

Single Sideband (SSB) demodulation in a down-converter receiver is the process of extracting the original message signal from an SSB signal that has been received. The received signal's frequency is changed throughout the down-conversion process to either a lower intermediate frequency (IF) or straight to the baseband for additional processing. The RF port serves as the signal input and the IF port serves as the output in down-converter applications as it shows in Figure 4, which may be stated mathematically as $f_{IF} = |f_{RF} - f_{LO}|$ .

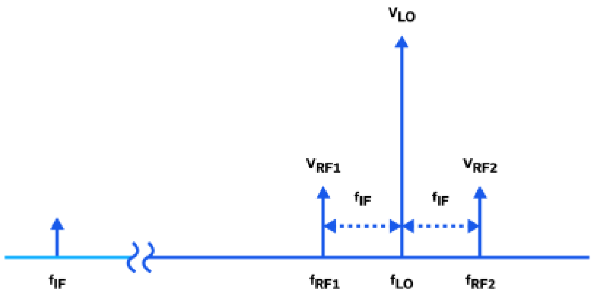

Figure 4. SSB Mixer representation in down converter [10].

# 3 Design and Manufacturing of Single Sideband Mixer

Designing, manufacturing, and assembling a complex RF component like a Single Sideband mixer with internal structures of two DSB mixers, a $90°$ branch line hybrid, a $90°$ hybrid coupler with lumped elements, and a Wilkinson divider is a detailed process that involves multiple steps and considerations.

## 3.1 90-Degree Branch-Line Hybrid Coupler (BLH)

The power can be combined or separated using the $3\ dB\ 90°$ BLH. Two sets of connected output ports with a $90°$ phase difference between them make up this kind of coupler. One input port allows power to enter, which is then split evenly between two output ports. A fourth port is left isolated. Branch line couplers have symmetrical designs, as seen in the following Figure 5:

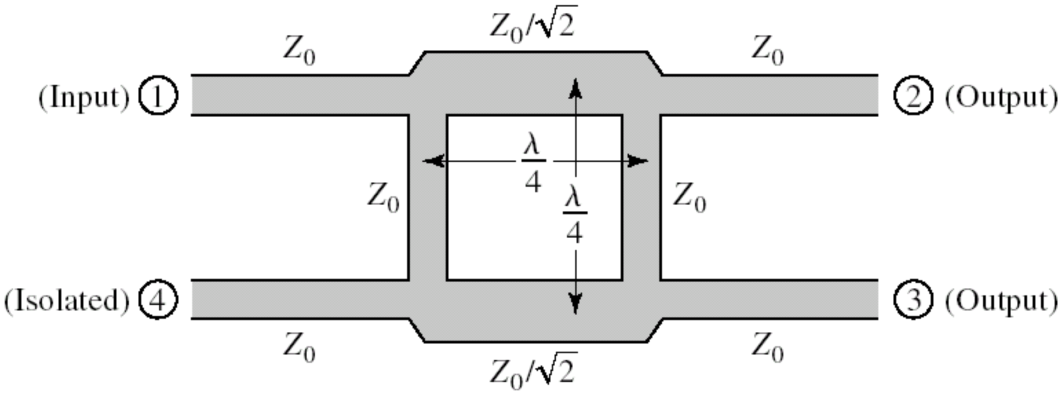

Figure 5. The Geometry of Branch Line Hybrid Coupler [6].

Given that Port 1 is marked as the input port, it follows that the signal or input to the system is applied there. The output ports, designated as 2 and 3, are where the system sends or generates signals, data, or responses. It states that port 4 is isolated.

Microstrip Substrate: The substance holding the conducting strip of a microstrip transmission line is called the microstrip substrate. Supporting the strip and maintaining the space between it and the ground plane are its two main goals. The basic characteristics required to define a microstrip substrate (MSUB) in AWR Microwave Office for the purpose of simulating microwave circuits are listed in the following Table 1. [14,95-157.]

Table 1. The Parameters of Microstrip Substrate.

| **Parameter** | **Symbol** | **Value** | **Description** |
|---|---|---|---|
| Relative Permittivity | $\varepsilon r$ | $4.2$ | This is the substrate material's dielectric constant. It measures how much the electric field strength is reduced inside the material compared to a vacuum. A higher $\varepsilon r$ means the material can store more electric energy. |
| Substrate Thickness | $H$ | $1.6\,mm$ | The thickness of the substrate. |
| Conductor Thickness | $T$ | $0.05\,mm$ | The thickness of the copper top of the substrate. |
| Resistivity | $Rho\ (\rho)$ | $1$ | a basic characteristic of materials that expresses in units of ($\Omega \cdot m$). the degree to which a material resists the flow of electric current. |
| Loss Tangent | $Tand\ (\delta)$ | $0$ | A measurement of the dielectric losses inherent in it. It is the complex permittivity expressed as the imaginary to real part ratio. An optimal dielectric with no loss is indicated by a $Tand = 0$ . |
| Nominal Relative Permittivity | $ErNom$ | $4.2$ | A duplicate of $\varepsilon r$, providing the nominal relative permittivity of the substrate. |
| Name | $Name$ | SUB1 | A user-defined identifier for the substrate definition. |

Microstrip Transmission Line: This is utilized for guiding and transmitting radio frequency (RF) and microwave signals. It is made up of a ground plane on one side and a conductor strip on the other of a dielectric substrate. The width and thickness of this conductor influence the characteristics of the microstrip. The dielectric material between the conductor and the ground plane is known as the substrate. [18, 141-150.]

Characteristic Impedance ($Zo$): The characteristic impedance is a fundamental parameter in the analysis and design of transmission lines and waveguides in RF, microwave, and high-frequency systems. It refers to the effective impedance presented to a signal propagating along the line. [14,343-347;13,115-140.]

### 3.1.1 Schematic of a 90-degree BLH

In the NI AWR Microwave Office, a schematic for BLH is created by configuring components that are already in the tool's library by the design parameters. Creating a schematic on the NI AWR microwave office to define the port numbers, and then plotting the S-parameters to analyze the BLH performance.

Using both a microstrip line calculator and quarter-wavelength calculations helps ensure that the transmission lines in BLH are accurately designed and matched to the desired electrical lengths.

#### 3.1.1.1 Microstrip Line Calculator

Utilizing the microstrip calculator within NI AWR Microwave Office to determine the initial microstrip line width and length for a particular characteristic impedance $(Zo = 50\Omega)$ and electrical length $(Elec. Length = 90°)$. The substrate parameters $(\varepsilon r = 4.2, h = 1.6mm, and\ f = 0.915GHz)$ and the frequency of interest are required. The calculator calculates the initial $width = 3.17mm$ and $length = 45.81mm$ of the microstrip transmission line based on the entered parameters.

### 3.1.1.2 Quarter Wavelength

The quarter-wavelength transformers in BLH are crucial for achieving the desired phase relationships and impedance transformations. To match the characteristic impedance of the transmission lines with the load impedance at the output ports, quarter-wave transformers are utilized. A quarter-wavelength length corresponds to $90°$ of phase shift in an electromagnetic wave.

The length of a quarter wavelength transmission line at a given frequency can be calculated using the following formula. [14,246-249;11,117-127.]

$$L = (\lambda / 4) \tag{4}$$

Where $L$ is length of the quarter-wavelength transformer, $\lambda$ is the wavelength of the signal. $\lambda$ is related to the frequency ($f$), effective dielectric constant ($\varepsilon_{eff}$) and velocity of propagation ($V_p$) by the equation:

$$\lambda = V_p/(f * \sqrt{\varepsilon_{eff}}) \tag{5}$$

To determine the substrate's effective dielectric constant ($\varepsilon_{eff}$) for a microstrip line, the formula that takes into account the influence of the dielectric substrate and the air above the microstrip line is used. The formula is as follows [14,148-150].

$$\varepsilon_{eff} = \frac{(\varepsilon_r+1)}{2} + \frac{(\varepsilon_r-1)}{2}\left(\frac{1}{\sqrt{1+12*\frac{h}{w}}}\right) \tag{6}$$

where:

$\varepsilon r = 4.2$ is the relative permittivity of the substrate.

$h = 1.6mm$ is the height of the substrate,

$W = 3.3mm$ is the width of the microstrip line.

With the provided parameters, the effective dielectric constant ($\varepsilon_{eff}$) for the substrate is computed to be around 3.2.

The center frequency, $f_{LO} = 915\ MHz$.

The velocity of propagation $V_p = 3 * 10^8$

The characteristic impedance, or $Z_0 = 50\ \Omega$.

Substitute the values into the formula $\lambda = V_p/(f * \sqrt{\varepsilon_{eff}})$:

$$\lambda\ =\ (3 * 10^8)\ )\ /(915 *\ 10^6 * \sqrt{3.2})\ \approx\ 183\ mm$$

Finally, calculate the quarter wavelength transmission line length:

$$L\ =\ \lambda/4\ =\ 183/4\ \approx\ 45.8\ mm$$

Each physical length of a quarter wavelength transmission line is $45.8\ mm$. In order to create a $90°$ phase shift between signals at a frequency of $915 MHz$, this length was selected.

Combining these approaches allows to take into account both the material properties and the desired electrical characteristics of the transmission lines in BLH as shown in the following Figure 6.

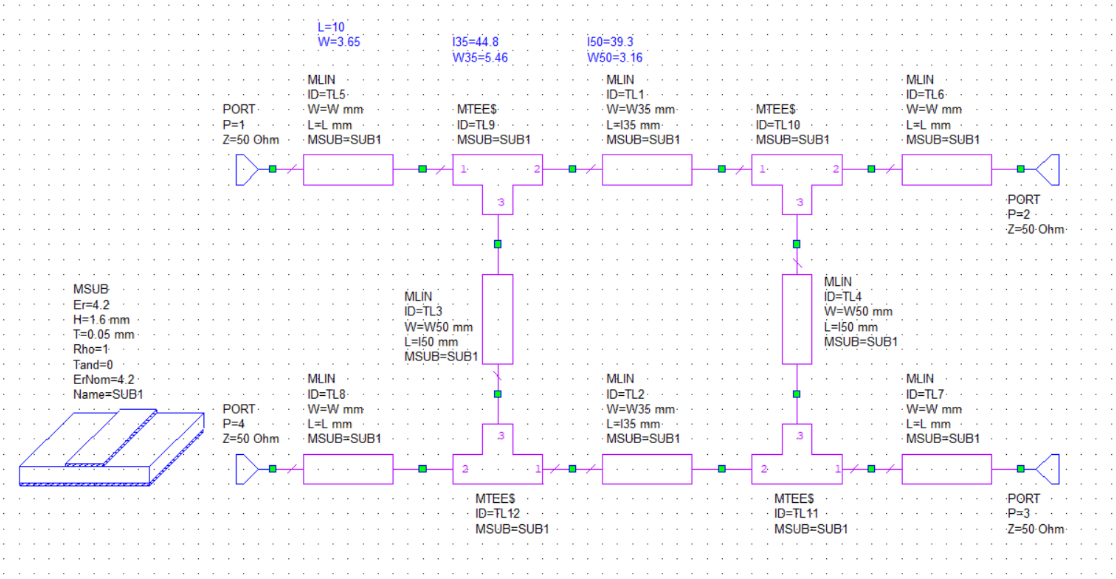

Figure 6. The schematic of BLH.

### 3.1.2 Matching of BLH

When matching BLH, the characteristic impedance and load impedance of the transmission lines must be matched. It is necessary for the power to move from the BLH to the associated loads in an efficient manner. In order to provide the necessary impedance-matching conditions for effective signal transfer, balanced transmission lines are used [14,229-245].

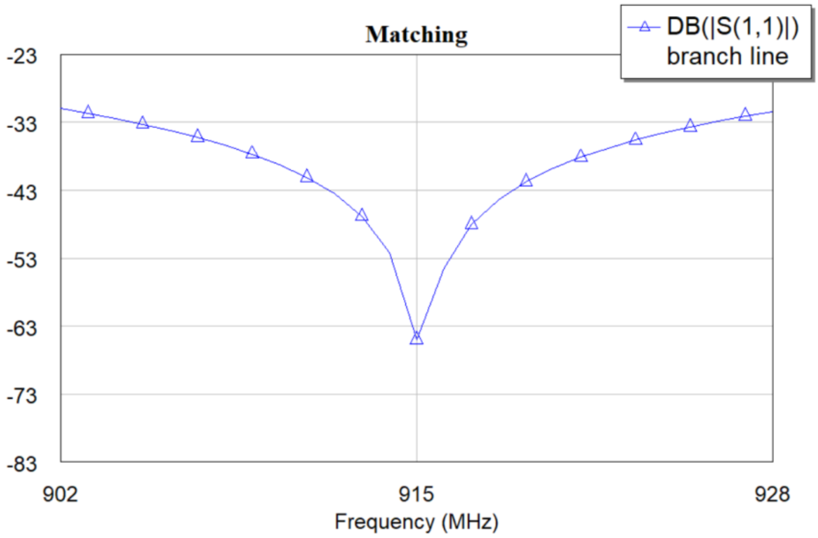

Figure 7. Matching of BLH.

As Figure 7 depicts the matching network has been simulated over the desired frequency range ($902MHz - 928MHz$), effective matching display in the BLH.

### 3.1.3 Isolation of BLH

Isolation refers to the degree to which the signals at one port are isolated or separated from the signals at another port. The isolation property is particularly important in applications where unwanted coupling between different ports can lead to signal interference. Port 4 in the BLH serves as an isolation port, acting as a common point for the two input ports. Its role is to provide isolation between the input ports while serving as a point of commonality. The signals at Port 4 are ideally isolated from the signals at the input ports, contributing to the overall performance of the BLH. [13,117-119.]

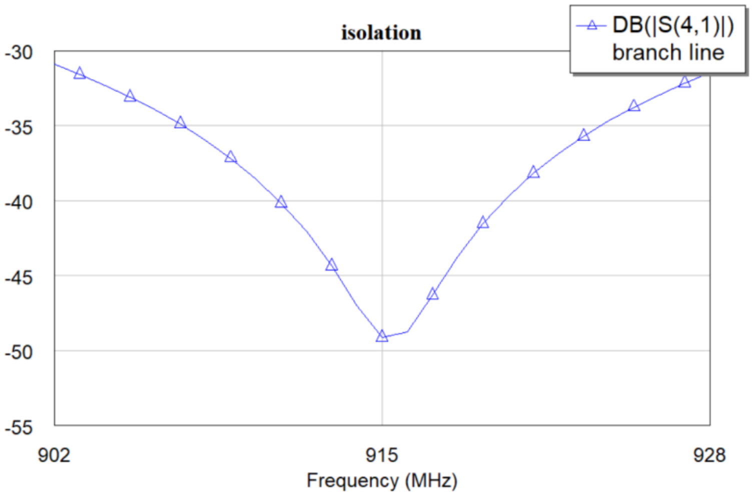

Figure 8. Isolation of BLH.

As Figure 8 depicts the isolation network has been simulated over the desired frequency range ($902MHz - 928MHz$), almost an effective isolation display in the BLH.

### 3.1.4 Power Division of BLH

Power division in a $3\ dB, 90°$ BLH describes the distribution of input power among the output ports. The two output ports (Ports 2 and 3) of the BLH are intended to receive a 3 dB power split. This indicates that if the power given to the input port (Port 1) is $P_{in}$, then the power produced at each output ports (Port 2 and Port 3) is roughly $P_{out} = P_{in}/2$. Using equation (7), the conversion loss mathematically calculated for a 3 dB loss, you substitute $\mathit{C}\mathrm{onversion\ loss(dB)} = 3dB$ into the formula and solve for the ratio $\frac{\mathrm{P_{in}}}{\mathrm{P_{out}}}$ [13,117-127].

$$\mathrm{Conversion\ loss(dB)} = 10 * \log 10\left(\frac{\mathrm{P_{in}}}{\mathrm{P_{out}}}\right) \tag{7}$$

Finally, the calculation result shows $\frac{\mathrm{P_{in}}}{\mathrm{P_{out}}} = 2$.

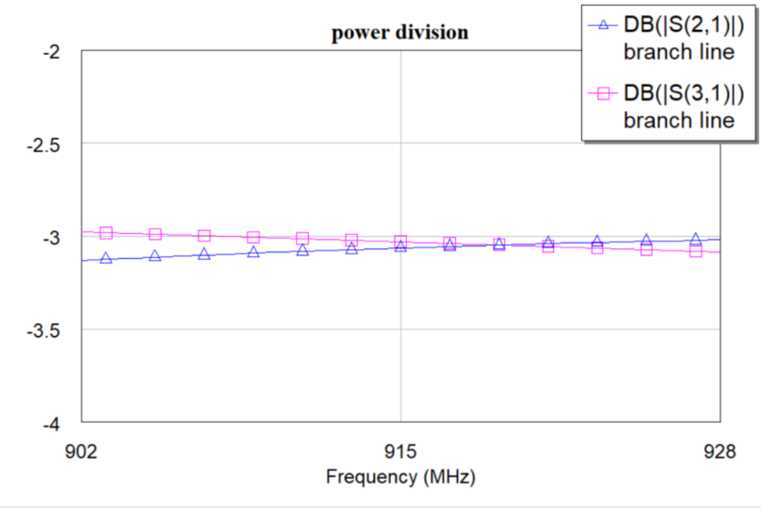

Figure 9. Power division of BLH.

As Figure 9 depicts the power division in the $3\ dB, 90°$ Branch-Line Hybrid (BLH) are aligning with expectations, with $S_{21}$ and $S_{31}$ meeting around 915MHz. This suggests that the power is being appropriately divided between the two output ports $S_{21}$and $S_{31}$ as intended.

### 3.1.5 Phase Difference of BLH

The ability of a 3 dB, 90° BLH to split an input signal into two equal output signals with a 90° phase difference is one of its primary characteristics.

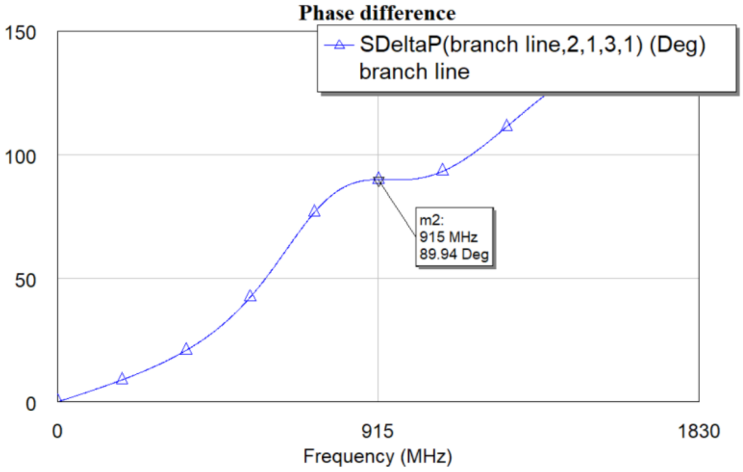

Figure 10. The phase difference of BLH.

As Figure 10 depicts the results, which show that viewing $S_{21}$ and $S_{31}$ resulted in a phase difference of $89.94^\circ$ between ports 2 and 3. When $S_{21}$ and $S_{31}$ are subtracted, the phase difference of $89.94^\circ$ is obtained, which is very near to the ideal $90^\circ$ phase shift only $0.06\%$ more than the ideal $90^\circ$ phase shift. For practical purposes, the minor difference of $0.06^\circ$ from the ideal value is acceptable.

### 3.1.6 Layout and Fabrication of BLH

The layout and fabrication of BLH involve designing the physical structure of the circuit on a PCB based on a design created in the NI AWR Microwave Office as shown in Figure 11.

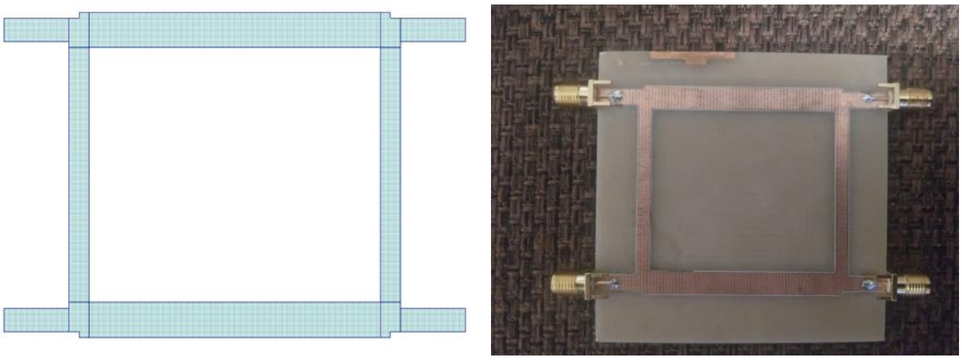

Figure 11. The layout and fabricated BLH.

## 3.2 Lumped Element 90-Degree Hybrid Coupler

A lumped element $3dB$, $90^\circ$ hybrid coupler is used at lower frequencies, built using discrete components, such as capacitors and inductors, and size made relatively compact to divide an input signal into two equal output signals with a phase difference of $90^\circ$. The power division at the output ports is typically designed to be $3dB$, meaning that each output receives half of the input power [7].

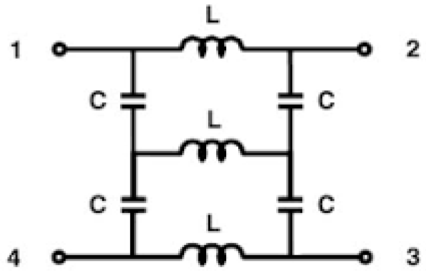

Figure 12. A lumped element hybrid coupler circuit [7].

As Figure 12 depicts the block diagram of lumped element design involving specific passive components (capacitors, inductors) configured in a way to achieve the desired power division and phase shift characteristics.

### 3.2.1 Schematic of Lumped Elements 90-Degree Hybrid Coupler

The schematic of a lumped element hybrid coupler designed with a center frequency of 13 MHz using NI AWR Microwave Office represents a compact and efficient solution for achieving signal splitting and combining with a $90°$ phase difference. This design leverages lumped passive components, including capacitors and inductors, to create a functional microwave circuit.

Utilize the microstrip calculator within NI AWR Microwave Office to determine the initial width and length of the microstrip line for a given characteristic impedance $(Zo = 50\Omega)$ and electrical length or vice versa. The substrate parameters $(\varepsilon r = 4.2\ and\ h = 1.6mm)$ and the frequency of interest are required. The calculator calculates the initial $width = 3.17mm$ and $length = 3224.08mm$ of the microstrip transmission line based on the entered parameters.

The initial step in synthesizing the nominal values of inductors and capacitors involved utilizing the equations provided to determine appropriate component values for a lumped-element hybrid coupler. Specifically, equation $L = Z_O/2\pi f$ was used to calculate the value of the inductor (L) required for the design, resulting in $612\ nH$. Subsequently, equation $C = 1/2\pi f Z_O$ was used to calculate the value of the capacitor (C), resulting in $245\ pF$. Both equations were applied using the given characteristic impedance ($Z0 = 50\,\Omega$) and frequency ($f = 13\,MHz$) to derive these nominal component values. [14,228-233 ;13,69-95.]

Initial values for the inductor ($L = 612\,nH$) and capacitor ($C = 245\,pF$) were chosen, through iterative simulations, adjustments were made to the values of inductors and capacitors to optimize the matching of the circuit components. The final adjusted values for the inductor ($L = 660\,nH$) and capacitor ($C = 220\,pF$) were determined to meet the desired specifications and achieve optimal performance as shown in Figure 13. The adjusted values were chosen to align with the characteristics of specific components, such as 0805 S-Series Capacitors and Wire Wound High Q Chip Inductor.

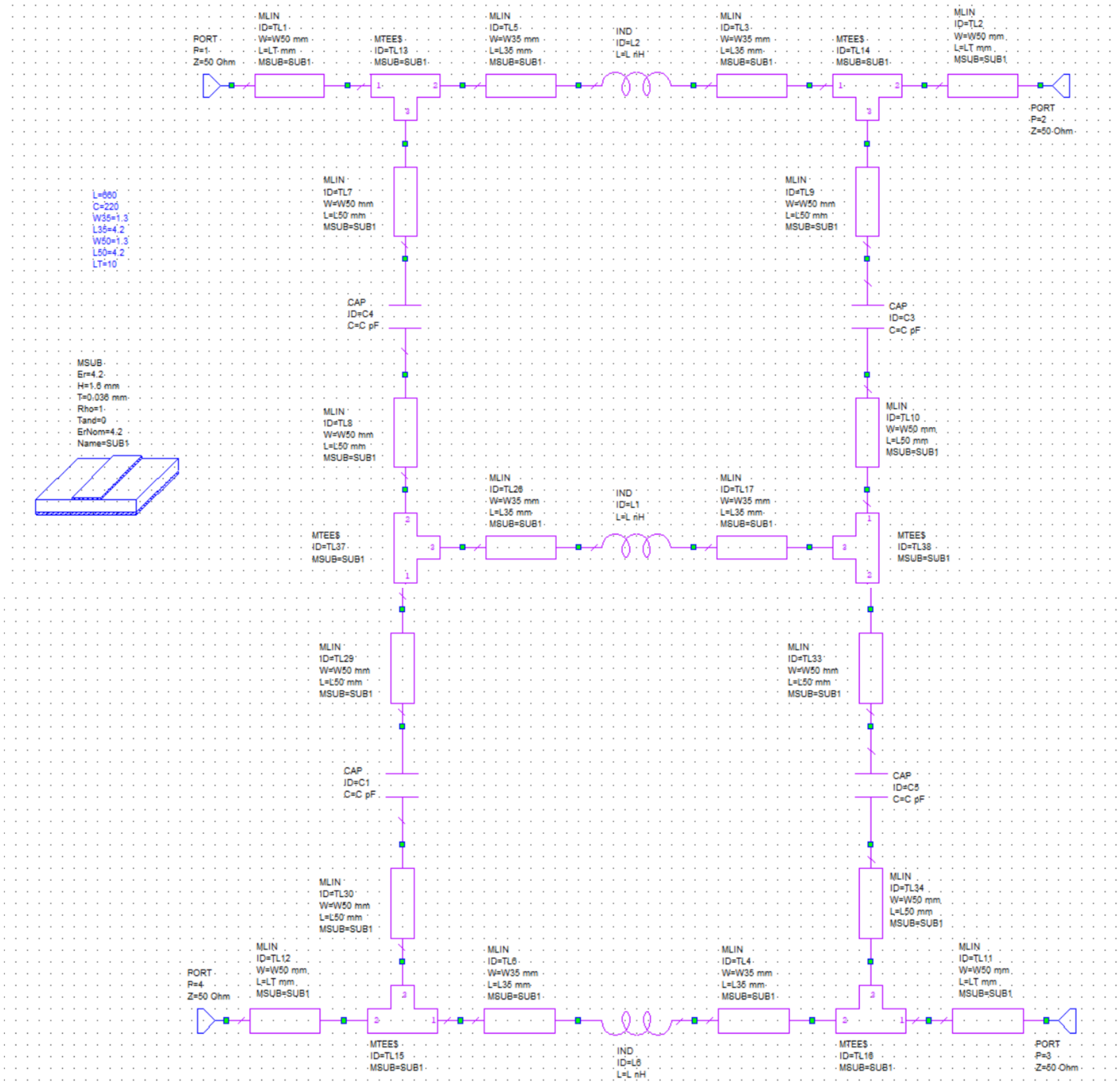

Figure 13. The Schematic of Lumped Elements Hybrid Coupler.

### 3.2.2 Matching and Isolation of Lumped Element Hybrid Coupler

Matching ($S_{11}$) and isolation ($S_{41}$) are critical parameters in the design and performance assessment of a lumped element hybrid coupler. This design is very sensitive to reactive components.

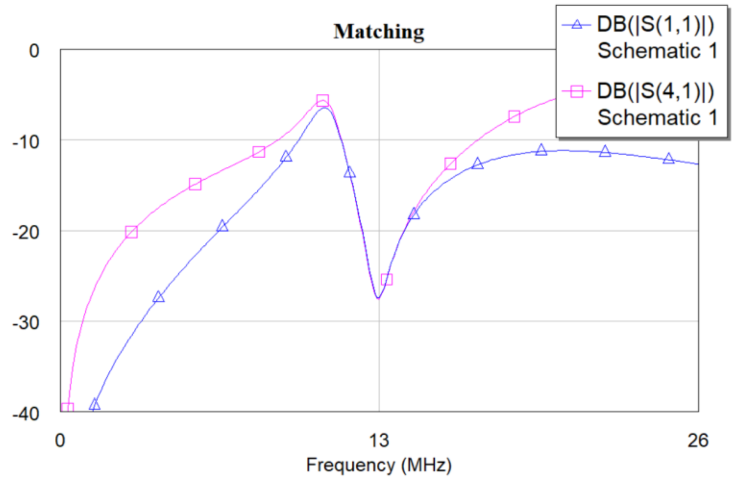

Figure 14. Matching and Isolation of Lumped Element Hybrid Coupler.

As Figure 14 depicts a narrow bandwidth operates within a narrow range of frequencies, centred around $13MHz$ frequency. Component Values, small variations in component placement can lead to changes in impedance characteristics. The device meets the design goals and functions effectively for its intended purpose, the narrowband behaviour is not necessarily be a problem.

### 3.2.3 Power Division of Lumped Element Hybrid Coupler

The two output ports have an equal distribution of input power, which is the main characteristic of a 3 dB power division. This indicates that if the power given to the input port (Port 1) is $P_{in}$, then the power produced at each output port (Port 2 and Port 3) is roughly $P_{out} = \frac{P_{in}}{2}$ [14].

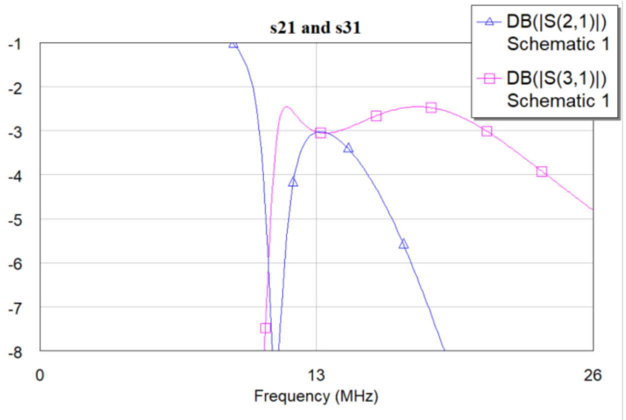

Figure 15. Power Division of Lumped Element Hybrid Coupler.

As Figure 15 depicts a good 3 dB power division in ports 2 and 3 is obtained by looking at $(S_{21} = -3.05dB)$ and $(S_{31} = -3.02dB)$ which have approximately the same magnitude. $S_{21}$ and $S_{31}$ values close to -3 dB and roughly equal in magnitude to achieve a balanced power division between the two output ports.

### 3.2.4 Phase Shift of Lumped Element Hybrid Coupler

The $90°$ phase shift is achieved by carefully designing the lumped elements, particularly the capacitors and inductors. The specific values of the lumped elements, as well as their arrangement and connection, determine the phase shift of the hybrid coupler as shown in Figure 16. [14.]

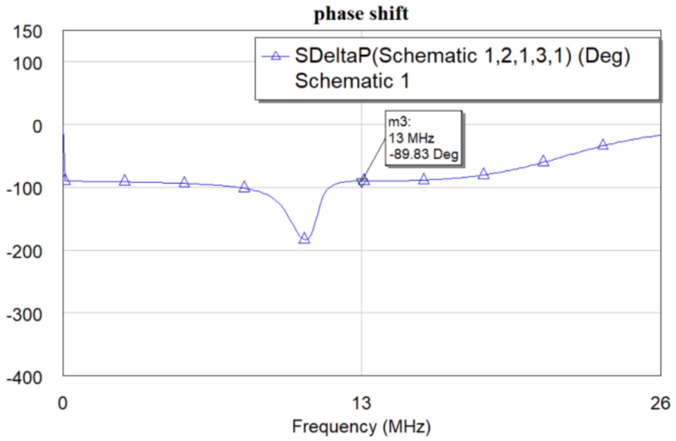

Figure 16. The Phase Shift of Lumped Elements Hybrid Coupler.

As Figure 16 shows the results, which show that observing $S21$ and $S31$ resulted in a phase difference of $89.83°$ between ports 2 and 3. Phase difference of $89.83°$, or only $0.18\%$ away from the ideal $90°$ phase shift, is obtained by subtracting $S21$ from $S31$. This is a very close approximation to the ideal $90°$ phase shift. For the practical application, the minor deviation of $0.17°$ from the ideal value is within an acceptable range.

### 3.2.5 Layout and Fabrication of Lumped Element Hybrid Coupler

The layout and fabrication of a $90°$ lumped element Hybrid Coupler circuit involve designing the physical structure of the circuit on a PCB and then manufacturing the PCB as shown in Figure 17.

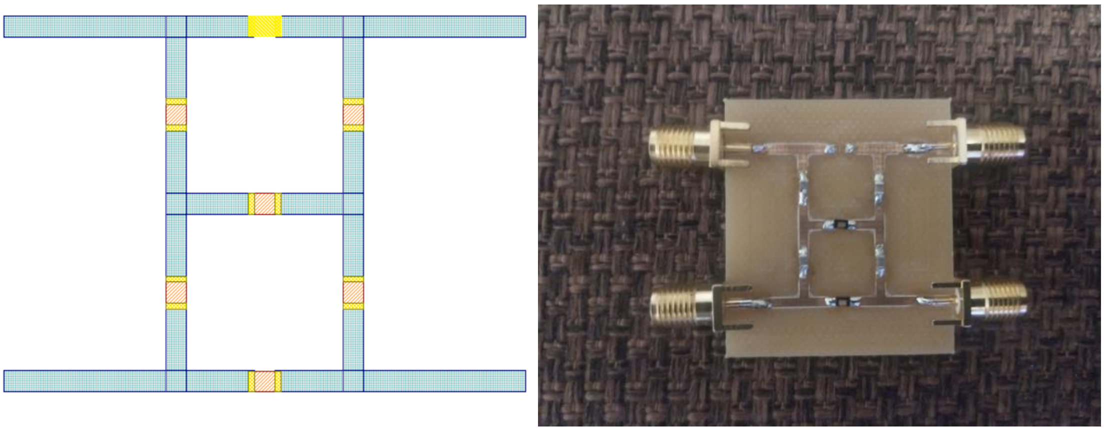

Figure 17. The Layout and Fabricated Lumped Element Hybrid Coupler.

## 3.3 Wilkinson Power Divider Design

An input signal is divided into two equal-phase output signals by a three-port passive radio device called a Wilkinson power divider, which also maintains isolation between the output ports. A Wilkinson power divider's typical design method has characteristic impedances of $Z_0, \sqrt{2} * Z_0$, and $2 * Z_0$ and operates at a particular frequency. The Wilkinson power divider has a straightforward structure that divides power evenly among the output ports by using quarter-wave transformers as shown in Figure 18. [18,328-332.]

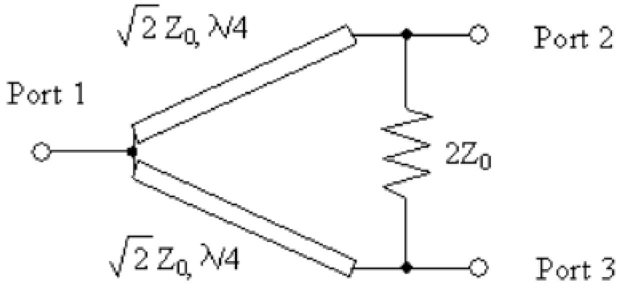

Figure 18. Wilkinson Power Divider [8].

The division of power is typically $3\ dB$, meaning that each output port receives half of the input power. Port 2 (Output Port) is where half of the input power is directed, output signal at port 2 is in-phase with the input signal. Port 3 (Output Port) is the second output port where the other half of the input power is directed, output signal at port 3 is $180°$ out-of-phase with the input signal and $180°$ out-of-phase with the output signal at port 2. [13,117-127;14,328-333.]

## 3.3.1 Schematics of Wilkinson Power Divider

The schematics of a Wilkinson power divider as shown in Figure 19 operating in the frequency range ($902MHz - 928MHz$) with a characteristic impedance $Z_O = 50\Omega$, $\sqrt{2} * Z0 = 70.7\Omega,$ and $2 * Z_O = 100\Omega$. It is designed using quarter-wave transformers to achieve equal power division between the output ports.

The microstrip line calculator takes the following parameters into account and provides the initial width and length of the microstrip line to achieve the desired characteristic impedance and electrical length. The frequency of operation is given as $915MHz\ or\ 0.915GHz$. Additionally, electrical length $\frac{\lambda}{4} = 90°$. The substrate parameters such as dielectric constant $\varepsilon r = 4.2$ and dielectric height $h = 1.6mm$. When $Zo = 50\Omega$, the microstrip line calculator suggests ($width = 3.17\ mm\ and\ length = 45.81mm$). When $Zo = 70.7\Omega$, the microstrip line calculator suggests ($width = 1.69\ mm\ and\ length = 46.89\ mm$).

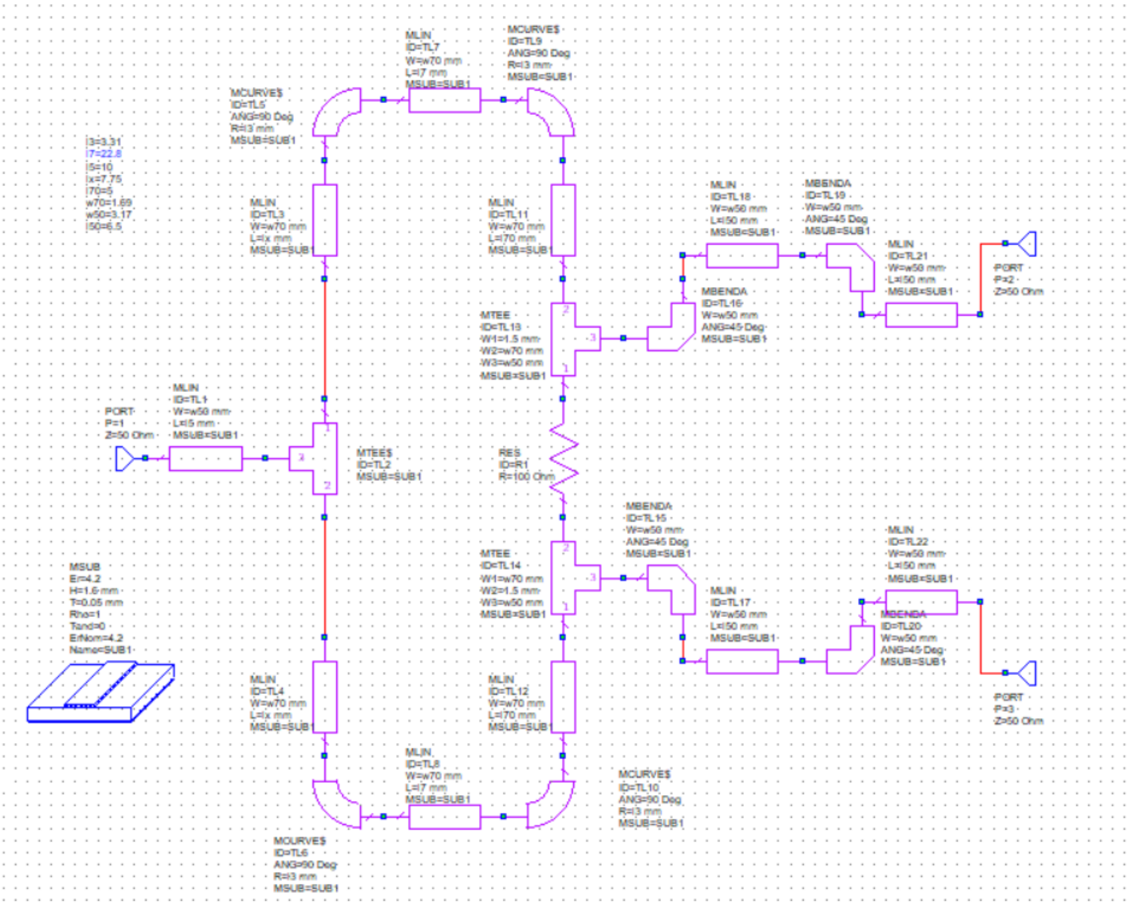

Figure 19. The Schematic of Wilkinson Power Divider.

## 3.3.2 Matching of Wilkinson

It is essential to have good matching at both the input ($S_{11}$) and output ($S_{22}$) ports to ensure efficient power transfer as shown in Figure 20.

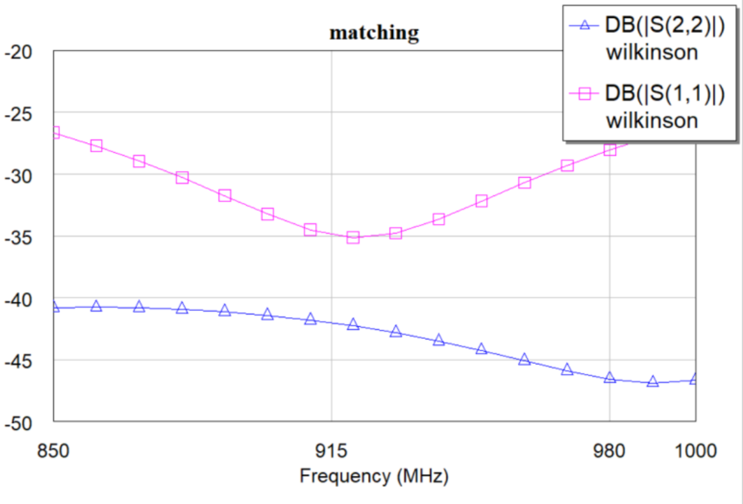

Figure 20. Matching of Wilkinson Power Divider.

### 3.3.3 Isolation of Wilkinson

To avoid interference and make sure that the electricity supplied to one output port does not adversely influence the other output ports, it is crucial to isolate the output ports from one another. $S_{23}$, which evaluates the degree of signal isolation at Port 2 from Port 3 and vice versa, describes the isolation between output ports 2 and 3 as shown in Figure 21.

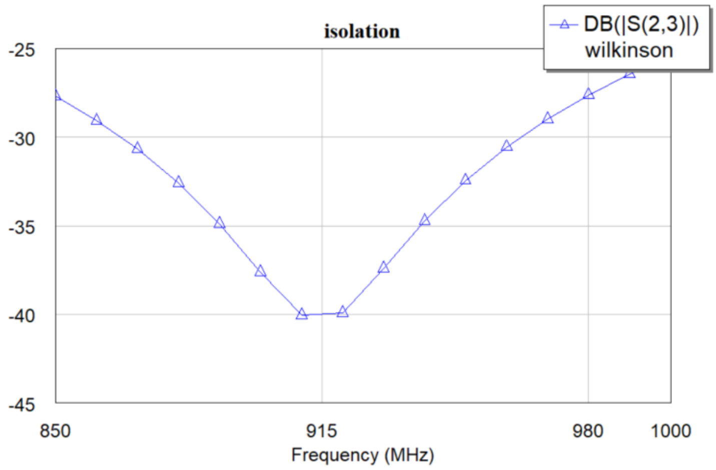

Figure 21. Isolation of Wilkinson Power Divider.

### 3.3.4 Power Division of Wilkinson

The $S_{31}$ and $S_{21}$ parameters represent the power division ratio between the input port (Port 1) and one of the outputs Port 3 and port 2 respectively in a 3 dB Wilkinson power divider as shown in Figure 22.

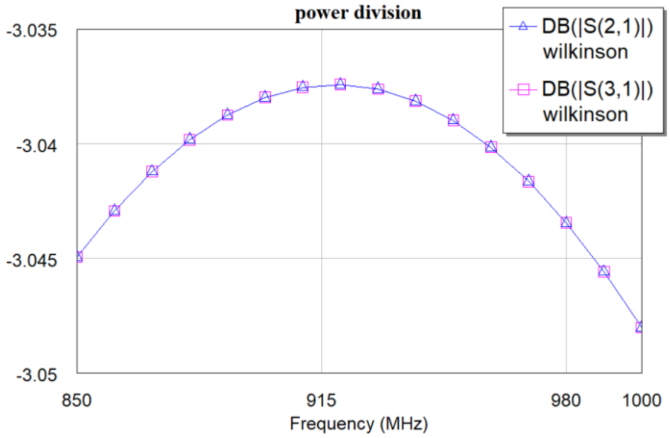

Figure 22. Power Division of Wilkinson Power Divider.

### 3.3.5 Layout and Fabrication of Wilkinson Power Divider

Fabricating a Wilkinson power divider involves PCB based on a design created in NI AWR Microwave Office as shown in Figure 23. There are a few steps to follow such as export Gerber files, initiating the milling process, inspecting, and assembling the connector.

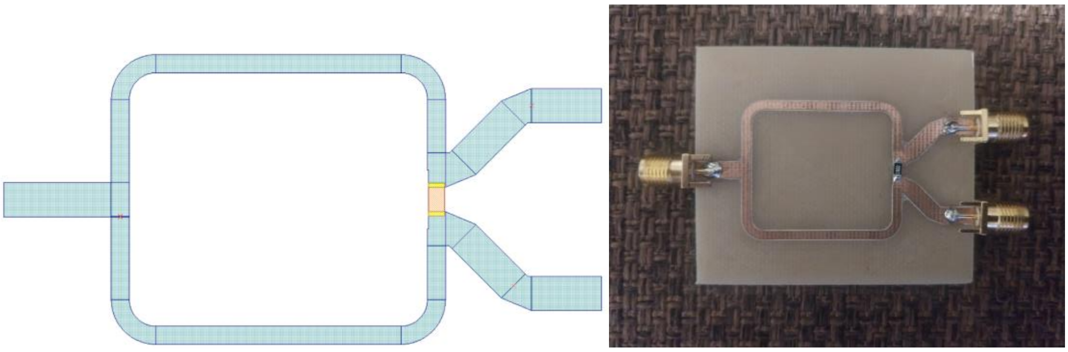

Figure 23. The layout and fabricated Wilkinson.

## 3.4 Double-Sideband Mixers (DSB)

A Double Sideband Mixer "ZX05-12MH-S+" from Mini-Circuits, is an RF/microwave component that typically generates both upper and lower sidebands in its output. Its conversion to a Single Sideband (SSB) mixer and integration into a larger RF system featuring a Wilkinson power divider, 90° lumped element hybrid coupler, and 90° BLH are the intended outcomes.

Figure 24. The ZX05-12MH-S+ Mixer.

### 3.4.1 Upconverter Operation

In up-conversion, the mixer is used to translate a lower-frequency signal (IF) to a higher-frequency signal (RF). The up-conversion equation for mixers is as follows:

$$f_{RF} = f_{LO} - f_{IF} \; or \; f_{RF} = f_{LO} + f_{IF} \tag{8}$$

$f_{LO} = 915MHz$ will combine $f_{IF} = 13MHz$. Using the formula (8), results $f_{RF1} = 902MHz$ and $f_{RF2} = 928MHz$.

### 3.4.2 Downconverter Operation

In downconverter operation using the mixer LO frequency of $915MHz$, using the following formula for down-conversion:

$$f_{IF} = | f_{LO} - f_{RF} | \tag{9}$$

$f_{LO} = 915MHz$ will combine with two different RF frequencies: $f_{RF1} = 902MHz$ and $f_{RF2} = 928MHz$. Using the formula (9), results $f_{IF1} = | 915MHz - 902MHz | = 13MHz$ and $f_{IF2} = | 915MHz - 928MHz | = 13MHz$ [16.]

## 3.5 Assembly of Single Sideband Mixer

Two DSB mixers (ZX05-12MH-S+), Wilkinson power divider, $90°$ BLH, $90°$ lumped element hybrid coupler, SMA Connector cables, and 50-ohm terminators are needed to assemble an SSB mixer.

It is mandatory to follow the block diagram as shown in Figure 1. used to create a Single Sideband (SSB) mixer. The transition to the next chapter testing and verification of the Single Sideband (SSB) mixer involves a systematic approach to ensure proper functionality and performance.

# 4 Measurement and Verification of Single Sideband Mixer

Testing and verification of a Single Sideband Mixer involves several steps to ensure proper functionality and performance. Here's a basic guide to go through the process:

## 4.1 Measurement of Single Sideband Mixer

Testing SSB Mixer assembly that includes two DSB ZX05-12MH-S+ mixers, a Wilkinson power divider, a $90°$ branch line hybrid coupler, and a $90°$ lumped element hybrid coupler involves verifying the performance of the system under specific frequencies 915MHz for LO signal.

### 4.1.1 Measurement set up of SSB Mixer Upconverter

The materials needed for testing are:

- Single Sideband Mixer assembly.
- Signal generator for LO (915MHz).
- Signal generator for IF (13MHz).
- Spectrum analyzer.
- RF cables SMA connectors
- Termination loads (50-ohm) for unused ports.

Below Figure 26. depicts the block diagram outlines the measurement setup for testing a Single Sideband Mixer Upconverter.

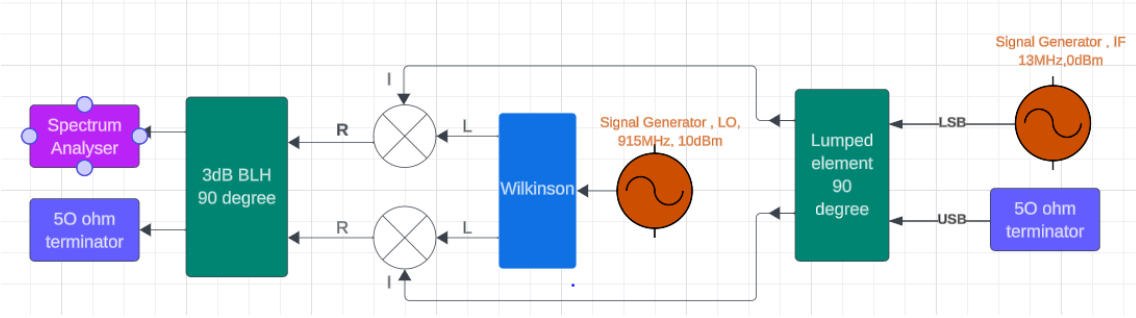

Figure 25. Block Diagram of Measurement set up in Upconverter USB suppressed.

The block diagram in Figure 25. depicts the SSB Mixer Upconverter's performance in converting the IF signal to the desired RF frequency suppressing USB.

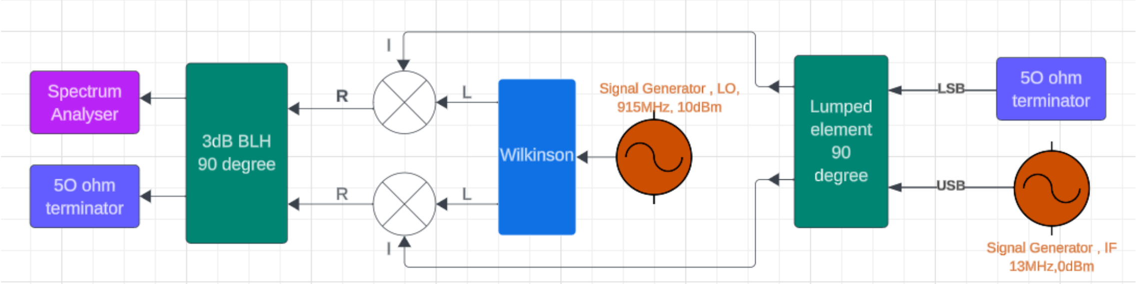

Figure 26. Block Diagram of Measurement set up in Upconverter LSB suppressed.

The block diagram in Figure 26. depicts the SSB Mixer Upconverter's performance in converting the IF signal to the desired RF frequency suppressing LSB.

#### 4.1.1.1 Suppressing Upper Sideband (USB)

To suppress the USB and keep the LSB, aim to remove the signal at 928MHz and retain the signal at 902MHz.

As the results are shown in the spectrum analyzer in appendix 3 , IF input signal $13MHz$ at $0dBm$, LO signal $915MHz$ at $10dBm$, the $USB = 928MHz$ at a power level $-18dBm,\ 915MHz\ at\ -28.3dBm$ and $LSB = 902MHz$ at a power level $-11dBm$.

To calculate the conversion loss for USB, the following formula is used:

$$Conversion\ loss\ (for\ USB) = Input\ signal\ level\ (IF) - Output\ signal\ USB$$
$$= 0dBm - (-18dBm) = 18dB$$

To calculate the conversion loss for LSB, the following formula is used:

$$Conversion\ loss\ (for\ LSB) = Input\ signal\ level\ (IF) - Output\ signal\ LSB$$
$$= 0dBm - (-11dBm) = 11dB$$

The conversion loss calculations show that the LSB is generated with a significantly lower conversion loss $11\,dB$ compared to the USB (Upper Sideband), which has a conversion loss of $18\,dB$. The conversion loss results strongly support the USB signal is significantly suppressed.

To calculate the Image Rejection (IR) in up-conversion, the following formula is used:

$$IR(dB) = LSB\ Power(dBm) - USB\ Power(dBm) \qquad (10)$$

Given:

$$USB\ Power(dBm) = -18dBm$$
$$LSB\ Power(dBm) = -11dBm$$

Calculate for $IR(dB)$ :

$$IR(dB) = (-11dBm) - (-18dBm) = 7dB$$

If the USB signal is completely eliminated or reduced to a very low level, it is considered optimal for SSB modulation. However, some residual USB $-18dBm$ still be present. The image rejection result $7dB$ means that the desired sideband (LSB) is stronger than the undesired sideband (USB) suggests that the USB is suppressed but not completely eliminated.

### 4.1.1.2 Suppressing Lower Sideband (LSB)

To suppress LSB while preserving USB, aim to remove the signal at 902MHz and retain the signal at 928MHz.

As the results shown in the spectrum analyser in appendix 4, IF input signal $13MHz$ at $0dBm$, LO signal $915MHz$ at $10dBm$, the $USB = 928MHz$ at a power level $-13dBm,\ 915MHz\ at - 28.8dBm$ and $LSB = 902MHz$ at a power level $-20dBm$.

To calculate the conversion loss for USB, the following formula is used:

$$\begin{aligned} Conversion\ loss\ (for\ USB) &= \ Input\ signal\ level\ (IF) - \ Output\ signal\ (USB) \\ &= 0dBm - (-13dBm) = 13dB \end{aligned}$$

To calculate the conversion loss for LSB, the following formula is used:

$$\begin{aligned} Conversion\ loss\ (for\ LSB) &= \ Input\ signal\ level\ (IF) - \ Output\ signal(LSB) \\ &= 0dBm - (-20dBm) = 20dB \end{aligned}$$

The conversion loss results indicate that the USB is generated with a lower conversion loss $13\ dB$ compared to the LSB, which has a higher conversion loss of $20\ dB$. The conversion loss results strongly support the LSB signal is significantly suppressed.

To calculate the Image Rejection (IR) in up conversion, you can use the following formula:

$$I(dB) = USB\ Power(dBm) - LSB\ Power(dBm)$$

Given:

$$USB\ Power(dBm) = -13dBm$$
$$LSB\ Power(dBm) = -20dBm$$

Calculate for $I(dB)$ :

$$I(dB) = \ (-13dBm) - \ (-20dBm) = 7dB$$

If the LSB signal is completely eliminated or reduced to a very low level, it would indeed be considered optimal in the context of suppressing the LSB in a single sideband mixer. However, some residual LSB $-20dBm$ still be present. The image rejection of $7dB$ means that the desired sideband (USB) is stronger than the undesired sideband (LSB). A value for the image rejection suggests that the LSB is suppressed but not completely eliminated.

### 4.1.2 Measurement set up of SSB Mixer Downconverter

The materials needed for testing are:

- Single Sideband Mixer assembly.
- Signal generator for LO ($f_{LO} = 915MHz$).
- Signal generator for RF ($f_{RF1} = 902MHz\ and\ f_{RF2} = 928MHz$).
- Two spectrum analyzers.
- RF cables SMA connectors
- Termination loads ($50\Omega$) for unused ports.

Below the block diagram outlines the measurement setup for testing a Single Sideband Mixer downconverter. This setup is designed to verify the functionality and performance of the mixer.

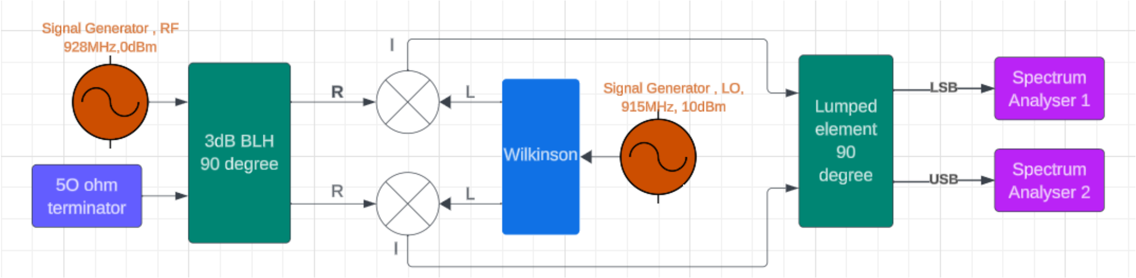

Figure 27. Block Diagram of Measurement set up in Downconverter suppressing LSB.

The block diagram in Figure 27. depicts the SSB Mixer downconverter's performance in converting the RF signal to the desired IF frequency suppressing LSB.

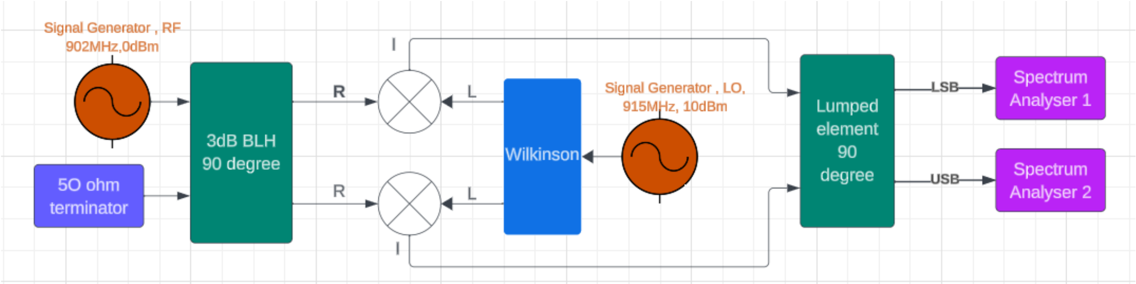

Figure 28. Block Diagram of Measurement set up in Downconverter suppressing USB.

The block diagram in Figure 28. depicts the SSB Mixer downconverter's performance in converting the RF signal to the desired IF frequency suppressing USB.

### 4.1.2.1 Suppressing Upper Sideband (USB)

The observation indicates a situation in an RF testing setup where an input RF signal at $902MHz$ is fed into a system. The expected outcomes involve analyzing the outputs at two different Intermediate Frequency (IF) ports, one for LSB at $f_{IF} = 13MHz$ and the other for USB suppressed.

The expectation was to observe the Lower Sideband (LSB) at the intermediate frequency (IF) of $13MHz$. However, there was an issue, and the LSB at the IF of $13MHz$ was not observed on the first spectrum analyzer. This may indicate a problem with the modulation or signal generation process that could lead to the failure of observing the LSB and the unexpected presence of the USB despite attempts to suppress it.

### 4.1.2.2 Suppressing Lower Sideband (LSB)

The RF signal generator at 928MHz signal, has observed the output on the first spectrum analyzer which is connected to the IF port USB at $f_{IF} = 13MHz$ and the second spectrum analyzer which is connected to the IF port LSB is suppressed signal.

As the results are shown in spectrum analyzers in appendix 5, RF input signal $928MHz$ at $0dBm$, LO signal $915MHz$ at $10dBm$, the $f_{USB} = 13MHz$ at a power level $-26.3dBm,\ f_{LO} = 915MHz\ at - 28.8dBm$ and $f_{LSB} = 13MHz$ at a power level $-88.8dBm.$

To calculate the conversion loss for USB, the following formula is used:

$$Conversion\ loss\ (for\ USB) = \ Input\ signal\ level\ (RF) - \ Output\ signal\ (USB)$$
$$= 0dBm - (-26.3dBm) = 26.3dB$$

The USB signal, with a power level of $-26.3\ dBm$ starting from RF signal level of $0\ dBm$, shows that the USB output is effectively generated with a noticeable reduction in power.

To calculate the conversion loss for LSB, the following formula is used:

$$Conversion\ loss\ (for\ LSB) = \ Input\ signal\ level\ (RF) - \ Output\ signal(LSB)$$
$$= 0dBm - (-88.8dBm) = 88.8dB$$

The conversion loss for LSB is calculated to be $88.8\ dB$, which is extremely high. Such a high loss effectively means that the LSB signal is significantly suppressed. From the perspective of suppressing the LSB signal, the results can be considered effective.

To calculate the Image Rejection (IR) in up conversion, the following formula is used:

$$I(dB) = USB\ Power(dBm) - LSB\ Power(dBm)$$

Given:

$$LSB\ Power(dBm) = -88.8dBm = 10 * \log P(mW)$$
$$USB\ Power(dBm) = -26.3dBm = 10 * \log P(mW)$$

Calculate for $I(dB)$ :

$$I(dB) = \ (-26.3dBm) - \ (-88.8dBm) \ = 62.5dB$$

If the LSB signal is completely eliminated or reduced to zero, it would indeed be considered optimal in the context of suppressing the LSB in a single sideband mixer. However, some residual LSB $-88.8dBm$ still present. The image rejection $62.5dB$ means that the desired sideband (USB) is stronger than the undesired sideband (LSB). The value of image rejection suggests that the LSB is suppressed but not completely eliminated.

## 4.2 Verification of SSB Mixer

A Single Sideband (SSB) mixer assembly must be verified and tested to make sure it meets the requirements and operates as intended.

### 4.2.1 Verification of SSB Mixer Assembly

It is verified that the assembly using two Double Sideband (DSB) mixers ZX05-12MH-S+, along with components like a Wilkinson power divider, a $90°$ BLH, a $90°$ lumped element coupler, and SMA connectors and all components such as inductors, capacitors, connectors and the resistor are correctly placed and soldered on the PCB.

### 4.2.2 Verification of Testing Results

The results obtained during testing align with the design requirements, indicating that the assembly is operating within the desired parameters.

#### 4.2.2.1 Successful Signal Mixing:

The mixer assembly successfully combines the LO (Local Oscillator), IF (Intermediate Frequency), and RF (Radio Frequency) signals to produce the desired RF and IF output. Frequency Conversion is effectively converting the RF signals to the desired IF frequency through the mixing process. Sideband Suppression of unwanted sidebands was almost successful, effective sideband suppression is essential for clean signal processing. LO Power and Stability ensure that the LO signal is at the correct frequency, and its power level is within the specified range.

#### 4.2.2.2 IF Output Frequencies in Down-conversion Confirmed

It is verified that the LO and RF signal generators are generating signals at $f_{LO} = 915MHz\ and\ f_{RF2} = 928MHz$, respectively. Spectrum Analyzer 2 is monitoring the output signal when the RF input is at $f_{RF2} = 928MHz$. Observing the output on Spectrum Analyzer 2 shows a signal at $f_{IF} = 13MHz$, indicating that the Upper Sideband (USB) has been down converted. Observing the output on Spectrum Analyzer 1 shows a suppressed or significantly reduced signal, indicating that the Lower Sideband (LSB) has been effectively suppressed.

It is also verified that the LO and RF signal generators are generating signals at $f_{LO} = 915MHz\ and\ f_{RF1} = 902MHz$, respectively. However, spectrum analyzer 1 was not monitoring the output signal when the RF input is at $f_{RF1} = 902MHz$. Observing the output on Spectrum Analyzer did not show a signal at $f_{IF} = 13MHz$.

#### 4.2.2.3 RF Output Frequencies in Up-conversion Confirmed

The USB suppression has successfully achieved in the up conversion with the desired outcome of suppressing the Upper Sideband (USB) and obtaining a signal at $f_{RF1} = 902MHz$. The configuration is effectively achieving the desired up-conversion. The LO signal at $f_{LO} = 915MHz$ mixed with the $f_{IF} = 13MHz$ IF signal at the LSB port of the SSB mixer assembly effectively suppresses the Upper Sideband (USB) $f_{RF2} = 928MHz$, resulting in a signal at $f_{RF1} = 902MHz$.

The LSB suppression has also successfully achieved in the up conversion with the desired outcome of suppressing the lower Sideband (LSB) and obtaining a signal at $f_{RF2} = 928MHz$. The configuration is effectively achieving the desired up-conversion. The LO signal at $f_{LO} = 915MHz$ mixed with the $f_{IF} = 13MHz$ IF signal at the USB port of the SSB mixer assembly effectively suppresses the lower Sideband (LSB) of $f_{RF1} = 902MHz$, resulting in a signal at $f_{RF2} = 928MHz$.

# 5 Conclusions

In summary, this thesis has been focused on the design, fabrication, testing, and verification of SSB mixer circuit incorporating two DSB mixers, a 90° BLH, a 90° lumped elements hybrid coupler and a Wilkinson power divider for enhanced performance in RF communication systems. The integration of DSB mixers for initial frequency conversion, along with the phase and signal management capabilities of the 90° hybrids and the equal signal distribution provided by the Wilkinson Power Divider, allows for enhanced control over signal quality and efficiency in frequency conversion processes.

The design phase of the 90° BLH, 90° lumped elements hybrid coupler and Wilkinson power divider was executed using NI MWO software. The specific parameters and configurations of each component were calculated to ensure optimal performance in terms of phase and signal management as well as signal distribution. Following the design phase, the physical fabrication of each of the devices was successfully completed, this step transformed the theoretical designs into tangible components. A vector network analyzer (VNA) was then used to examine each of the manufactured devices to confirm that the 90° hybrids' phase-shifting and impedance matching properties, and equal power-splitting features of the Wilkinson power divider. The assembly phase involved integrating the fabricated components with two DSB mixers to form the complete SSB mixer circuit. The testing process has been done using measurement devices such as signal generators and spectrum analyzers focused on confirming the circuit's ability to perform efficient down-conversion and up-conversion of RF signals, the effectiveness of the sideband suppression, crucial for achieving the desired signal quality and efficiency, and assessing the overall integration of the circuit components in facilitating the targeted frequency conversion processes. The core objective was to achieve effective down-conversion and up-conversion of radio frequencies while successfully suppressing unwanted sidebands using a phasing approach to enhance signal quality and efficiency.

In the up-conversion process, the SSB mixer assembly plays a vital role in modulating the input signal, encoding information carried in one sideband, and suppressing the unwanted sideband has demonstrated effective performance. The choice of $f_{IF} = 13MHz$ in the up-conversion process is crucial, where the local oscillator was consistently set at $f_{LO} = 915MHz$. The verification is conducted for two different RF frequencies ($f_{RF1} = 902MHz\ and\ f_{RF2} = 928MHz$). The output via a spectrum analyser, has shown peak RF signals suppressing one of the sidebands either the at $f_{LSB} = 902MHz$ or $f_{USB} = 928MHz$. This observation underscores the mixer works efficiently modulating signals, further confirming its crucial role in signal processing. This outcome proves the assembly's proficiency in elevating signal frequencies, effectively achieving up-conversion. The technical details describe the successful performance of the SSB Mixer assembly in the up-conversion process on the transmission side.

In down-conversion process in receiver side, the SSB mixer assembly continues playing a vital role in demodulating the input signal, extracting the information carried in one sideband, and suppressing the unwanted sideband. The two different RF input frequencies ($f_{RF1} = 902MHz\ and\ f_{RF2} = 928MHz$), where the local oscillator was consistently set at $f_{LO} = 915MHz$. The appearance of the IF output signal at $f_{IF} = 13MHz$ is crucial. The results demonstrated that when the RF input was at $f_{RF2} = 928MHz$, the SSB mixer successfully down convert this signal to an Intermediate Frequency of $f_{IF} = 13MHz$, confirming the suppression of the LSB and retention of USB. However, when the RF input was at $902MHz$, the expected IF signal of $13MHz$ in suppressing USB was not observed, indicating an area for further investigation. The observation of the suppressed sideband, whether the USB or LSB, further affirms the mixer's important role in achieving effective signal processing. The technical details indicate that the receiver's down-conversion process is partially operating effectively in the receiver side.

The results obtained from testing with signal generators and spectrum analyzers played a vital role in verifying the circuit's performance, showcasing its effectiveness in handling RF signals, and manipulating sidebands as intended. The up-conversion process achieved comprehensive success, the down-conversion process revealed opportunities for improvement, particularly in the suppression of the USB at certain frequencies. Future work will benefit from investigating these areas further to enhance the SSB mixer circuit's overall efficacy and reliability. This research not only confirms the circuit's critical role in signal processing but also plays a foundation for subsequent innovations in RF communication technology. It has not only validated the theoretical concept of the SSB mixer circuit design but has also laid the groundwork for future developments in RF communication systems.

As RF communication systems continue to evolve, the insights and findings from this research enrich the academic discourse and contribute to practical applications in the field. The knowledge gained from this endeavour opens avenues for further research, particularly in optimizing sideband suppression techniques and enhancing the efficiency of signal modulation and demodulation processes. The SSB mixer circuit, with its core functionality proven, stands as a testament to the importance of meticulous design, fabrication, and testing in the development of advanced RF communication technologies.

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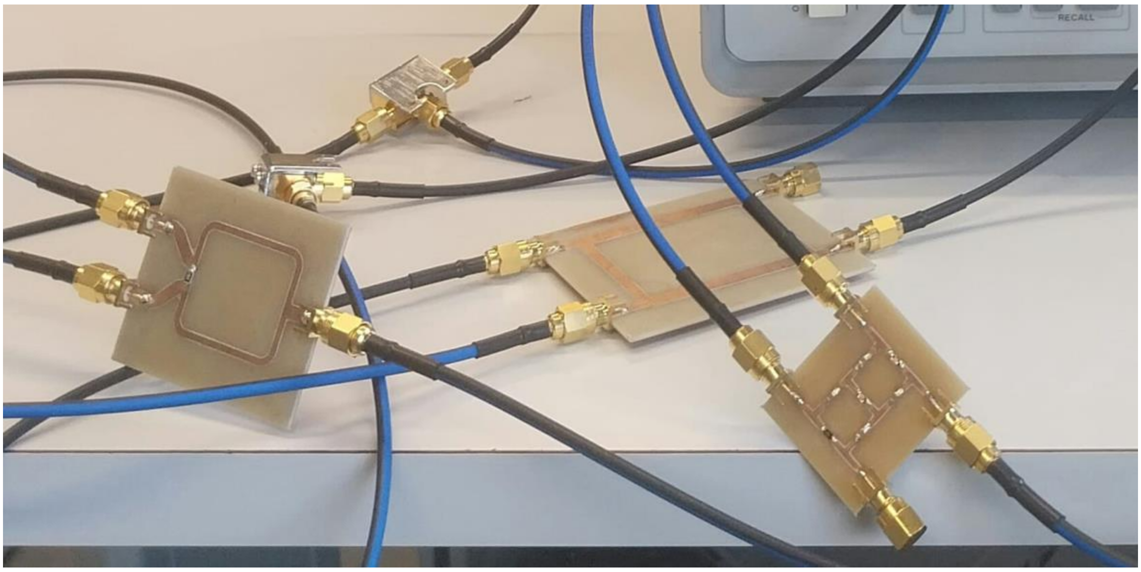
# Appendices

## Appendix 1: Assembled SSB mixer



## Appendix 2: SSB Mixer and Testing Devices.

Appendix 3: SSB Up conversion USB suppressed

Mkr 3 at 928.0MHz -18.0 dBm

Ref: 10.0dBm

Start: 900.0MHz Center: 915.0MHz Stop: 930.0MHz

RBW: 300kHz Span: 30.0MHz Sw: 500.0ms

Marker Table

| No. | MHz | dBm | No. | MHz | dBm |
|---|---|---|---|---|---|
| 1 | 902.0 | -11.0 | Δ1 | 0.0 | |
| 2 | 915.0 | -28.3 | Δ2 | 0.0 | |
| 3 | 928.0 | -18.0 | Δ3 | 0.0 | |
| 4 | | | Δ4 | 0.0 | |
| 5 | | | Δ5 | 0.0 | |

Marker:928.0MHz

Appendix 4: SSB Up Converion LSB suppressed

Mkr 1 at 902.0MHz -20.0 dBm

Ref: 10.0dBm

Start: 900.0MHz Center: 915.0MHz Stop: 930.0MHz

RBW: 300kHz Span: 30.0MHz Sw: 500.0ms

Marker Table

| No. | MHz | dBm | No. | MHz | dBm |
|---|---|---|---|---|---|
| 1 | 902.0 | -20.0 | Δ1 | 0.0 | |
| 2 | 915.0 | -28.8 | Δ2 | 0.0 | |
| 3 | 928.0 | -13.0 | Δ3 | 0.0 | |
| 4 | | | Δ4 | 0.0 | |
| 5 | | | Δ5 | 0.0 | |

Marker:902.0MHz

# Appendix 5: SSB down conversion LSB suppressed.

Mkr 1 at 0.0kHz -45.1 dBm
Ref: 20.0dBm
Start: 0.0kHz
RBW: 300kHz
Center: 13.0MHz
Span: 26.0MHz
Stop: 26.0MHz
Sw: 500.0ms

Marker Table

| No. | MHz | dBm | No. | MHz | dBm |
|---|---|---|---|---|---|
| 1 | | -45.1 | Δ1 | 0.0 | |
| 2 | 13.0 | -26.3 | Δ2 | 0.0 | |
| 3 | 26.0 | -44.1 | Δ3 | 0.0 | |
| 4 | | | Δ4 | 0.0 | |
| 5 | | | Δ5 | 0.0 | |

Entry Invalid

Mkr 2 at 13.0MHz -88.8 dBm
Ref: -30.0dBm
Start: 0.0kHz
RBW: 300kHz
Center: 13.0MHz
Span: 26.0MHz
Stop: 26.0MHz
Sw: 500.0ms

Marker Table

| No. | MHz | dBm | No. | MHz | dBm |
|---|---|---|---|---|---|
| 1 | | -94.3 | Δ1 | 0.0 | |
| 2 | 13.0 | -88.8 | Δ2 | 0.0 | |
| 3 | 26.0 | -94.8 | Δ3 | 0.0 | |
| 4 | | | Δ4 | 0.0 | |
| 5 | | | Δ5 | 0.0 | |

Marker 13.0MHz