A Project Report on

200- 450 MHz QUADRATURE HYBRID USING LANGE COUPLER

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Introduction

"Lange coupler" is an interdigited microstrip quadrature hybrid coupler as described by Dr. Julius Lange in 1969 [1]. The main advantages are the small size and its relatively large bandwidth, when compared with Branch-Line Coupler. Branch-Line Couplers offer bandwidth of about 20% and they require large substrate area. The other alternative approach to design the quadrature hybrid is the use of Sage Laboratories make "WIRELINE". "WIRELINE" is available in two types, one for 30% bandwidth and the other for octave bandwidth. WIRELINE is more lossy as compared with Lange coupler. Lange coupler can give upto 3:1 bandwidth and if realized on low dissipation factor substrates it can yield low insertion loss.

Giant Meterwave Radio Telescope (GMRT) is being upgraded to have a frequency band of 200-450 MHz. This requires low loss polarizers covering this frequency range to convert linearly polarized signals from the upgraded feed to right and left circularly polarized signals. This report highlights the design aspects of a low loss 200- 450 MHz Quadrature Hybrid based on Lange coupler approach for possible use in GMRT.

HISTORY OF LANGE COUPLER

Lange couplers are a modern miracle of microwaves. Here is the quadrature coupler at its best: low loss, wide bandwidth, compact layout. This coupler spawned an entire industry of wide band hybrid-style amplifiers that is still here today inspite of a lot of good competition from MMIC'S.

"In 1969 at Texas Instruments, Julius Lange and others were building microwave amplifiers on thin film ceramic substrates. They were using the scheme invented by Engelbrecht at Bell Labs, which required 3-dB quadrature couplers. The challenge was to get tight coupling on single layer microstrip. On the other hand transistors had too much coupling between the interdigitated base and emitter fingers. Lange built an interdigitated coupler and it did not work well. Then he remembered that geometric symmetry guarantees quadrature, a 90° split between the outputs. So he moved some of the crossovers from the ends to the middle; and it worked! . So they could get a microstrip interdigitated quadrature coupler with low loss and wide, one octave, bandwidth."

Introduction

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Theory of Lange coupler

The Lange coupler is often used in hybrid and monolithic microwave integrated circuit applications. To balance voltages of alternate lines, bond wires have to be used.

The physical length of a Lange coupler is approximately equal to one quarter wavelength at the center frequency on the host substrate. The combined width of the strips is comparable to the width of a line of characteristics impedance Z_0 (50 ohm) on the host substrate.

Lange couplers are a common circuit used in microwave applications. They provide equal power division and 90 degrees of phase shift between the coupled ports. They are widely used as power combiners and splitters in microwave amplifiers and in mixers/modulators. They are based upon interdigitated lines with narrow lines and tight spaces.

The coupling in coupled lines coupler is too loose to achieve coupling factors of 3 db or 6db. One way to increase coupling between edge coupled lines is to use several lines parallel to each other, so that fringing fields at both edges of a line contribute to the coupling. Lange coupler can easily achieve 3 db coupling ratios, with an octave or more bandwidth. The design tends to compensate for unequal even and odd phase velocities, which also improves the bandwidth.

There is 90 degrees phase difference between output lines(port 2 and 3), so the Lange coupler is also called quadrature coupler. The main disadvantage of Lange coupler is, as the lines are very narrow, closed together, it is difficult to fabricate the necessary bonding wires across the lines.

For a given input on a Lange coupler (or other types of quadrature couplers for that matter), the three output ports can be denoted

1] isolated port

2]through or direct port

3]coupled port (-90 degree transmission angle compared to through port)

Referring to the six finger Lange coupler below, if the bottom left port is the input, the top left is the "coupled" port, the top right is the "direct" port and the bottom right is the "isolated" port. The isolated port is on the same side of the coupler as the input for a normal Lange coupler.

The network in figure b still belongs to the Lange Coupler family shown in part a of the figure. It was first suggested by R.Waugh and D. Lacombe(2).It is usually called an "Unfolded Lange Coupler",and the difference between these two networks is that they exchange the isolated and direct port as we see in figure a & b. For both the versions each of the coupled lines is called a "Finger" in the normal practice.

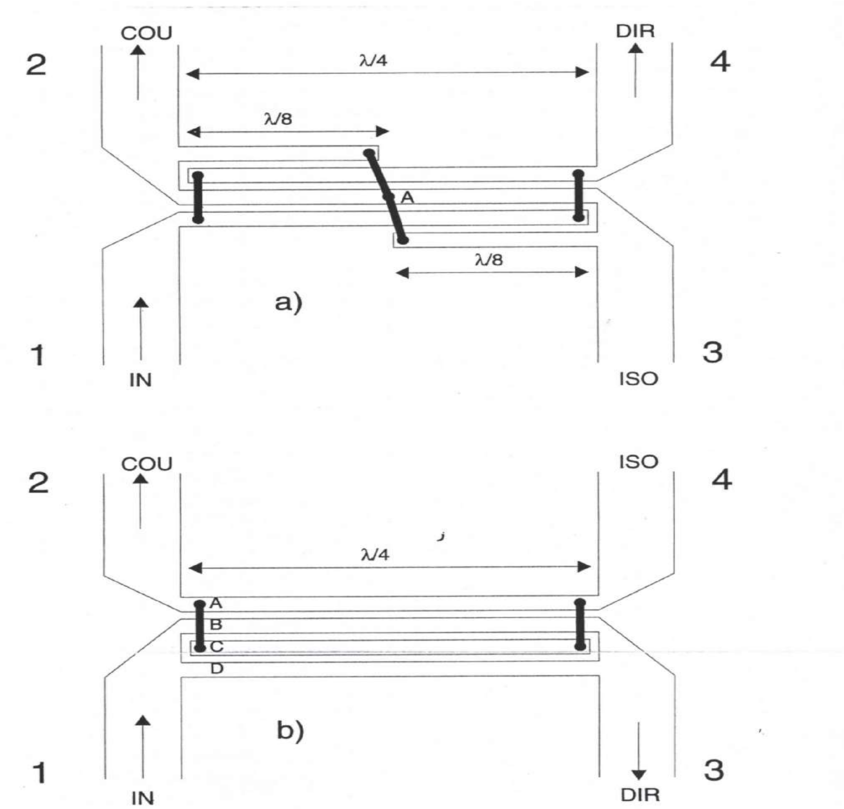


Figure 1: Lange coupler

We see that a number "n" of coupled lines with length λ/4 are connected together at each extreme. In the case of part a of the figure the two λ/8 lines form λ/4 line for those frequencies where the length of connecting wires may be neglected. The number "n" of coupled lines is usually an even number, typically 4 or 6 although in theory it is possible to use 3 lines. The Lange coupler is also called an "interdigital coupler" or simply "hybrid". The connections are indicated in figure with solid thick lines and are called " air bridges". With the hypothesis of neglecting the length of the air bridges the Lange Coupler may be thought of as many Quarter wavelength directional couplers connected in parallel.

With reference to figure, a signal entering in port 1 has the coupled port 2 and the direct port 4, while port 3 is isolated. In addition, phase shift between signals at direct and coupled ports is 90 degrees. For this reason, the Lange coupler is also called a "3db quadrature hybrid".

Due to this multicoupling effect between the fingers, with the Lange coupler it is possible to reach 3db of coupling or even more with the consequences that this network is the only "3db Quadrature microstrip coupler" employed in practice in wide bandwidth circuits. For 4 fingers network and 2.5db of center band coupling, it is possible to reach operating bandwidth of 100%, that is 3:1 between the limits of frequency band. Therotically, coupling increases with the number of fingers, but in practice only 4 fingers are used. The therotical increase of coupling is limited by the increase in the number of discontinuities encountered using a higher number of fingers.

One of the simplest studies on the Lange coupler was made by Wen Pin Ou [3]. His paper attempts to give a theoretical treatment of the interdigitated structure. In this method the equivalence of the coupler is used with an array of coupled transmission lines. The air bridges that connect the coupled lines in parallel must be evaluated with zero length in such a case all the lines connected in parallel are equipotential at the connection points in particular the two λ/8 lines are connected in series with a zero length connection. R.M.Osmani

[4] showed that it is possible to synthesize Lange Couplers directly and there by saving considerable computing time. In this direct synthesis procedure Wen Pin Ou's method is first used to determine odd and even-mode impedances of any adjacent pair of lines. Final dimensions are obtained by applying the synthesis technique of Akhtarzad *et al*[5] for a pair of coupled microstrip lines. This synthesis technique was found to be fairly accurate and quite simple to use. The procedure described above assumed coupled lines of zero conductor thickness. Neglecting finite conductor thickness in design is known to result in couplers with over coupled responses to counter this, Presser[6] suggested an empirical technique which increase zero thickness design spacing and reduces zero thickness design width by an equal amount determined from Wheeler's[7] edge correction for single strips of small thickness. For the coupler fabricated above over coupling caused by assuming T=0 was estimated by using Presser's method. Since the nominal T/d ratio of the substrate used is 0.07(1 oz/Sq.Ft copper). The equation given by Presser[6] cannot be applied straight away. Instead,Wheeler's edge correction for single strips of moderately large thicknesses is applicable[8].

Lange Coupler Design

Lange couplers consist of very narrow coupled lines of a quarter wavelength coupled in parallel to allow fringing on both sides of the line to contribute to the coupling. To increase the coupling it is necessary to use very narrow gaps and to still further increase the coupling bond wire interconnections are used. The resultant coupler will have a large bandwidth of at least an octave and so for our application we will have plenty of bandwidth (Lange bandwidth ~ 200MHz to 450MHz).

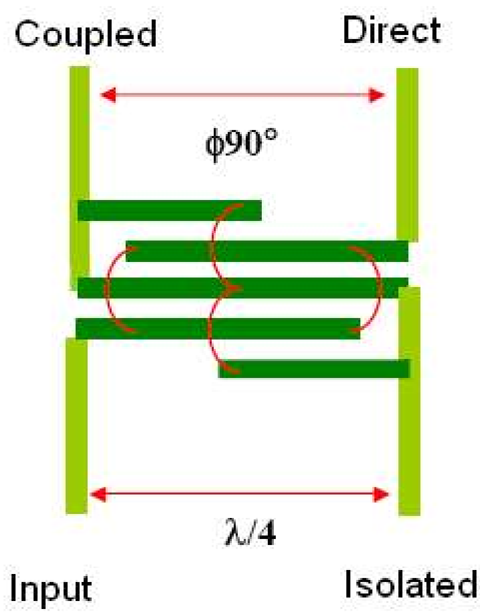


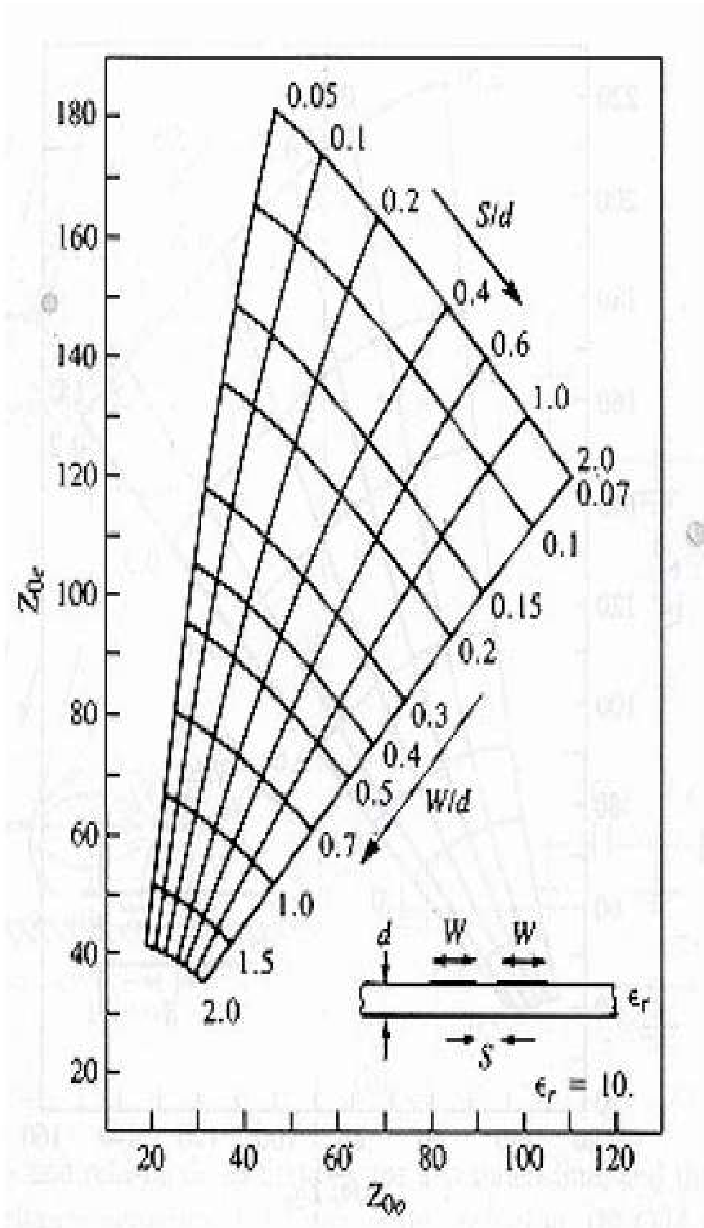
Figure 2

$$C = 10^{\frac{\text{Coupling coefficient}}{20}}$$

$$Z0e = \frac{4C - 3 + \sqrt{9 - 8C^2}}{2C\sqrt{(1-C)/(1+C)}} Z0$$

$$Z0o = \frac{4C + 3 - \sqrt{9 - 8C^2}}{2C\sqrt{(1+C)/(1-C)}} Z0$$

To calculate the finger dimensions and spacings, we need to calculate the even and odd mode line impedences:



Even and odd-mode characteristic impedance design data for coupled micro-strip lines.

Figure:3

Design Formulas:

1) λair = c/f

where,

c = speed of light in air (3E8 m/s)

f = desired center frequency

2) λ/4(in microstrip) = λair/4*√ εe

where,

λ/4(in microstrip) = length of Lange coupled lines

εe = effective dielectric constant

3) Port width for a 50 ohms line:

For a given characteristic impedance Z_0 and dielectric constant ϵ_r, the W/d ratio can be found as

$$\frac{W}{d} = \begin{cases} \dfrac{8e^A}{e^{2A}-2} & \text{for } W/d < 2 \\ \dfrac{2}{\pi}\left[B - 1 - \ln(2B-1) + \dfrac{\epsilon_r - 1}{2\epsilon_r}\left\{\ln(B-1) + 0.39 - \dfrac{0.61}{\epsilon_r}\right\}\right] & \text{for } W/d > 2, \end{cases} \quad 3.197$$

where

$$A = \frac{Z_0}{60}\sqrt{\frac{\epsilon_r + 1}{2}} + \frac{\epsilon_r - 1}{\epsilon_r + 1}\left(0.23 + \frac{0.11}{\epsilon_r}\right)$$

$$B = \frac{377\pi}{2Z_0\sqrt{\epsilon_r}}.$$

4) Effective dielectric constant

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\frac{1}{\sqrt{1 + 12d/W}}.$$

Specifications of RT/duroid 5870 substrate

For realizing the Lange coupler low loss substrate RT/duroid 5870 glass microfibre reinforced polytetra fluoroethylene(PTFE) composite manufactured by ROGERS corporation,USA has to be used. The specifications for this substrate are as under

1. **Dielectric constant (εr) =2.33**
2. **Substrate height (d) = 1.6mm**
3. **Metal Thickness = 35μm**
4. **Loss Tangent (tan δ)= 0.0012**
5. **1 ounce/ sq.ft electrodeposited copper clad on both sides**

Design of Lange coupler for 200- 450MHz at a center frequency of 325MHz using RT/duroid 5870 Substrate(εr =2.33)

From graph as shown above we get,

s/d= 0.1 & w/d= 0.07

where d= height of substrate=0.06inch = 1.6mm

s = spacing between coupled lines

= 0.1* 1.6= 0.16mm

w = width of coupled lines

= 0.07* 1.6

= 0.112mm

$$\varepsilon eff = (2.33+1)/2 \quad + (2.33-1)/2 * 1/\sqrt{(1+12(d/w))}$$

$$= 1.7156$$

$$\lambda air = 3e8/325MHz$$

$$= 0.923 \text{ metre}$$

$$\lambda/4(\text{in microstrip}) = 0.923/4\sqrt{1.71}$$

$$= 176.170mm$$

This is the final design for a Lange coupler showing all the dimensions:

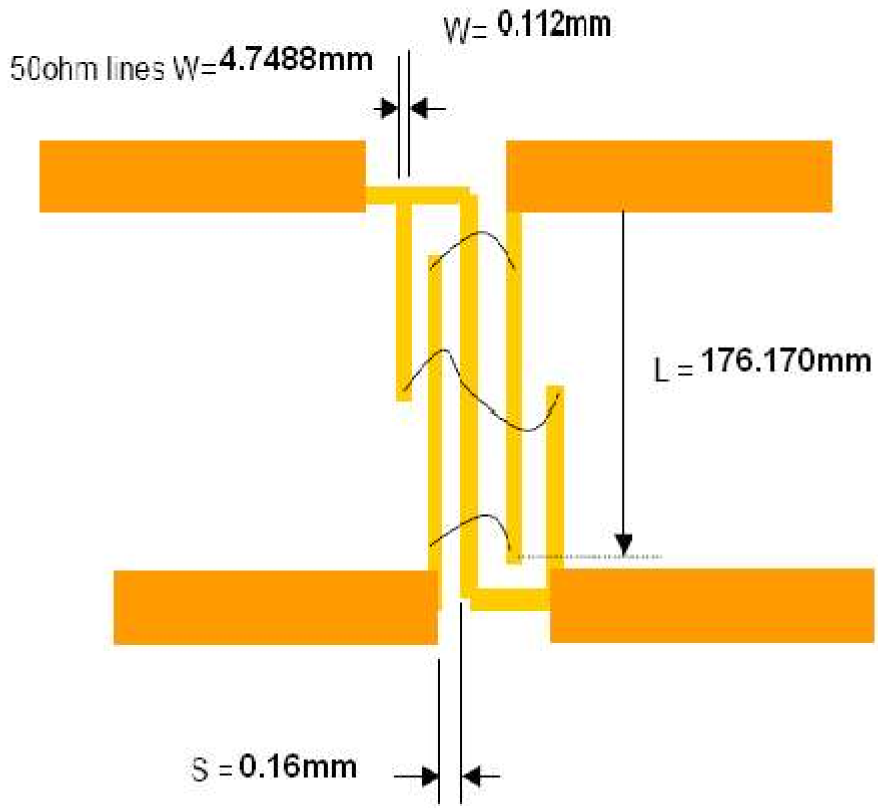


Figure 4: Final Design (Layout)

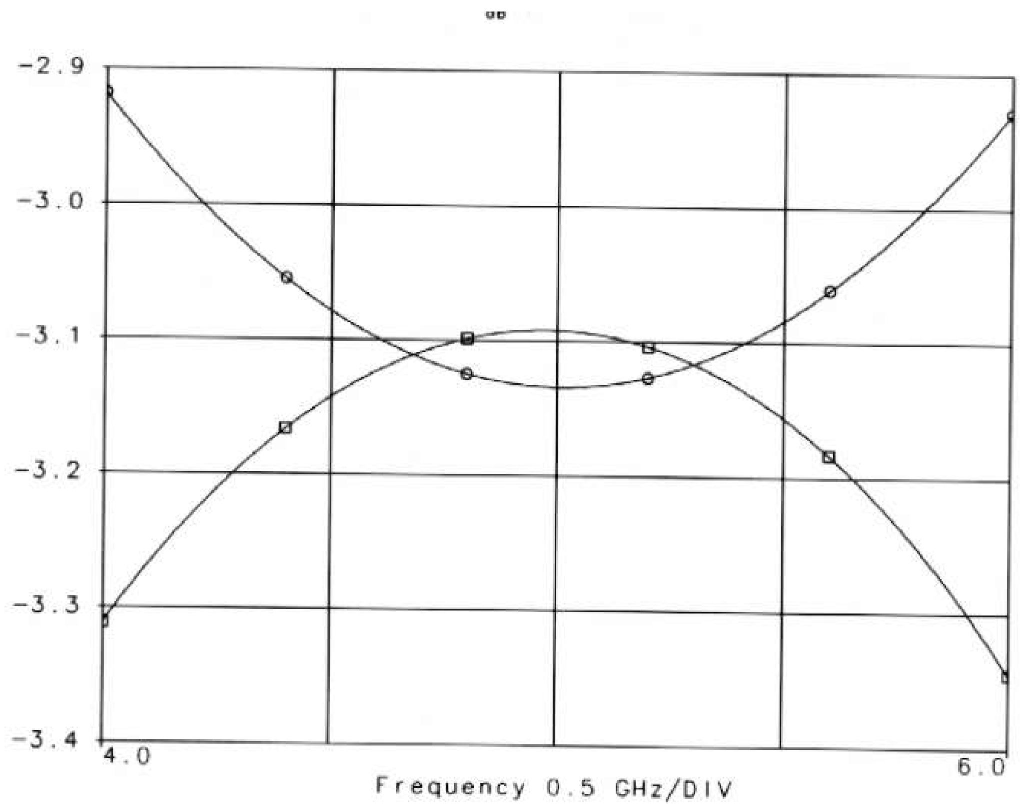


Figure 5: Ideal Response of Lange Coupler

An ideal responses for a particular design centered at 7.5 GHz frequency simulated by using ADS Agilent Software

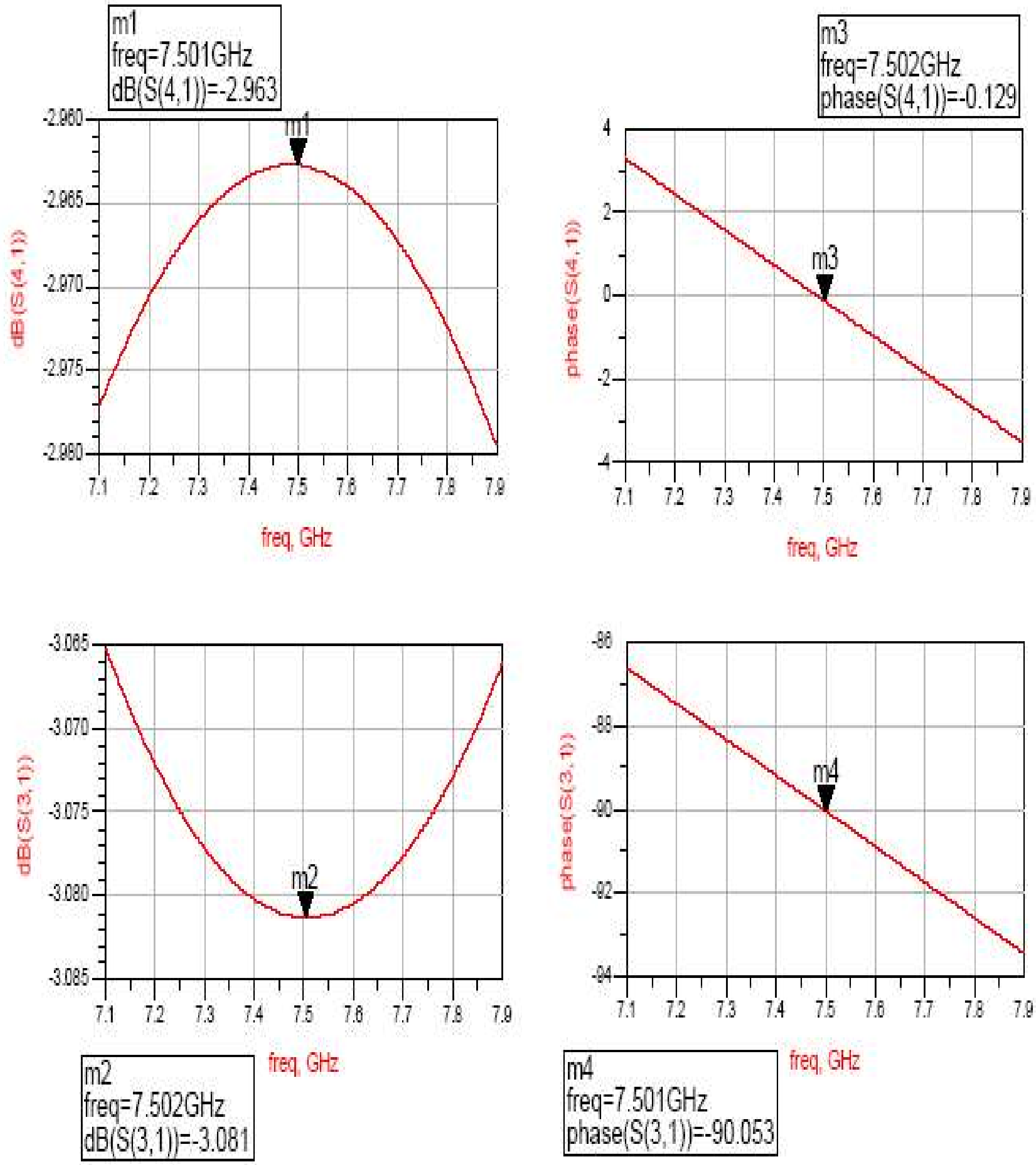


Figure 6: Amplitude & Phase Response of Lange Coupler

Design Realization

The Lange Coupler was designed using the above mentioned procedures. The design was then simulated using the RF Design CAD Software GENESYS V8 of Eagleware Corporation,USA .The summary of the simulated results are as under:

Average Insertion Loss	:0.15 dB
Signal Division (200-450MHz)	:3 +/- 2 dB
Phase Response (200-450MHz)	:90 (+ 4)/(- 0.5) degrees
Input Return Loss (200-450MHz)	: 25 dB(min.)
Isolation (200-450MHz)	:37 dB(min.)

The simulated response are shown in the figures:

Limitations of Lange Coupler:

Although Lange coupler is the most used wideband microstrip Quadrature Hybrid , its physical realization always requires quite a small line width 'w' and coupling spacing 's'. Therefore fabrication of Lange Coupler requires high precision PCB manufacturing facility.

Applications of Lange Couplers

1) **Attenuators**
2) **Balanced Amplifiers**
3) **Balanced Mixers**
4) **Discriminators**
5) **Phase Shifters**
6) **Modulators**
7) **90 Degrees Power Splitter**
8) **Polarizers**

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Conclusion

This work was carried out by the authors of GMRT Observatory of NCRA,TIFR as part of the B.Tech Final Year Project. This report presents methods of analyzing and designing high performance Lange couplers. The scope of this report is limited to the design aspects only. Simulated results are presented. The fabrication of the Lange Couplers has to be done using high precision Printed Circuit Board (PCB) manufacturing facility.The track width and the track spacings are of the order of about 0.1mm and cannot be realized on the PCB prototyping machine. It covers the frequency range of 200-450 MHz and gives expected results for converting the linearly polarized signals received from GMRT to dual circularly polarized signals.