Implementation of a 35 GHz Microstrip Antenna System

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IMPLEMENTATION OF A 35 GHz MICROSTRIP ANTENNA SYSTEM

BY

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B.S.E, University of Central Florida, 1986

RESEARCH REPORT

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ABSTRACT

Millimeter waves, corresponding to the frequency range 30 to 300 GHz, have characteristics which make them ideal for many applications. Antennas at these frequencies have the advantage of reduced size and weight and can be fabricated as an integral part of the system they are used in.

Millimeter wave microstrip antennas have been extensively researched over the past decade. The purpose of this report was to build and test 35 GHz microstrip antennas as well as put into operation a high voltage klystron power supply, Micro-Now Model 756. The antennas were fabricated and tested in the lab and the results obtained are reported. The operation of the Model 756 power supply is also outlined in detail.
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CHAPTER 1

KLYSTRON POWER SUPPLY

The millimeter wave antennas constructed and tested were powered and driven by an advanced power supply system. This system was composed of a high voltage klystron power supply and a millimeter wave signal generator, the reflex klystron. The description and operation of the component parts of this power supply system will be addressed in this chapter.

1.1 Reflex Klystron

Reflex klystrons are used quite frequently as laboratory signal generators, low power transmitters, or local oscillators. An overview of the reflex klystron and its operation will be presented.

A schematic diagram of a reflex klystron and the voltages required for operation is shown in Figure 1.1. The components composing the tube are the cathode, a focusing electrode at cathode potential, a reflector which is at a negative potential with respect to the cathode, and an anode which operates as a cavity resonator. The teamwork of the cathode, the focusing electrode, and the anode produces an electron beam that
travels through the resonator gap toward the reflector. The reflector, being at a negative potential with respect to the anode, repels the electrons back toward the anode. This reverse path of the electrons sends them back through the gap a second time \[1\].

The operation of the klystron is based on the principle of velocity modulation. An RF signal is
applied across the gap in the resonator. Electrons passing through the gap are accelerated or decelerated according to the voltage they experience from the gap. Once they leave the gap they then travel through the drift space toward the reflector at different speeds. This difference in velocities causes the electrons to bunch in the drift space as they approach the reflector and are repelled. These bunches of electrons are turned back toward the cavity by the negative repeller voltage. Figure 1.2 shows the distance-time plot of the electrons or Applegate diagram [2].

In order to maintain oscillations and obtain amplification in the cavity, the returning electron

![Figure 1.2. Applegate Diagram.](image)
bunches should arrive at the gap when the RF voltage is decreasing so that the electron bunch is slowed down. These electrons will then give up energy to the resonant cavity. The frequency of the cavity oscillation is the frequency of the output produced by the klystron.

The electron transit time can be tuned by adjusting the reflector voltage. The more negative the reflector voltage with respect to the cathode, the shorter the transit time. The oscillation of the klystron produces a signal at the frequency of oscillation. This signal is coupled out of the cavity by either a loop, a coaxial line, or slots. The latter is used for the reflex klystron used in the lab [3].

With the resonant cavity tuned to one frequency, different repeller voltages will produce the same frequency oscillation. The resulting repeller modes are shown in Figure 1.3. The power output and frequency variation versus repeller voltage is shown. As mentioned above, different transit times of the electron bunches produce slightly different frequencies. This provides a fine control of the reflex klystron. The plot shows that the highest power output within a mode is obtained at the center of the mode. Therefore, this technique of frequency variation is used only for slight variations.
Figure 1.3. Power Output and Frequency Characteristics of a Reflex Klystron.
Frequency modulation of the reflex klystron was achieved by applying a 1 kHz square wave to modulate the repeller voltage.

The millimeter wave reflex klystrons available for use in the lab are the VA-97, Oki 35V11, and Oki 35V12. These are all very sensitive to feed conditions and will be damaged if not properly handled. Table 1.1 defines the operating conditions for the three types of reflex klystrons [3;4].

**TABLE 1.1**

**KLYSTRON OPERATING CONDITIONS.**

<table>
<thead>
<tr>
<th>OPERATIONAL PARAMETER</th>
<th>OPERATIONAL VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VA-97</td>
</tr>
<tr>
<td>Frequency Range (GHz)</td>
<td>34.0 to 35.6</td>
</tr>
<tr>
<td>Resonator Voltage (volts)</td>
<td>400</td>
</tr>
<tr>
<td>Resonator Current (mA)</td>
<td>40</td>
</tr>
<tr>
<td>Grid Voltage (Volts)</td>
<td></td>
</tr>
<tr>
<td>Reflector Voltage (volts)</td>
<td>-140</td>
</tr>
</tbody>
</table>
Figure 1.4 shows the reflex klystron, Oki 35V12, used for this report. It is manufactured by the Oki Electric Industry Company which produces a family of reflex klystrons covering the frequency range from 15 to 180 GHz. The Oki 35V12 covers the range from 33.0 to 37.0 GHz [3].
1.2 Klystron Power Supply

The high voltage klystron power supply used was the Model 756 by Micro-Now Instruments. This power supply is capable of supplying up to 2800 volts to the resonator, 1000 volts to the reflector, and 200 volts to the grid. It includes a regulated DC heater supply which minimizes incidental FM. Reflector modulation can be internally or externally applied, and the oscillator tube frequency stabilization can be controlled by external means. A switchable front panel meter offers convenient monitoring of the operating currents and voltages. The power supply protects the reflector, beam current, and filament from overload [5]. Since this is a very high voltage power supply, the use of the instrument requires a thorough knowledge of safety procedures and extreme care. The front panel of this power supply is shown in Figure 1.5.

The basic procedure for setting up the power supply for the operation of a reflex klystron is as follows [5]:

A. Check that the following controls are positioned as specified below:

<table>
<thead>
<tr>
<th>Control</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Power</td>
<td>OFF</td>
</tr>
<tr>
<td>Beam</td>
<td>OFF</td>
</tr>
<tr>
<td>Reflector Modulation</td>
<td>OFF</td>
</tr>
<tr>
<td>1 kHz Modulation Amplitude</td>
<td>OFF</td>
</tr>
<tr>
<td>Reflector</td>
<td>Mid-Range</td>
</tr>
</tbody>
</table>
Control Grid
Beam (500,1000,1500,2000)
(100,500)

Full CW
500 V.
100 V.

Figure 1.5. Power Supply Front Panel.

B. Connect the klystron cable to back panel port.
C. Connect the klystron to cable as well as all waveguides and system components before power is turned on. Connect the cable ground wire to the chassis of the klystron.
D. Turn the main power ON. The amber power light should then come on. The reflector and grid voltages should be indicated and these can be monitored by the front panel meter.

E. After 3 minutes, the time delay relay will energize.

F. With the Beam switch in the OFF position, adjust the heater control, grid voltage, and reflector voltage according to the klystron's manufacturer's specification.

G. Turn Beam Power switch to ON. The red lamp will light and the beam voltage should be indicated on the front panel meter.

H. In the event that the beam current overload protection is triggered:

Reset the beam voltage by depressing the illuminated overload indicator switch. If the overload continues, verify that the beam current is not excessive, or that the current overload adjust (located on rear panel) is not adjusted too low for the tube being used.

I. Increase the beam voltage slowly to avoid excessive internal arcing within the klystron. If an arc occurs, the reflector arc overload indicator will illuminate and the beam voltage will automatically be reduced. To reset, turn the Beam Power switch OFF for a few moments and then back ON. If the overload occurs
again, recycle the Beam Power switch after first reducing the front panel Beam Voltage controls. After a few minutes of operating at this lowered potential, slowly increase the beam voltage. Repeat the above procedure until the correct operating potential is reached [5].

J. When operating any reflex klystron, forced air cooling must be applied. The use of a small powerful fan is sufficient. Never operate a klystron without cooling compensation.

K. If the beam voltage required by the klystron is below 550 volts, adjust the potentiometer on the back panel of the power supply to lower the output voltage while monitoring the front panel meter for the correct beam voltage.

L. The front panel meter is accurate and should be monitored when voltage adjustments are made by the front panel controls.

To check the frequency of the klystron, the following procedure is adopted [1]:

A. Follow the start up procedure defined previously using the equipment set up shown in Figure 1.6.

B. Set the Modulation to a square wave and its Amplitude to mid-range.

C. The oscilloscope horizontal input should be AC coupled to the 1 kHz signal generator, and the vertical
KLYSTRON POWER SUPPLY MODEL 756

OSCILLOSCOPE HP 1205A

1 kHz SQUARE WAVE

1 kHz SQUARE WAVE

Figure 1.6. Equipment Set Up for Frequency Measurement.

input should be DC coupled to the crystal detector output. The attenuator should be set to approximately 15 db. The frequency meter should be set to approximately 28 GHz.

D. Turn the scope on and adjust the horizontal and vertical sensitivities.

E. Slowly turn the frequency meter through the range of the klystron while looking for the modes as shown in Figure 1.7 to appear.

F. Tune the frequency meter until the pip appears in the dominant mode. The dominant mode can be recognized as the mode with the most power.
G. Adjust the attenuation as needed with great awareness of the sensitivity of the crystal detector.

H. While monitoring the beam current, adjust the reflector voltage and modulation amplitude to obtain maximum amplitude of the dominant mode with the frequency pip centered.

I. Record the reflector voltage, frequency, attenuation setting, and beam current.

The frequency produced by the reflex klystron can be finely tuned by varying the reflector voltage and coarsely tuned by mechanically adjusting the cavity size. Through fine tuning it is possible to work with maximum
power in the dominant mode and through coarse tuning cover the frequencies in the operating range of the klystron.

For our experiment the klystron frequency was set to 35 GHz. The power supply settings to obtain the 35 GHz output were as follows: The reflector voltage was -452 volts, the grid voltage was -80 volts, the beam voltage was 2300 volts, and the beam current was 30 mA. The 1 kHz modulation source was used with the frequency and amplitude controls at mid-range, and the attenuator set to 13 dB. The power supply and the klystron were then ready for use for the desired experiments.
CHAPTER 2
MICROSTRIP ANTENNAS

Microstrip antennas have received increased attention over the last three decades. Microstrip antennas are very attractive for a number of reasons which will be presented in this chapter. In this chapter the microstrip antenna will be defined and applications presented. In addition, the antenna radiation field, an overview of the rectangular microstrip antenna, and microstrip arrays will be given.

2.1 Microstrip Antenna

A microstrip antenna can be defined in its simplest form as consisting of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side, as shown in Figure 2.1. The patch conductors normally consist of copper or gold and have a shape that is dictated by the designer. The shapes of the conductors are designed to control the performance of the antenna [6].
Figure 2.1. Sketch of a Microstrip Antenna.

The microstrip antenna has many advantages over other conventional antennas, but there are also some disadvantages. In order to have a balanced view, these considerations will be listed.

Some of the principle advantages of microstrip antennas over conventional antennas are: thin profile, light weight, simple manufacture, can be made conformal, low cost, easily mounted on missiles, rockets and satellites without major alterations. These advantages make the microstrip antenna quite attractive to the design engineer [7].
Some disadvantages of microstrip antennas over other antennas are: smaller bandwidth, low efficiency, poor endfire performance, the possibility of exciting surface waves, loss due to junction radiation, and limited gain. The advantages of the microstrip antenna far outweigh the disadvantages in many applications and these disadvantages can be minimized with precision design and fabrication techniques [6;7].

The present applications for microstrip antennas are varied and growing. Research and development has advanced the use of microstrip antenna system applications and will continue to further the replacement of conventional antennas with microstrip antennas in many areas. Some of the extensive applications for microstrip antennas which have been developed include [6]:

* Satellite communication
* Doppler and other radars
* Missile telemetry
* Weapon fuzing
* Environmental instrumentation
* Remote sensing
* Biomedical radiator

For microstrip antennas, the radiation field pattern is based on the fact that the source of the radiation is from the electric field. This field is
across the small gap formed by the edge of the microstrip element and the ground plane directly below. Since this gap is very small with respect to the wavelength, the individual slots can not exhibit any directionality. Therefore, an omnidirectional pattern is radiated from each slot into the half space above the ground plane. For resonance, most microstrip antenna elements are designed to be approximately one half wave length long causing the fields on the two opposite slots to be excited 180 degrees out of phase [8]. This mechanism of radiation is depicted in Figure 2.2.

![Figure 2.2. Microstrip Element Radiation Mechanism.](image)

The microstrip patch is regarded as a line resonator with no transverse field variations. The radiation occurs mainly from the fringing fields at the open circuit ends and the fields vary along the length of the antenna.
The far field radiation of a single slot is [6]:

$$E_\phi = -j2V_0 W k_0 \exp[-jk_0 r/4r] \cdot F(\theta, \phi)$$

(1)

$$E_\theta = 0$$

(2)

where $V_0$ is the voltage across the slot, $W$ is the width of the element, $r$ is the field distance from the center of the microstrip patch and $F(\theta, \phi)$ is given as [6]:

$$F(\theta, \phi) = \frac{\sin \left( \frac{k_0 h}{2} \sin \theta \cos \phi \right)}{\frac{k_0 h}{2} \sin \theta \cos \phi} \cdot \frac{\sin \left( \frac{k_0 W}{2} \cos \theta \right)}{\frac{k_0 W}{2} \cos \theta} \sin \theta$$

(3)

$F(\theta, \phi)$ is the total field pattern and can be used to find the $E$ and $H$-plane radiation patterns.

The $E$-plane pattern can be determined from the above expressions by setting $\theta = 90$ degrees. This results in the following expression [6]:

$$F(\phi) = \frac{\sin \left( \frac{k_0 h}{2} \cos \phi \right)}{\frac{k_0 h}{2} \cos \phi}$$

(4)

The $H$-plane pattern is represented by setting $\phi = 90^\circ$ in equation (3), giving:

$$F(\theta) = \frac{\sin \left( \frac{k_0 W}{2} \cos \theta \right)}{\frac{k_0 W}{2} \cos \theta} \sin \theta$$

(5)
For two slots at a separation distance of $L$, the E-plane field is [6]:

$$E(\phi) = \frac{\sin \left( \frac{k_0 h}{2} \cos \phi \right)}{\frac{k_0 h}{2} \cos \phi} \cos \left( \frac{k_0 L}{2} \cos \phi \right)$$  \hspace{1cm} (6)$$

The H-plane field is independent of $L$ and is given by equation (5).

The effect that the length and the width of the microstrip antenna element have on the E and H fields is to direct the main beam to broadside and create a null at endfire. A length of one half wavelength creates a null at endfire as seen in the equation for the E field, equation (6). A width of one half wavelength creates the main beam at broadside as seen in the sinc function of the H field in equation (5). Both field equations go to zero at endfire and have their main beam at broadside.

The antenna input impedance can be calculated using the equivalent circuit shown in Figure 2.3. $R_r$, the radiation resistance of each slot, is given by [9]:

$$R_r = 120 \frac{\lambda_o}{W} \quad (W \text{ - width of the antenna})$$  \hspace{1cm} (7)$$

The input impedance becomes:

$$R_{in} = 60 \frac{\lambda_o}{W}$$  \hspace{1cm} (8)$$

This input impedance can be matched at the feed point. $R_{in}$ is a function of the location of the feed
point along the length of the patch and goes to zero at the center of the element [9]. An element could be fed at the edge and the impedance be transformed to the desired level using quarter wave transformers.

\[ P_0 = 3 \text{ dB for } \omega \ll 2 \]

\[ P_0 = 4(\omega/\gamma) \text{ for } \omega \gg 2 \]

Figure 2.3. Transmission Line Model.
2.2 Microstrip Array

An array of antenna elements has an advantage over a single element antenna because the radiation pattern of the single element is relatively wide. Therefore, the array can be designed to have a high directivity. The total field of the array antenna is equal to the product of the single element field and the array factor of the array. The array factor is a function of the relative spacing of the elements, the number of elements, the progressive phase, and the individual feed amplitudes [10]. This report addresses a uniform linear array with zero phase shift and identical amplitudes.

The feed design can affect the array factor by introducing a phase difference to develop between the elements. A progressive phase can be accomplished by varying the path length of the individual feeds thus introducing time differentials which translate into phase shifts. Another means of changing phase with the feed lines is by electrically varying the signal propagation times through the different feed lines. The effect of progressive phase on the radiated field is to steer the main beam off broadside.

The element spacing affects the radiation pattern by the additive constructive and destructive interference of the collection of the individual element fields. The
element separation and phase difference introduced by the elements can be designed such that nulls and lobes in the radiation pattern propagate in the desired directions [10].

With the array antenna, greater directivity and beam steering can be achieved, and the lobes and nulls of the total field pattern can be precisely placed. For the operating frequency of 35 GHz, the antenna and array design were obtained by scaling the results available at the lower X band frequencies. No detailed theoretical design analysis at 35 GHz was conducted. The next chapter will outline the design procedure, fabrication, testing, and analysis of the microstrip antenna realized in the lab.
CHAPTER 3
MICROSTRIP ANTENNA DESIGN

The design procedure used to realize the 35 GHz microstrip antenna was arrived at from a collection of resources. Design programs specifically written for microstrip antennas were used to obtain the dimensions of the antennas. Once the designs were finalized, the masks were drawn using the MaskCad software package [12], and the antennas were fabricated and tested. This chapter outlines in detail the total design, fabrication, and testing procedures followed.

3.1 Microstrip Patch Antenna

The most basic microstrip antenna is the single square patch antenna with a simple feed arrangement. For this design, the element dimensions were calculated using the program MSANT [9], written specifically for the design of rectangular microstrip antennas. It uses a cavity model to predict the input resistance and resonant frequency of a rectangular microstrip antenna element [7].
To run MSANT for the data desired, the following procedure is observed. The program prompts for the resonant width and length of the patch antenna in centimeters. The width and length for this design were both chosen to be just less than one half the wavelength. The slight reduction from a length of one half wavelength is required in order to tune out the reactive part of the radiation resistance. The length is given by the equation below [7]:

\[ L = 0.49 \frac{\lambda_o}{\sqrt{\varepsilon_r}} \]  

(9)

where \( \lambda_o = c/f_o \)

\( \varepsilon_r = \) relative dielectric constant of the substrate

\( \lambda_o = \) free space wavelength

Once the width and length of the element are loaded into the program, MSANT prompts for the dielectric constant, the substrate thickness in centimeters, the loss tangent, and the distance from the feed point to the radiating edge. Information regarding the substrate is available through the manufacturer. With the "distance from the feed point" entered as zero for an edge fed microstrip element, the program gives the value of the input impedance.
The program computes the resonant frequency in GHz, the resonant resistance at the feed point, and some other parameters. For this design we are only concerned with the mentioned parameters. Since we are designing for a specific frequency, iterations using slightly different values of the element dimensions are done until an acceptable resonant frequency is achieved. These dimensions and the value of the resistance are recorded. It was necessary in our design to transform the impedance at the radiating edge to the desired impedance for matching to the 50 ohm feed impedance [9]. This impedance transformation was done with a quarter wave transformer. Figure 3.1 shows a sketch of the single patch and the transformer.

![Figure 3.1. Single Patch Element.](image-url)
3.2 Linear Microstrip Array

A simple linear microstrip array with four identical elements, zero phase progression between the elements, equal spacing, and uniform excitation was considered for design purposes. The individual elements were described in the previous section. The element separation was set to just less than a free space wavelength in order to achieve good broadside directivity as well as avoid feed line crowding [7].

Figure 3.2 is a sketch of the microstrip array and the feed system. By use of power splitters and quarter wave transformers, the feed system can be designed for 50 ohm feed impedance with minimal reflections. Starting from the elements and working toward the feed, the following procedure was used to calculate the dimensions of the microstrip antenna array and feed system.

The impedance looking into each antenna element at the feed point for the chosen design was found by MSANT to be 165.59 ohms. Small feed lines were desired so as not to interfere with the radiation pattern of the antenna. The 165.59 ohms was transformed to 100 ohms by using a quarter wave transformer. As shown in Figure 3.2, these 100 ohm lines from the four elements converge into two tee sections, with a quarter wave transformer at
the end of each tee. The top of the first tee was formed by the 100 ohm lines extending from the first two elements. The second tee was formed by the 100 ohm lines from the last two elements. The quarter wave transformer at the end of these two tee joints was used to convert the 50 ohms resulting from the mergence of the two 100 ohm lines at each tee, into a single 100 ohm line from each tee. These 100 ohm lines were then joined together to form a 50 ohm junction.

The two quarter wave impedance transformers shown in Figure 3.2 were needed to transition from one impedance to another without reflections. The impedance of each transformer was calculated using the following equation [7]:

$$R_T = \sqrt{R_1 \cdot R_2}$$

Where $R_T$ is the characteristic impedance of the quarter wave transformer. $R_1$ and $R_2$ are the impedances of the lines being matched.

The next step was to obtain the widths of the lines, the lengths of the transformers and the required impedances. Two programs were available for this calculation. The results obtained for the dimensions are listed in Table 3.1.
Figure 3.2. Microstrip Antenna Array Design.

The first program used was TLINE which was written by Pozar [11] and revised by students at this university. The program offers a selection of line types to analyze. The line type used for this design was the microstrip line. The program prompts for the dielectric constant, substrate thickness, and the characteristic impedance. With this information, TLINE calculates the effective dielectric constant and provides the line width for the required characteristic impedance [9]. This information
about the line width is used in the program LINECALC to calculate the lengths \( L = \frac{c}{4f_0} \sqrt{\varepsilon_r} \) of the quarter wave transformers.

With the microstrip dimensions and the geometry of the feed system known, the mask can be made using MaskCad. The mask was plotted by MaskCad [12] on Mylar using India Ink and used for the antenna fabrication.

**TABLE 3.1**  
ANTENNA DIMENSIONS.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>PROGRAM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TLINE</td>
</tr>
<tr>
<td>CHARACTERISTIC IMPEDANCE (ohms)</td>
<td>LINE WIDTH (mm)</td>
</tr>
<tr>
<td>50.0</td>
<td>2.42</td>
</tr>
<tr>
<td>70.711</td>
<td>1.39</td>
</tr>
<tr>
<td>90.992</td>
<td>-</td>
</tr>
<tr>
<td>100.0</td>
<td>0.71</td>
</tr>
<tr>
<td>128.68</td>
<td>0.38</td>
</tr>
<tr>
<td>QUARTER WAVE TRANSFORMER IMPEDANCE (ohms)</td>
<td>LINE LENGTH (mm)</td>
</tr>
<tr>
<td>70.711</td>
<td>1.584</td>
</tr>
<tr>
<td>90.992</td>
<td>-</td>
</tr>
<tr>
<td>128.68</td>
<td>1.629</td>
</tr>
<tr>
<td>ANTENNA ELEMENT DIMENSIONS</td>
<td>WIDTH (mm)</td>
</tr>
<tr>
<td></td>
<td>2.27</td>
</tr>
</tbody>
</table>
Fabrication of the microstrip antennas was done in the RF/Microwaves lab. The process was done with extreme care so as to preserve the thin microstrip lines.

Individual boards whose sizes were determined by the mask sizes were rough cut, and the edges were filed smooth. The ground plane was chosen on the board as the side with the most defects and was placed facing up on the spinner. Photoresist was applied to the surface and the board was spun at a rate of 2000 r.p.m. for 30 seconds and then baked at 100°C for 10 minutes. Next the board was placed ground plane down on the spinner and photoresist applied to the top plane and spun and baked as before. The mask was centered over the board and exposed to ultraviolet light for 5 minutes and then developed, using a 1:1 concentrated developer. The etching was done in an acid solution of 3:1 H₂O and nitric acid. The acid bath took 20 to 30 minutes and was closely monitored throughout to avoid over etching. Once the microstrip pattern was pronounced and all of the surrounding copper etched away, the board was removed from the acid bath, rinsed with acetone to dissolve the photoresist on the microstrip and ground plane, and then rinsed with methanol to eliminate any residue left by the
acetone. The board was then inspected and any remaining unwanted copper removed with a razor knife or file. If the board passed inspection it was then ready for mounting the feed connection.

The connector was mounted by the following method. A hole, the size of which was determined by the width of the connector's center conductor and the surrounding insulation, was drilled at the feed point. The connector was inserted so that the insulation was almost level with the top surface and the center conductor rose just even with the copper feed line. The center conductor was soldered to the feed line and the ground plane was connected to the shield of the connector.

3.4 Measurement of the Radiated Field

The designed and fabricated microstrip antennas were tested for their ability to function by measuring their field pattern and power received. The procedure and the results of this experiment were recorded as follows.

An antenna test bench was used for the pattern measurements. A block diagram of the entire set up is shown in Figure 3.3.

The standard gain (26.5 - 40.0 GHz, 24 dB gain) horn was used as the transmitter and the microstrip antenna as the receiver. There were no facilities available for
checking the impedance at the feed point of the antenna so losses due to mismatch were to be expected. The feed connector of the antenna, an OSSM jack (33 - 37 GHz) was connected via an OSSM plug to a waveguide - coax transition (RG 599/U - OSSM). The waveguide end was then connected through a 26.5 - 40 GHz power sensor to a power meter. All the components were delicate and expensive and needed to be handled with care.

Figure 3.3. Set Up for Antenna Radiation Pattern Measurements.
The pattern was measured in the far field which is defined approximately as \( d > 2D^2/\lambda \), where \( D \) is the largest antenna dimension, \( \lambda \) is the free space wavelength of the transmitted signal and \( d \) is the far field distance.

For this set up, the largest dimension of the horn was 3.5 inches and \( \lambda \) was 0.337 inches. Hence \( d \) was approximately 72.6 inches.

The power supply unit was allowed to warm up. The power sensor is provided with a coaxial connection for calibration which is done using the 1 mW, 50 MHz 'Power Reference' on the power meter with 100% calibration factor and "Sensor Zero" on. Once this is done the calibration factor is set at 95% corresponding to 35 GHz. The power meter measures either absolute or relative power. It displays absolute power in either watts or dBm and relative power in dB. The power range for the sensor that was used was from 10 uW to 100 mW. The transmitter and receiver were placed on the test bench a distance \( d > 72.6 \) inches directly opposite to each other. The height of the microstrip antenna was adjusted to be the same as the horn. The test bench has facilities for measuring the scanning angle.

The klystron power supply was then set up as outlined in Chapter 1. The klystron was already tuned to
the frequency of 35 GHz, and the power supply settings were set to the values reported in Chapter 1. The reflector voltage was varied slightly for fine tuning and the beam current was monitored at a value of 32 mA.

The output power of the klystron was measured to be 120 mW. Only the E-plane pattern in dB was measured with the power meter calibrated at $\Phi = 0^\circ$. The radiation pattern results obtained for the fabricated array are shown along with the calculated radiation pattern [10] in Table 3.2. Due to mismatch at the feed point and losses at the connections and transitions, the sidelobes were

<table>
<thead>
<tr>
<th>Location of Main Lobe</th>
<th>THEORETICAL</th>
<th>MEASURED</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Phi = 0^\circ$</td>
<td>$\Phi = 0^\circ$</td>
<td></td>
</tr>
<tr>
<td>3 dB Beam Width</td>
<td>$\Phi = 7^\circ$</td>
<td>$\Phi = 4^\circ$</td>
</tr>
<tr>
<td>Location of First Null</td>
<td>$\Phi = 15^\circ$</td>
<td>$\Phi = 12^\circ$</td>
</tr>
<tr>
<td>First Side Lobe</td>
<td>-13.47 dB at $\Phi = 24^\circ$</td>
<td>Not Detected</td>
</tr>
</tbody>
</table>
too low to be detected. The first theoretical side lobe of -13.47 dB occurred at \( \Phi = 23.7^\circ \). There was good correlation with respect to the half power beam width of the major lobe.

For future experiments with microstrip antennas at 35 GHz, it would be necessary to measure the impedance at the feed point to minimize as much as possible the conditions of mismatch. The results obtained from our experiments indicate that with the use of analyzing equipment and proper components, complete accurate radiation patterns could be obtained.
CONCLUSION

This research report successfully accomplished the objective of putting into operation a high voltage klystron power supply, Micro-Now Model 756, and the building and testing of 35 GHz microstrip antennas. The radiation pattern measurements of the microstrip array designed and fabricated were close to the theoretical pattern. Losses in received power occurred due to lack of equipment to measure the actual input impedance, and due to the connections and transitions. Significantly better results are expected with better resolution of the layout of the antenna masks and with proper impedance matching.
LIST OF REFERENCES


