1987

Design and Implementation of an Interdigitated Directional Coupler for use in Microwave Mixers

Golnaz Pourparviz
University of Central Florida

UNIVERSITY OF CENTRAL FLORIDA

OFFICE OF GRADUATE STUDIES

THESIS APPROVAL

DATE: November 20, 1987

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION

BY Golnaz Pourparviz

ENTITLED "The Design and Implementation of an Interdigitated Directional Coupler for Use in Microwave Mixers"

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS OF THE

DEGREE OF Master of Science in Engineering

FROM THE COLLEGE OF Engineering

Parveen Wahid
Parveen Wahid
Supervisor of Thesis

RECOMMENDATION CONCURRED IN:

Bruce E. Mathews
Coordinator of Degree Program

COMMITTEE ON FINAL EXAMINATION

Louis M. Trefonas
Dean of Graduate Studies

THE DESIGN AND IMPLEMENTATION OF AN INTER-DIGITATED DIRECTIONAL COUPLER FOR USE IN MICROWAVE MIXERS

BY

GOLNAZ POURPARVIZ
B.S.E., University of Central Florida, 1985

THESIS

Submitted in partial fulfilment of the requirements
for the degree of Master of Science in Engineering
in the Graduate Studies Program of the College of Engineering
University of Central Florida
Orlando, Florida

Fall Term
1987

ABSTRACT

The purpose of this thesis is to present a design for a balanced microwave mixer, operating in the X-band region(8-12 GHZ). The major emphasis of this work is on the coupling structure of the mixer. A 3-db interdigitated Lange coupler is designed, fabricated, and tested. The design obtained through numerical procedures is compared with that obtained with the TOUCHSTONE CAD package. A brief comparison between this coupler and other commonly used couplers is also presented. The diode circuitry of the mixer is discussed in detail, focusing mainly on the operation of the Schottky barrier diode, and finally a total layout of the mixer is discussed.

ACKNOWLEDGEMENTS

I would like to thank my entire committee, especially my chairman Dr. Parveen Wahid, for their support throughout the completion of this thesis work. A special thanks goes to my friend Mr. Ron Turner for his assistance in fabrication and bonding of the device, to Mr. Carl Bishop for his help in fabrication and line measurements, to Mr. A.J. Vigil for his help in generating the photomask, and to SAWTEK company for their effort in producing the actual photomask. Additionally, I would like to thank Mr. Darrell Turner for his effort in providing me with a program to use in generating the design curves.

Last but not least, I thank my parents and my entire family for love and support they have given me during the completion of this work.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter I

INTRODUCTION

During World War II the development of radar systems was the focus of many research groups across the world. Each of these groups concentrated on developing a high quality system. One of components of the radar system which got the most attention was the mixer at the receiving end, because the receiver end sensitivity was very critical in providing range capability for the radar system as whole. Radars developed in the past had to be operated at least at UHF in order to view targets the size of an airplane. Low noise amplifiers did not exist at these high frequencies so the received signal was down converted using a mixer in the first stage of the receiver. The use of the mixer improved considerably the sensitivity of the receiver[2].

Before 1940 little theoretical work had been done on mixers; the quality of point-contact diodes was very poor, causing high conversion losses in the low microwave frequency ranges. By the end of 1950's quality improvement of diodes, the use of special diode packages and extensive research on microwave mixers helped conversion losses drop to around 6 dB compared to 20 dB in early 1940's. Today, diode mixers are designed with conversion losses of 4 dB or smaller at frequencies around 50 GHz.

A mixer can be looked at as a simple analog multiplier. Any nonlinear device can perform the multiplying function. Nonlinear devices used in a mixer usually generate many harmonics and mixing products other than the one desired. The desired output frequency component can simply be filtered out at the output of the nonlinear device. Figure 1.1 shows an ideal analog multiplier.

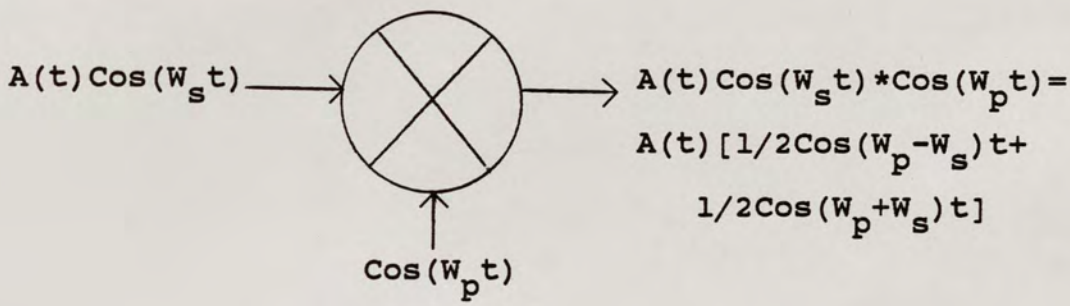

Figure 1.1 Ideal Analog Multiplier

Although any nonlinear or rectifying device can be used as a mixer, only a few devices satisfy the practical requirements of a mixer. Such requirements are strong nonlinearity, low noise, and adequate frequency response(large bandwidth).

One of the nonlinear devices used most often for a mixer design is the Schottky barrier diode, a diode created by a rectifying metal/semiconductor contact. The superiority of the Schottky barrier diode over the pn junction devices lies in the fact that this device is a majority carrier device and hence is not subject to recombination time limitation.

Schottky barrier diodes are now used in almost all mixers, and are availabe in a wide variety of packages, as well as bare chips. The main reason for improvements of mixer performance in the last few years has been the succesful development of high quality Schottky barrier junctions on gallium arsenide(GaAs). Gallium arsenide is much more attractive than silicon for high frequency applications due to its high electron mobility and saturation velocity, resulting in lower junction capacitance and hence improved switching times.

GaAs Schottky barrier diodes are more expensive than silicon diodes but their superior performance overrides the expense and for this reason are used in all microwave mixer applications.

A block diagram of a singly balanced mixer is shown in Figure 1.2. In a singly balanced mixer a 3 dB coupler is used to apply the local oscillator signal (LO) and the incoming RF signal to the diode circuitry by preventing any leakage from one of these port to another.

The main focus of this thesis will be on the coupler structure, specifically on the Lange Coupler.

The interdigitated 3 dB Lange coupler designed for the balanced mixer is a quadrature (90 degree) coupler, which is well suited for realization in microstrip form.

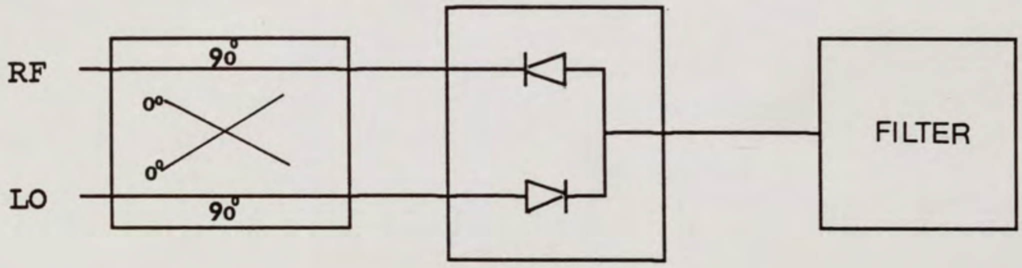

Figure 1.2 Block diagram for a singly balanced mixer

This coupler has the property of having conjugate pairs, that is, when power flows into one terminal of the coupler the power is isolated from the conjugate terminal and the power divides equally between the other two terminals. The main advantages of this 3 dB coupler are its small size and relatively large line separation when compared with the gaps of a conventional two coupled line device, and its relatively large bandwidth when compared with branch line couplers. Considering the above advantages and the available facilities for the fabrication of such a device the design and study of this coupler and its use in a microwave mixer was undertaken. The next chapter will present the characteristics of the Schottky barrier diode; it will also discuss the mixing process in a mixer.

CHAPTER TWO

SCHOTTKY BARRIER DIODE

In order to understand the behavior of the mixer, we first need to understand the characteristics of the nonlinear device used in the mixer design. The Schottky barrier diode which is a metal-semiconductor junction, is the non-linear device most often used. By looking at the energy-band diagram of the Schottky barrier diode and the nonlinear relationship which exists between the voltage and current we can analyze the mixing process in the microwave mixer.

Figure 2.1 shows the energy band diagrams for a metal and an n-type semiconductor before contact.

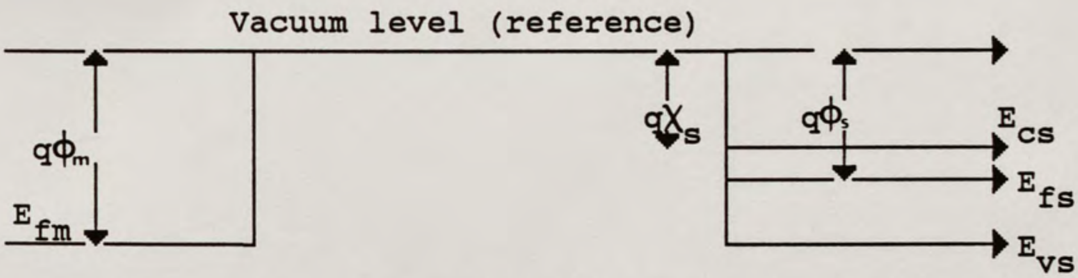

Figure 2.1 Energy-band diagram of metal and semiconductor before contact

E_{fm} : Fermi level of the metal

E_{fs} : Fermi level of the semiconductor

E_{cs} : Conduction band of the semiconductor

E_{vs} : Valance band of the semiconductor

$q\phi_s$ and $q\phi_m$: Work functions for semiconductor and metal

The work function represents the amount of the work required to bring an electron from the Fermi level of the material to the vacuum level. χ_s, called the electron affinity, specifies the energy required to bring an electron from the bottom of the conduction band to the vacuum level.

Figure 2.2 shows the metal and semiconductor in contact at equilibrium state with the Fermi levels aligned.

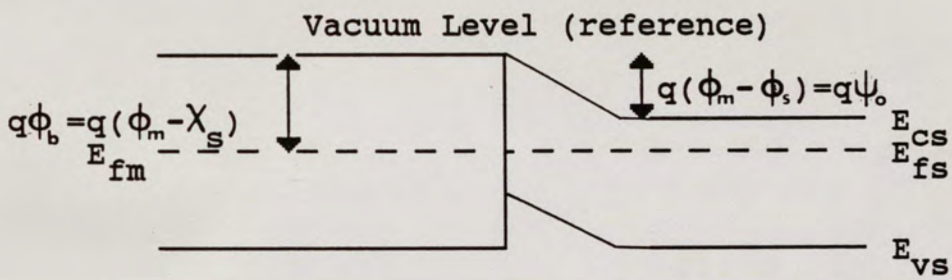

Figure 2.2 Metal and Semiconductor after contact

Let $q\phi_b = q(\phi_m - X_s)$ and $\psi_o = \phi_m - \phi_s$,

ϕ_b is called the barrier height of the metal-semiconductor contact and ψ_o is the built in potential established as the result of the contact. If we apply a forward bias of magnitude V, the semiconductor-to-metal potential is reduced to ψ_o-V, while ϕ_b remains unchanged.

The electron in the conduction band of the semiconductor can now move to the metal due to the reduction of the barrier potential resulting in a large current flow from metal to semiconductor. Since the current flow is due to majority carriers in the Schottky barrier diode, this device does not suffer from the charge-storage effects which limits the switching speeds in regular p-n junctions. This particular characteristic of the Schottky barrier diode makes it more attractive for use in mixer designs at high frequency.

2.1 General Concepts of The Mixing Process in a Mixer Diode

A 90 degree hybrid mixer consists of two individual diodes connected to the two mutually isolated ports of the hybrid coupler, with the other two ports used for LO and RF inputs. In order to understand the mixing process we approximate the I/V characteristic of the Schottky diode by a power series. The Schottky-barrier diode I/V characteristic is given by the following formula

$$I(v)=I_s*(\exp\ (q*v/n*K*T)\ -1)$$

I_s= diode saturation current

q= charge of an electron

T= absolute temperature

K= Boltzmann's constant

n= a constant slightly larger than 1

v= voltage across the metal and semiconductor junction

The Taylor series is used to expand the exponential nonlinearty of the diode junction, which holds over a limited range of voltage.

I= a*V+b*V**2+c*V**3+...

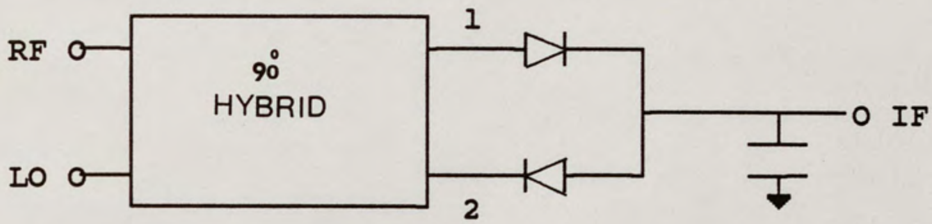

Figure 2.3 90 degree hybrid balanced mixer

Figure 2.3 shows a balanced mixer in normal operation, let the RF and LO signals be

$RF=V_{rf}*Cos(W_s*t)$

$LO=V_l*Cos(W_p*t)$

According to the operation of the quadrature hybrid coupler (Figure 2.3) the following relationships hold[3]

$$V_1= V_{rf}*Cos(W_s*t) + V_l*Cos(W_p*t+90) \quad (1)$$

$$V_2= V_l*Cos(W_p*t) + V_{rf}*Cos(W_s*t+90) \quad (2)$$

$$I_1=a*V_1+b*V_1**2+C*V_1**3 \quad (3)$$

$$I_2=-a*V_2+b*V_2**2-c*V_2**3+... \quad (4)$$

and $$I_{IF}= I_1-I_2 \quad (5)$$

By substituting (1) in (3) and (2) in (4) the currents I_1 and I_2 can be written as sum of sinusoidal terms with angular frequencies of nW_p+W_s. The current I_{IF} will also have the same angular frequency components. The desired signal can then be filtered out using a low pass filter. In a balanced mixer, the diodes should be oriented in such a way that the mixer will reject the undesired frequency components.

The development of small high quality Schottky junctions, with diameters below one micron, has allowed the recent improvements of mixers at frequencies above 1000 GHz. Shottky barrier diodes are now used in all type of mixers, and they come in large variety of packages, as well as bare chips [3].

CHAPTER THREE

INTERDIGITATED DIRECTIONAL COUPLER

In this chapter, the coupling section which forms an essential and important part of the mixer will be discussed. The theory of the Lange coupler which is the topic of this thesis will be presented along with design procedure used. The coupler provides isolation between the Local Oscillator output port (LO) and RF/IF ports. Hybrids couplers are four port devices, with all ports matched to their sources. If RF power is applied to any one port, it is split between two of the other ports, according to the power ratio it has been designed for, and no output comes out of the fourth port. For example, if a signal is applied to port 1 of a 180^{o} hybrid coupler, shown in Figure 3.1, the outputs at port 3 and 4 are 180^{o} out of phase, and 3 dB lower in level than the input, and no output appears at port 2. In a 90^{o}degrees (quadrature) coupler the phase difference between ports 3 and 4 will be 90^{o} degree instead of 180 degrees.

Figure 3.2 shows a simple model for a directional coupler. The characteristics of a directional coupler are usually expressed in terms of its coupling factor and its directivity. These factors are defined as

$$\text{Coupling Factor(dB)} = 10 \text{ Log}(P_1/P_4)$$

$$\text{Directivity factor(dB)} = 10 \text{ Log}(P_4/P_2)$$

P_1 is the input power, P_2 and P_4 are the power outputs at ports 2 and 4.

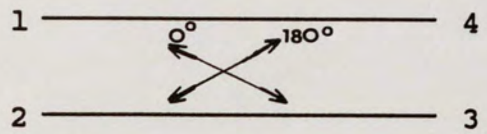

Figure 3.1 Hybrid coupler

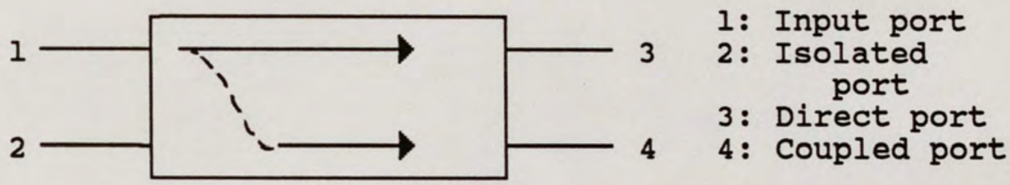

Figure 3.2 Directional Coupler Model

A directional coupler is considered ideal if its directivity comes close to infinity which implies that the output power at port 2 is close to zero. Usually a well designed directional coupler has directivity values between 25 to 35 dB. The goal of any design is to achieve complete isolation between the input port and output port 3.

The coupling factor is an indication of the power ratio between the input port 1 and coupled port 4. This ratio depends on the design requirements; a 3 dB coupling factor implies that the power level at port 4 is half the input power at port 1. In a balanced mixer, we design the directional coupler for a 3 dB coupling factor in order to have half the power present at the coupled port.

In the past, branch-line couplers were used in mixer designs but now coupled line hybrids are used most often due to the advantages that they have over the branch-line couplers. The branch-line coupler consists of two parallel transmission lines coupled through by a number of branch lines. These interconnecting lines are quarter-wavelength long and spaced one or multiples of quarter-wavelength apart. Figure 3.3 shows a simple single-section of a 3-dB branch line hybrid. The plot of the performance of this single section is shown in Figure 3.4[3].

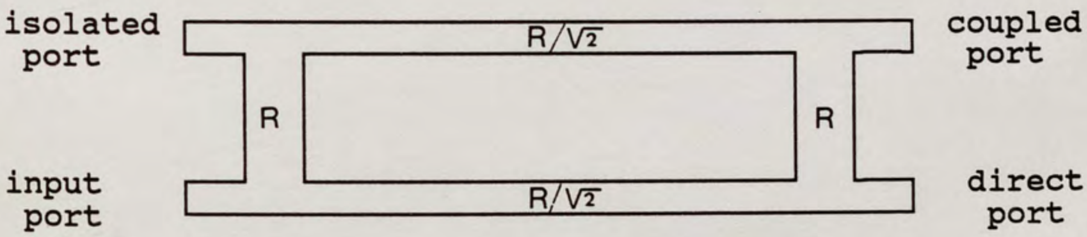

Figure 3.3 Single section branch-line hybrid

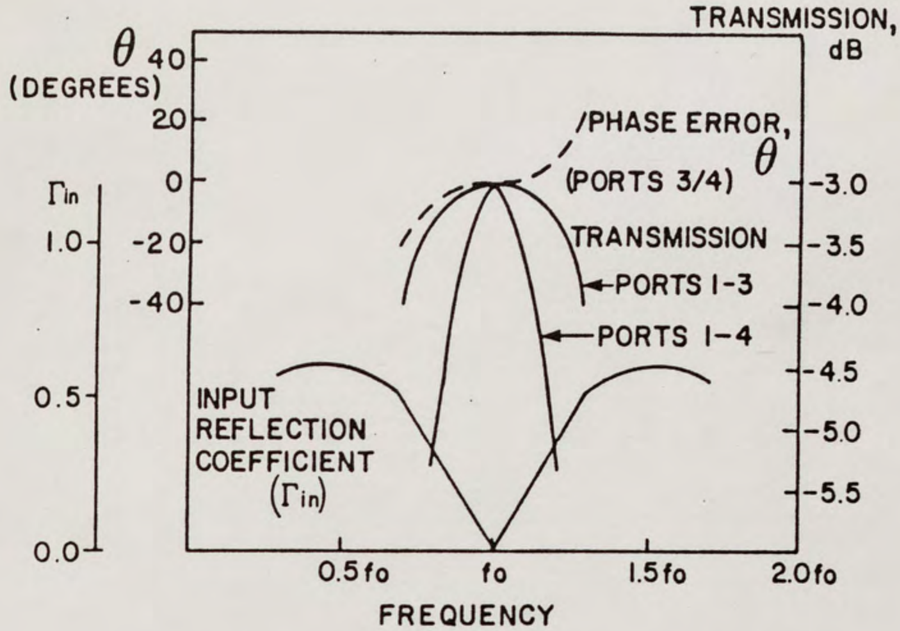

Figure 3.4 Performance plot of a single section of the branch-line hybrid

As can be seen in this plot the transmission bandwidth between ports 1 and 3 (taking port 1 as the input port) is larger than the transmission bandwidth between ports 2 and 4. This can cause amplitude unbalance over the desired bandwidth, which limits use to narrow band applications. Although we can overcome the narrow bandwidth problem of the coupler by cascading the single sections together there would still be another problem, that of achieving practical line impedances for the hybrid. Obtaining practical line impedances are difficult for single-sections but are especially difficult for multi-section designs. Another problem with branch line coupler is that as frequancy increases, a point is reached where the transmission line lengths become almost equal to their widths. Along with all these problems, there is still one major problem with the use of branch-line hybrids in mixer design, and that is the size of these hybrids. The branch-line hybrids are larger than coupled-line hybrids and they are also limited in microstrip realization.

The interdigitated directional coupler shown in Figure 3.5, first introduced by Lange, provides a more suitable and stable coupler for X-band operation and is well suited for realization in microstrip form. This coupler has the same property as the other quadrature coupler having conjugate pairs, that is power flows into one terminal of the coupler, is isolated from the conjugate terminal and divided between the other two terminals depending on the design power ratio. This coupler has a larger bandwidth than that obtained with branch couplers and is also an ideal component for balanced microwave cicuits and for binary power divider trees[7].

The interdigitated coupler can be viewed as a multiconductor transmission line of N (N must be even) elements, not including the ground plane. On any TEM, N wire transmission line, N orthogonal modes can exist. Figure 3.6 shows the four different modes which can exist in the Lange coupler, two out of the four

1: input port
2: isolation port
3: coupled port
4: direct port

Figure 3.5 The Interdigitated Lange Coupler

orthogonal modes are eliminated because the potentials on the strip are equated by wire bonds. Thus there are only two modes that we should consider, the even and the odd mode. The even mode excitation occurs when all conductors are at the same potential, and the odd mode exists when the adjacent conductors are at opposite potential of equal magnitudes as shown in Figure 3.7. In this chapter, the design parameters for this coupler will be derived from current/voltage relationship.

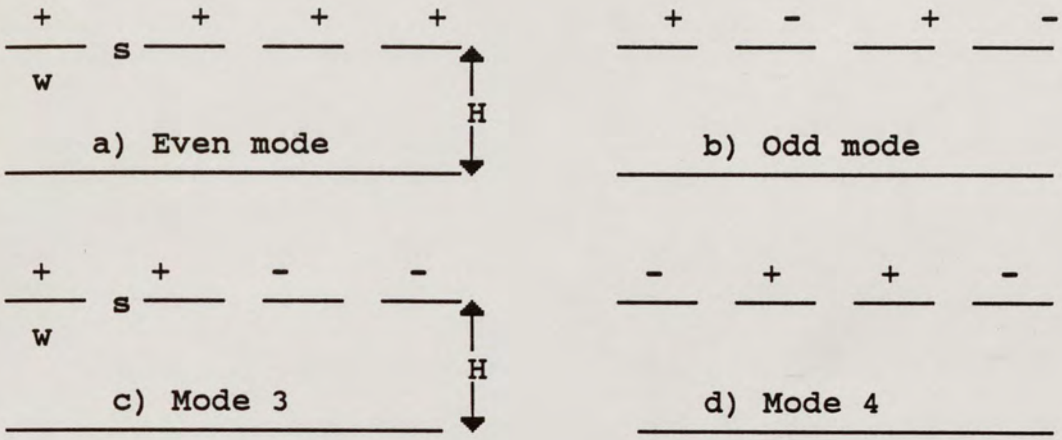

Figure 3.6 The four modes existing in the Lange coupler [6]

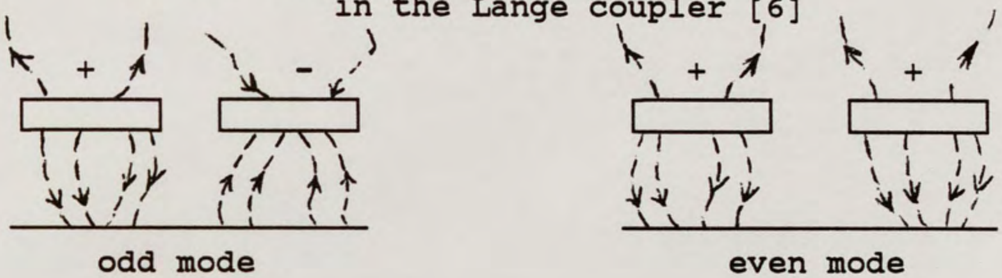

Figure 3.7 The even and odd modes

3.1 Design Equations For Interdigitated Coupler

This interdigitated directional coupler cannot be designed by use of traditional coupled-line methods, such as the popular computer program of Bryant and Weiss since the charge distribution for the four-strip coupler is completly different from that of two coupled lines[6]. The design equations for the interdigitated directional coupler are derived from the current and voltage relation for an array of transmission lines. To form an interdigitated structure the alternate terminals of the array are connected together on both ends as shown in Figure 3.8. The four ports of the resulting network are assigned as ports A, B, C,and D. The terminal currents and voltages of this four-port network can be writen as following[5]:

$$\begin{bmatrix} I_A \\ I_B \\ I_C \\ I_D \end{bmatrix} = \begin{bmatrix} -jMCot\theta & -jNCot\theta & jNCsc\theta & jMCsc\theta \\ -jNCot\theta & -jMCot\theta & jMCsc\theta & jNCsc\theta \\ jNCsc\theta & jMCsc\theta & -jMCot\theta & -jNCot\theta \\ jMCsc\theta & jNCsc\theta & -jNCot\theta & -jMCot\theta \end{bmatrix} \begin{bmatrix} V_A \\ V_B \\ V_C \\ V_D \end{bmatrix}$$

where θ is the electrical length of K(an even number) transmission lines, M and N are defined as:

$$M=K/2*Y_{11}+(K/2\ -1)*Y_{12}{}^2/Y_{11} \qquad (1)$$

$$N=(K-1)*Y_{12} \qquad (2)$$

Y_{mn} (m,n=1,2,... K)is the admittance between line m and n and it can be expressed in terms of self and mutual capacitances and phase velocity

$$Y_{m(m+1)}=-V_p*C_{m(m+1)} \qquad (3)$$

$$Y_{mm}=V_p*(C_{mo}+C_{(m-1)m}+C_{m(m+1)}) \qquad (4)$$

where

$C_{m(m+1)}$ mutual capacitance per unit length between lines m and m+1;

C_{mo} capacitance per unit length between line m and ground;

V_p phase velocity.

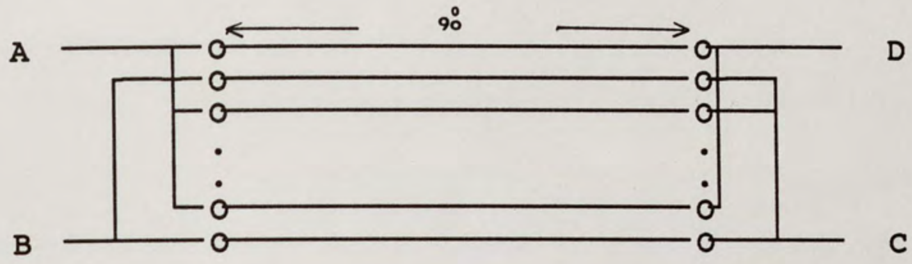

Figure 3.8 Interdigitated directional coupler

When this four-port network is used as a directional coupler, Θ is choosen to be 90 degrees at frequency of interest and as a result the current-voltage relation at the center frequency is reduced to [5]:

$$\begin{bmatrix} I_A \\ I_B \\ I_C \\ I_D \end{bmatrix} = \begin{bmatrix} 0 & 0 & jN & jM \\ 0 & 0 & jM & jN \\ jN & jM & 0 & 0 \\ jM & jN & 0 & 0 \end{bmatrix} \begin{bmatrix} V_A \\ V_B \\ V_C \\ V_D \end{bmatrix}$$

For a perfect directional coupler good match and high isolation are desired and these can be achieved if the terminated admittance at four ports, Y_o satisfies the condition:

$$Y_o^2 = M^2 - N^2 \qquad (5)$$

if port A is the input, then the power coupling ratios at the other ports can be determined as following:

$$P_B/P_{in} = N^2/M^2 \qquad (6)$$

$$P_C/P_{in} = 0 \qquad (7)$$

$$P_D/P_{in} = (M^2 - N^2)/M^2 \qquad (8)$$

since $P_C/P_{in} = 0$, port C is perfectly isolated from the input port. To obtain the design equation for the interdigitated directional coupler, equations (1) and (2) are substitued in equations (5) and (6), to give

$$Y_o^2=[K/2*Y_{11}+(K/2-1)*Y_{12}^2/Y_{11}]^2 - [(K-1)*Y_{12}]^2 \quad (9)$$

$$P_B/P_{in}=[2*(K-1)*Y_{11}*Y_{12}/K*Y_{11}^2+(K-2)*Y_{12}]^2 \quad (10)$$

Equations (9) and (10) can be written in terms of even and odd-mode admittances, Y_{oe} and Y_{oo}, of a pair of coupled lines. By definition:

$$Y_{11}=1/2*(Y_{oo}+Y_{oe}) \quad (11)$$

$$Y_{11}=-1/2*(Y_{oo}-Y_{oe}) \quad (12)$$

Substituing equations (11) and (12) in (9) and (10) the followings are obtained:

$$Y_o^2=[(K-1)*Y_{oo}^2+Y_{oo}*Y_{oe}]*[(K-1)*Y_{oe}^2+Y_{oo}*Y_{oe}]/(Y_{oo}+Y_{oe})^2 \quad (13)$$

$$P_B/P_{in}=\{[(K-1)*Y_{oo}^2-(K-1)*Y_{oe}^2]/[(K-1)*Y_{oo}^2-2*Y_{oo}*Y_{oe}+(K-1)*Y_{oe}^2]\}^2 \quad (14)$$

For a pair of coupled lines, K=2, equations (13) and (14) are reduced to:

$$Y_o^2=Y_{oo}*Y_{oe} \quad (15)$$

$$P_B/P_{in}=[(Y_{oo}-Y_{oe})/(Y_{oo}+Y_{oe})]^2 \quad (16)$$

Equation (16) is the power coupling ratio for an interdigitated coupler and equation (15) shows the relationship between the even and odd-mode admittances and the characteristic admittance of the coupled lines. The effects of ridging connections and junction discontinui ties have been neglected in deriving the above design equations. As a result there is a limitation on the number of lines to be used in the interdigitated coupler. However for most practical purpose K=2 and K=4 are satisfactory choices.

One popular technique used in deriving the self and mutual capacitances for a set of coupled lines is through the use of Green's function. Paolino [6] used this method to analyze interdigitated directional coupler and obtained a set of design curves in the frequency range of 1.5 t0 2.5 GHz with coupling factor varying between 2.5 db to 6 db. He then used the same basic design equations for interdigitated coupler shown in equations (15) and (16) to observe the relation between coupling ratio and the modes impedances. His approach for finding the capacitance to ground of the strips is to subdivide each strip into ten substrips, each substrip considered a line charge. The Green's function describing a microstrip line charge is used along with a moment method to calculate charge distribution on the strips. Then from charge density design parameters such as mode impedances and velocities are determined. The width and spacing of the four coupled lines are derived from these design parameters [6].

In designing the coupler for this thesis, a set of design curves was derived for two diferent substrates using the TOUCHSTONE program for a frequency of 2 GHZ [1]. Paolino's results were checked with this program and the same design parameters were obtained. After confirming the TOUCHSTONE results, two sets of design curves were derived for 9 GHZ. The results from these curves were used in fabricating the interdigitated coupler. A complete discussion of these design curves is the subject of the next chapter.

CHAPTER FOUR

DESIGN, FABRICATION, AND EXPERIMENTAL RESULTS

In this chapter, the design process, fabrication, and testing of a four-strip interdigitated Lange coupler at the X-band is presented. The variation of the even and odd mode impedances with spacing and width of the lines, and the variation of coupling with line dimensions are presented.

4.1 Dependance of Impedance and Coupling Coefficient on Line Dimension

The design procedure was carried out using the TOUCHSTONE and LINECALC software packages. The procedure is based on the analysis presented in Chapter III. To facilitate future research on four-strip Lange couplers, sets of design curves for a low dielectric substrate (ϵ_r=2.5) and a high dielectric substrate (ϵ_r =10.5) were generated using the LINECALC program and are presented in Figures 4.1 and 4.2. These curves show the dependance of the even and odd mode impedances on the width to height (W/H) and spacing (S/H) ratios of the coupled lines. The values of the impedances were obtained using the LINECALC program. The validity of the results were checked against those obtained by Paolino [6] in his analysis, and very good agreement was obtained.

The relation between Z_{oo} and Z_{oe}, the impedance of the even and odd modes, and Z_o the characteristic impedance is

$$Z_{oo}=Z_o((1-C)/(1+C))^{1/2} \qquad (1)$$

$$Z_{oe}=Z_o^2/Z_{oo} \qquad (2)$$

Where C is the voltage coupling coefficient. For a given Z_o and C, Z_{oe} and Z_{oo} can be calculated from the above equations and the corresponding values of S/H and W/H can be read from the design curves.

In Figure 4.3, the variation in shape ratios S/H and W/H as a function of the coupling coefficient for 50 ohm coupler on a dielectric substrate of 2.5 at 9 GHz is shown. It can be seen that required coupling decreases as the shape ratios increase. It was also found that the coupling coefficient was not very sensitive to changes in values over the range of 2 to 10.5.

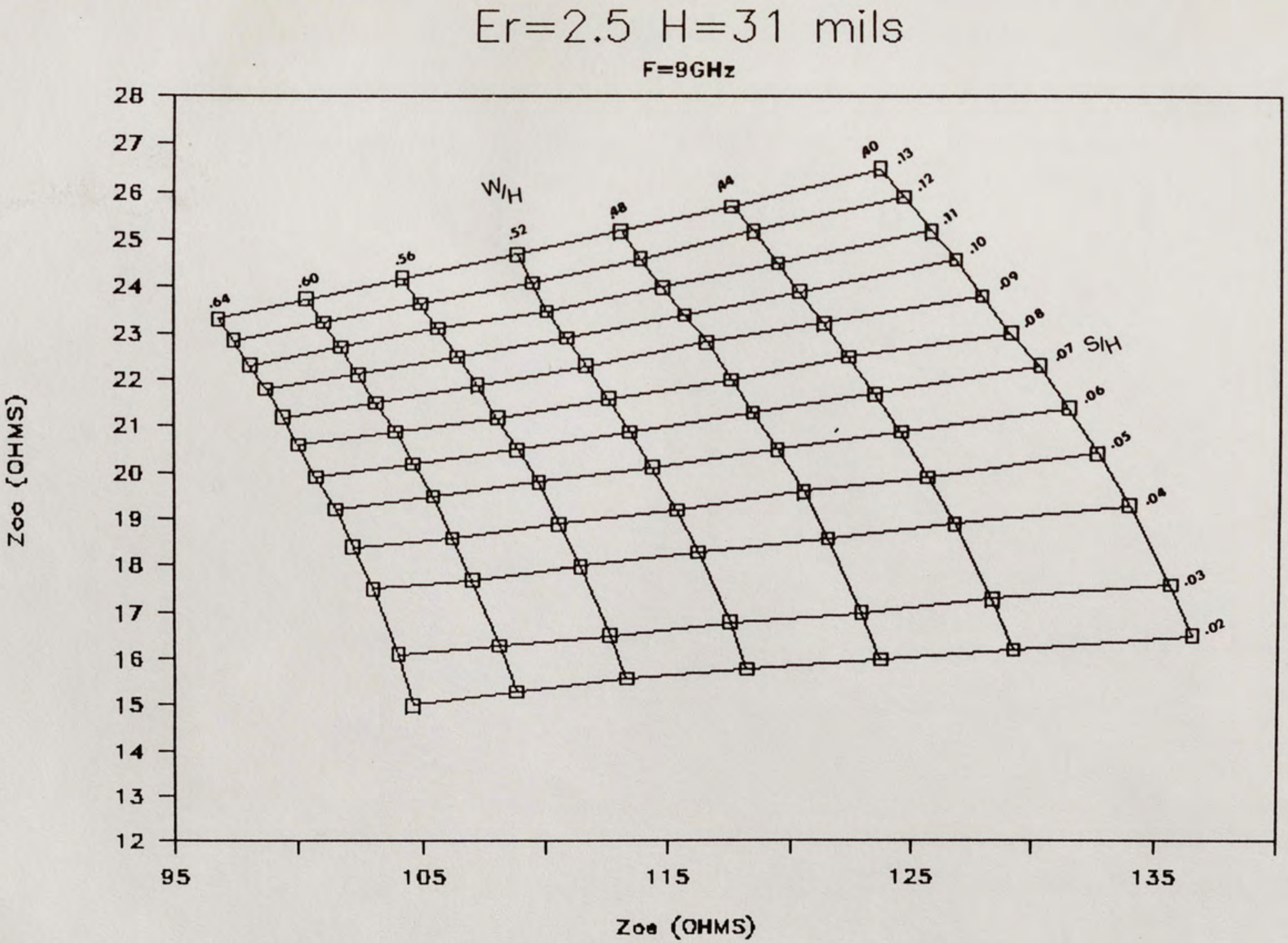

Figure 4.1 Design curve for $\epsilon_r = 2.5$

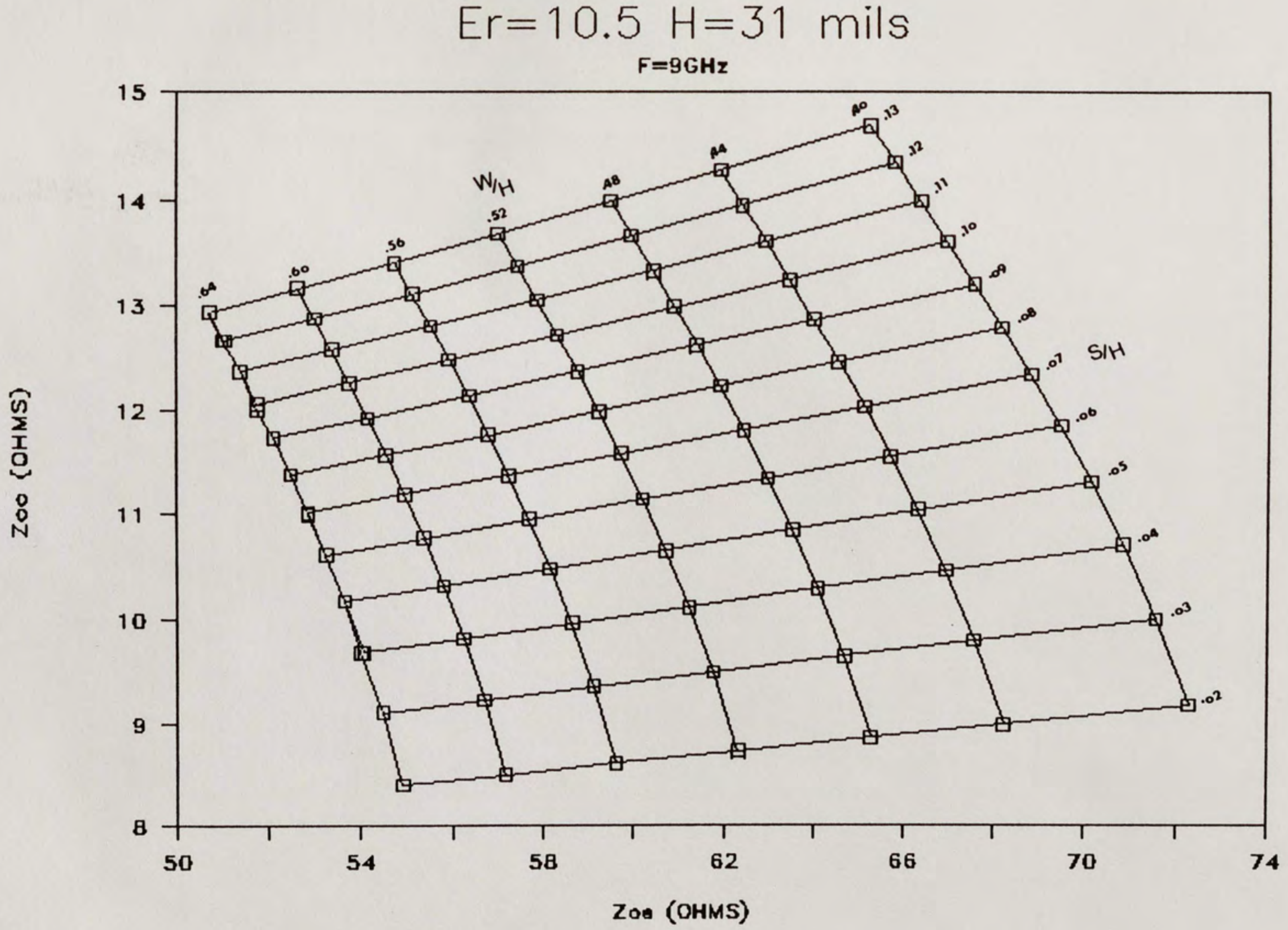

Figure 4.2 Design curve for $\epsilon_r = 10.5$

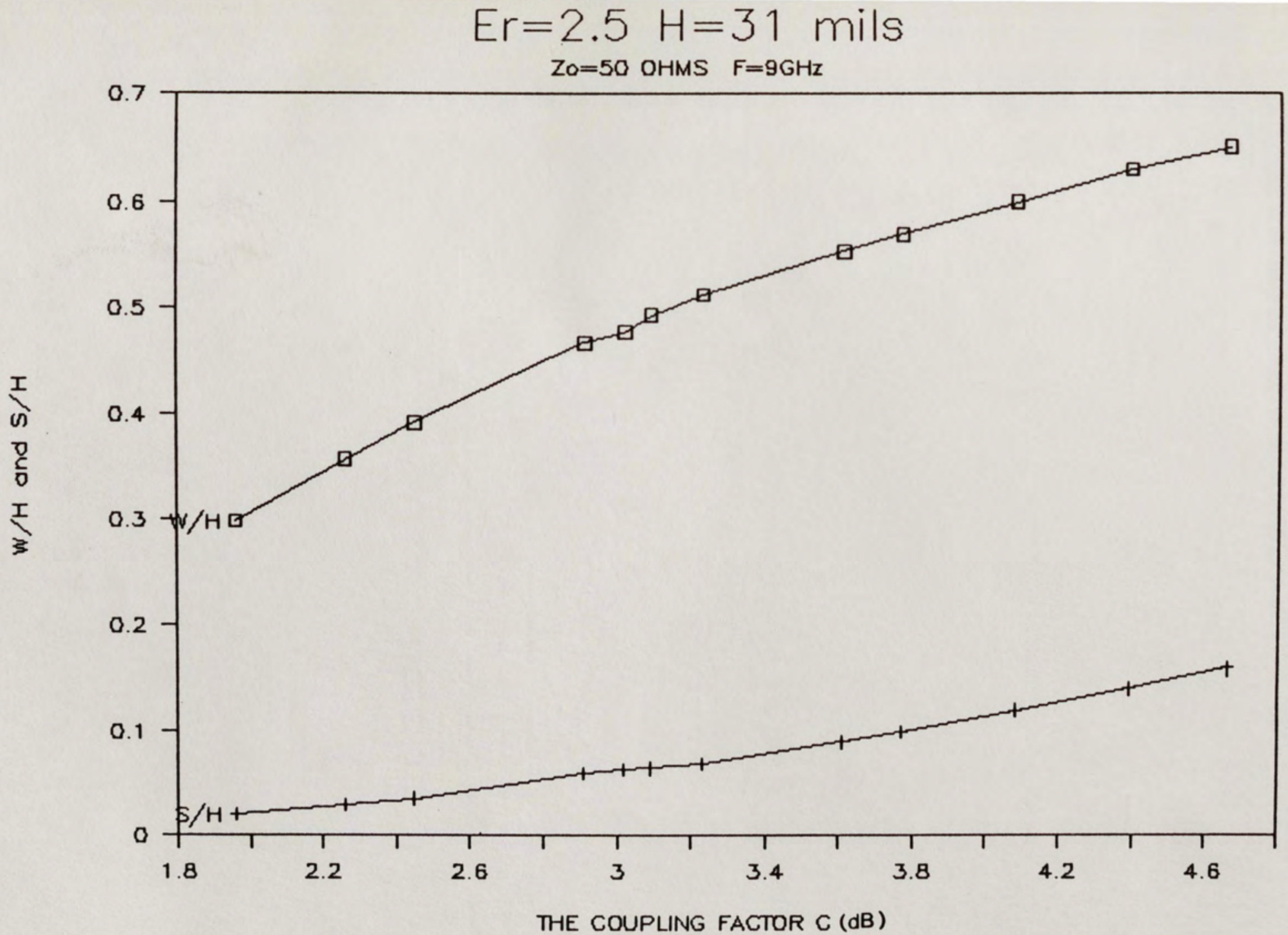

Figure 4.3 Shape ratios versus coupling coefficient

4.2 Design of The Lange Coupler

The Lange coupler considered was a four-strip interdigitated coupler to provide 3 dB coupling at 9 GHz. Using equations (1) and (2), the values of Z_{oo} and Z_{oe} were calculated for =2.5. From the design curves of Figure 4.1 the required values of S/H and W/H were obtained these values are given in Table 4.1

Z_o (Ohms)	C	Z_{oe} (Ohms)	Z_{oo} (Ohms)	W/H	S/H
50	.5	28.86	86.60	.683	.288

Table 4.1 Data obtained from equations 1 and 2 and the design curve for =2.5

To achieve desired coupling and good isolation an optimization process was carried out using TOUCHSTONE program. The final optimized results are shown in Table 4.2

Z_o (Ohms)	C	Z_{oe} (Ohms)	Z_{oo} (Ohms)	W/H	S/H
49	.5	28.40	78.55	.772	.319

Table 4.2 Optimized data for the Lange coupler

The data in Table 4.2 was used to generate the photomask for fabricating of the Lange coupler. The actual mask was generated at SAWTEK Inc. in Orlando. The actual dimensions used in the fabrication of the coupler are shown in Figure 4.4.

The Lange coupler was fabricated on copper-plated RT-duroid board (#5883) with =2.5 thickness of.031" inches, and loss tangent of .0012. The fabrication process consisted of

- Cleaning the copper board
- Applying positive photoresist to metalized surface and soft bake
- Exposing the board to ultraviolet ligth with photomask on top
- Developing the board to remove the exposed photoresist
- Etching with Nitric Acid.

1: input port
2: isolation port
3: coupled port
4: direct port

Figure 4.4 The Lange coupler with actual dimension used in fabrication

The next step was to bond the strips, this step was the most difficult task of all due to the small dimensions of the lines and spacing between them. The bonding was done by soldering gold wires, with special care taken to minimize the effect of bonding-wire inductance and to maintain electrical symmetry. Good performance of a quadrature coupler, i.e., high isolation, tight coupling, and exact 90° phase difference are dependent on good symmetry.

4.3 The Coupler Test Results

The Lange coupler was tested using the HP 8408A automatic network analyzer. Each port was tested separately while the other two ports were terminated in 50 ohm loads, since the pads on the coupler had a characteristic impedance of 50 Ohms. The test results were taken over the frequency range of 7.5 to 9.5 GHz. Table 4.3 shows the test results for all the three ports of the coupler.

Table 4.3 Test results for the coupler

A. Coupled port

Frequency (GHz)	Insertion loss Magnitude (dB)	Phase (Degrees)
8.2	2.8	57
8.35	3.8	28
8.4	6.5	13
8.6	8.9	-13

B. Direct port

Frequency (GHz)	Insertion loss Magnitude (dB)	Phase (Degrees)
8.2	.9	-20
8.35	1.1	-54
8.4	2.0	-44
8.6	3.3	-62

C. Isolated port

Frequency (GHz)	Insertion loss Magnitude (dB)	Phase (Degrees)
8.2	8.2	-11
8.35	9.6	-53
8.4	8.9	-43
8.6	10.2	-66

It is seen that at 8.35 GHz, a coupling of 3.8 dB and isolation of 9.6 dB is obtained. The actual width of the lines and the spacing of the fabricated device were measured using a microscope, the spacing was 12.9 mils and the width was 21.1 mils giving S/H=.416 and W/H=.68 these values deviate a little from the values used to generate the photomask . It should be noted that the effects of the bond wires, edge reflection, and copper thickness were not considered. The deviation from 9 GHz for which the coupler was designed could be due mainly to errors in fabrication because of the very small dimensions involved and not accounting for the above effects. Figure 4.4 shows a view of the actual fabricated device used for testing.

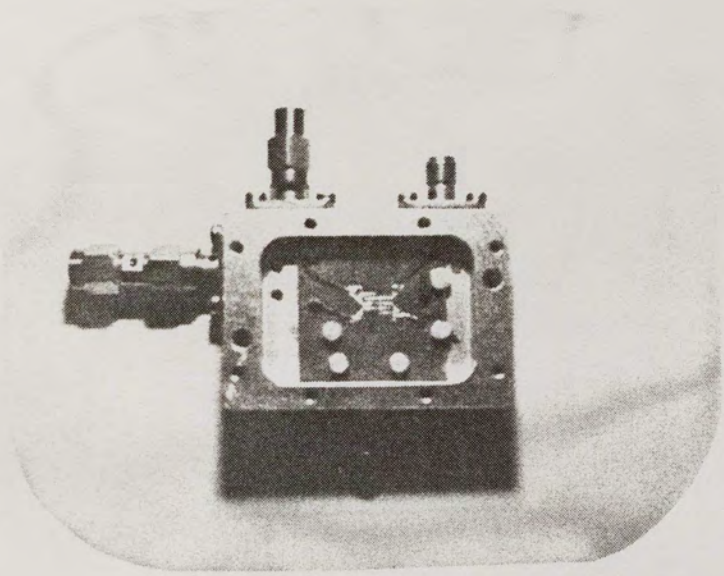

Figure 4.5 View of the fabricated coupler

4.4 Overall Mixer Realization

The availability of low-parasitic diodes which can be used at high frequencies (millimeter wave region) have lead to investigations on low-cost easily realizable mixer circuits. Cost reduction can be achieved in a mixer when all the mixer circuitry is realizable in a microwave strip transmission medium, rather than as waveguide components. The Lange coupler discussed in this thesis illustrates this point and can be integrated in planar microwave/millimeter wave circuits. Feeding to the signal and local oscillator ports can be achieved through waveguide to microstrip transitions. The filter section of the mixer can be realized in planar circuits [4]; the TOUCHSTONE program also has the capability to aid in the design of the filter in the planar form. Hence the various parts of the mixer can conveniently be integrated in a planar cicuit form.

CHAPTER FIVE

CONCLUSION

The design, fabrication, and test results of a Lange coupler at 9 GHz are presented. Design curves are given which allow one to obtain required line dimensions for any given coupling coefficient. The even and odd mode theory for coupled lines was used, with design data being generated through the use of the TOUCHSTONE program. Measurements on all ports of the coupler were done over a frequency range of 7.5 t0 9.5 GHz. The size of the coupler and dimensions of the lines being very small gave cause for many sources of error in the fabrication process. The contributions due to bond wires and sharp edges of the coupler were not accounted anywhere in the design, though they do contribute to the overall performance of the coupler. For more precise and accurate design these factors plus the thickness of the copper need to be considered. Reasonable results were obtained with values of 3.8 dB for coupling and 9.6 dB for the isolation at 8.35 GHz.

This work illustrated the fact that the Lange coupler can be designed and manufactured in a planar cicuit form which makes it a very usefull component for use in microwave and millimeter wave mixers.

REFERENCES

[1] Childs, William H. "A 3-dB interdigitated coupler on fused silica." IEEE Microwave Symposium, 1977.

[2] Kollberg, Erik, ed., Microwave and millimeter Mixers. New York: IEEE Press, 1984.

[3] Maas, Stephen. Microwave Mixers. Dedham: Artech House, Inc., 1986.

[4] Meier, P.J. "Planar multiport millimeter integrated circuits." IEEE MTT Symposium Digest, June, 1977.

[5] Ou, Wen Pin. " Design equations for an interdigitated directional coupler." IEEE Transaction on MTT, Vol. MTT-23 (February 1975): 253-255

[6] Paolino, Donald D. "Design more acurate interdigitated couplers", IEEE Microwaves (May 1976): 34-38

[7] Presser, Adolph. "Interdigitated microstrip coupler design", IEEE Transaction on MTT, Vol.MTT-26 (October 1978): 801-805